DECISION ANALYSIS AND POLICY FORMULATION FOR TECHNOLOGY-SPECIFIC RENEWABLE ENERGY TARGETS

By

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ABSTRACT

IRENE TESHAMULWA OKIOGA. Decision Analysis and Policy Formulation for Technology-Specific Renewable Energy Targets (Under the direction of DR. YESIM SIRELI)

This study establishes a decision making procedure using Analytic Hierarchy Process (AHP) for a U.S. national renewable portfolio standard, and proposes technology-specific targets for renewable electricity generation for the country. The study prioritizes renewable energy alternatives based on a multi-perspective view: from the public, policy makers', and investors' points-of-view, and uses multiple criteria for ranking the alternatives to generate a unified prioritization scheme. During this process, it considers a 'quadruple bottom-line' approach (4P), i.e. reflecting technical "progress", social "people", economic 'profits", and environmental "planet" factors.

The AHP results indicated that electricity generation from solar PV ranked highest, and biomass energy ranked lowest. A "Benefits/Cost Incentives/Mandates" (BCIM) model was developed to identify where mandates are needed, and where incentives would instead be required to bring down costs for technologies that have potential for profitable deployment. The BCIM model balances the development of less mature renewable energy technologies, without the potential for rising near-term electricity rates for consumers. It also ensures that recommended policies do not lead to growth of just one type of technology – the "highest-benefit, least-cost" technology. The model indicated that mandates would be suited for solar PV, and incentives generally for geothermal and concentrated solar power. Development for biomass energy, as a "low-cost, low-benefits" alternative was recommended at a local rather than national level, mainly due to its low resource potential values. Further, biomass energy generated from wastewater treatment plants (WWTPs) had the least resource potential compared to other biomass sources. The research developed methodologies and recommendations for biogas electricity targets at WWTPs, to take advantage of the waste-to-energy opportunities.

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LIST OF ABBREVIATIONS

AHP	Analytic Hierarchy Process
Ast	Overlap area between source and target layer
At	Target area
BCIM	Benefits/Cost Incentives/Mandates
CHP	Combined Heat and Power
CI	Consistency Index
CO_2	Carbon dioxide
CPP	Clean Power Plan
CR	Consistency Ratio
CSP	Concentrated Solar Power
DSS	Decision Support Systems
DSIRE	Database of State Incentives for Renewables & Efficiency
DOE	Department of Energy
EGS	Enhanced Geothermal System
EIA	Energy Information Administration
EPA	Environmental Protection Agency
EPA	Environmental Protection Agency

GW	Gigawatt
GWh	Gigawatt-hour
i, j	Alternatives considered during a pairwise comparison
IOU	Investor Owned Utility
IPCC	Intergovernmental Panel on Climate Change
IRENA	International Renewable Energy Agency
Km	Kilometer
kW	Kilowatt
kWh	Kilowatt-hour
LCOE	Levelized Cost of Electricity
LL	Lower Level Confidence Limit
m	Number of values in a sample
MADM	Multiple Attribute Decision Making
MCDM	Multiple Criteria Decision Making
mgd	million gallons per day
MODM	Multiple Objective Decision Making
Mw	Megawatt
Mwh	Megawatt-hour

n	Number of criteria being compared
NC	North Carolina
NREL	National Renewable Energy Laboratory
PEC	Portfolio Energy Credit
PoV	Point-of-View
PV	Photovoltaics
REC	Renewable Energy Certificates
RI	Random Consistency Index
ROC	Renewable Obligation Certificate (U.K.)
RPS	Renewable Energy Portfolio Standard
RPSes	Renewable Energy Portfolio Standards
SREC	Solar Renewable Energy Credit
SODM	Single Objective Decision Making
TVA	Tennessee Valley Authority
TW	Terawatt
TWh	Terawatt-hour
UL	Upper Confidence Limit
U.K.	United Kingdom

U.S.	United States
WWTP	Wastewater Treatment Plant
λ	Consistency Measure
λ_{max}	Eigenvalue
$U_{(x)}$	Relative renewable energy rating
E_{min}	Minimum regional energy potential
E_{max}	Maximum regional energy potential

1 INTRODUCTION

1.1 Background and Problem Statement

Historically, energy planning in the United States (U.S) has focused on cost only (Løken, 2007). In the 1960's, the main focus was on energy security surrounding the "peak oil" theory that was concerned with rising oil prices and energy costs, which, then changed towards energy planning for cost optimization during the 1970's (Strantzali and Aravossis, 2015; Samouilidis and Mitropoulos, 1982; Meirer 1983). The cost optimization was done to identify the most efficient energy source at the lowest cost (Samouilidis and Mitropoulos, 1982; Meirer, 1983). However, over the years, researchers have suggested the exploration of other factors such as social acceptability and environmental impacts in policy decision-making regarding energy planning. Stirring from the 1980s, increased awareness on health, and generally social and environmental issues have made it essential to incorporate these factors into energy policy-making (Nijcamp and Volwahsen, 1990; Løken, 2007; Strantzali and Aravossis, 2015). It has even been suggested that formulating policies without taking into account the multiple parameters involved is "socially unacceptable" (Strantzali and Aravossis, 2015).

Renewable energy sources are cleaner and have less environmental impact in comparison to conventional sources, and are, therefore, important in reducing carbon emissions, especially when installed on a large scale. Consequently, recent energy policies in the U.S. have proposed and encouraged clean and renewable energy generation via Renewable Energy Portfolio Standards (RPSes); the Energy Independence and Security Act of 2007 (the Clean Energy Act of 2007); and the proposed

Environmental Protection Agency (EPA) Clean Power Plan (proposed in 2014). RPSes are state-level policies that stipulate the minimum percentages of renewable energy that local utilities need to distribute, as well as timelines to reach specified renewable energy targets (U.S. National Archives and Records Administration, 2015). The Clean Energy Act aims to "move the United States toward greater energy independence and security" by increasing the renewable fuel production; and the EPA Clean Power Plan establishes state-by-state targets for emission reduction from power plants, with a nationwide estimated reduction of approximately 32% between 2005 and 2030.

Despite the aforementioned shift in energy prioritization, however, an extensive state by state investigation yielded by this research indicates that the U.S. still highly focuses on cost and the technical level of maturity only, when it comes to policy-making for energy planning. In addition, in spite of the existence of the RPSes, the Clean Power Plan and the Clean Energy Act, there is no nationwide energy policy or guidance available for different regions to achieve set renewable energy targets, for a predictable and steady renewable energy growth.

As a result, this research aims to develop a decision making process that accounts for not only cost and technical aspects of energy, but also social and environmental impacts. To achieve this goal, it explores the energy policy decision-making in the U.S.; integrates said factors into the policy considerations, provides currently lacking guidance to achieve renewable energy goals on a region by region basis, and assimilates the regional goals into national renewable energy targets. Along with the multiple criteria aspects of the policy framework, the study also considers a multi-perspective view.

Public perception is weighed in under the social criteria, and the interaction between policy makers' and investors' points-of-view is used to gauge on the need for incentives for renewable energy development.

The rest of Section 1 discusses the reasoning on the aforementioned goals of this study in more detail and states the assumptions made in the research approach.

Section 2 reviews how individual states mandate or encourage the implementation of renewable energy development. Regulatory policies are reviewed to understand the strategies currently used by states for technology-specific renewable energy prioritization.

Section 3 discusses the basis of decision analysis and explains why Analytic Hierarchy Process (AHP) was selected as the method of choice for the renewable energy decision analysis conducted.

The actual AHP analysis is conducted in Section 4. The Section details how the AHP method was uniquely developed to be able to comprehensively formulate national renewable energy policy, taking into consideration the policy maker's point-of-view, as well as the investor's point-of-view. A model is also developed to guide in the selection of mandates or incentives, which will ensure technologies do not receive more financial support than is needed for them to deploy. The model also identifies where incentives towards research and development need to be facilitated, to bring down costs for technologies that have potential for profitable deployment. It rules out high-cost, low-benefits alternatives. Mandating high-cost low-benefits renewable energy alternatives would potentially result in high electricity rates that would allow utilities to profit or break even. The simple Benefits/Cost Incentives/Mandates (BCIM) model would therefore encourage the adoption of new renewable energy technologies while balancing the potential for rising near-term electricity rates for consumers.

It also ensures that RPSes do not lead to growth of just one type of technology – the highest-benefit, least-cost technology.

Section 5 compares current state-level policies with the renewable energy prioritization results obtained using the AHP methodology developed. Based on the comparison, shortcomings in the existing state policies that could be remedied using the AHP procedure are identified. In addition, limitations of the AHP analysis, which are addressed by current state level policies, are also acknowledged. One of the main limitations identified with the AHP analysis, is that, based on ranking that favors renewable energy generation with high resource potential, policy developed using the AHP method does not promote low-ranking resources that offer waste-to-energy opportunities, specifically biomass energy.

Since biomass energy would not have a significant contribution to a national-level renewable energy portfolio, rather than establish national mandates for biomass energy, the study explores how voluntary based targets can be set at a local scale, or smaller distribution-generation scale, for waste-to-energy resources. This analysis is conducted in Section 6, using biomass energy from wastewater treatment plants (WWTPs).

Section 6 uses a statistical approach to determine the range of electrical energy potential targets for Combined Heat and Power (CHP) systems at WWTPs, based on wastewater treatment capacities. Waste-to-energy resources in the U.S. are usually developed as a means of managing waste disposal, and not with the aim extracting full energy potential (Gohlke and Martin, 2007). Therefore, instead of selecting targets by using the energy potential, Section 6 develops a reference chart for CHP target selection based on data listings of successful installations that suggest targets that are clearly and readily achievable. The methodology can be modified, as need be, and potentially transferred to develop charts for other waste-to-energy biomass resources.

Finally, Section 7 discusses the research conclusions and recommendations, and offers insight to future studies.

1.2 Current Renewable Energy Policies in the U.S

While the U.S. does not have any national energy policies aimed at achieving technology-specific renewable energy targets, the country has state-level RPSes, some that specify renewable energy targets for particular technologies. In addition to Washington, D.C., three U.S. territories and 29 states currently have mandatory RPSes, while eight states and one territory have voluntary RPSes (N.C. Clean Energy Technology Center at the N.C. State University, 2017). The RPSes can facilitate state-level efforts to diversify the renewable energy mix, promote economic development and reduce emissions (National Conference of State Legislatures, 2016). However the individual state-level RPSes are not designed to work together towards reaching common goals at a national-level, nor formulated with that intention. The individual states have varying definitions of what counts as renewable energy, as well as varying targets and goals for renewable energy generation. These state-level targets and goals do not align with a national renewable energy mandate.

The states set and amend the RPS goals mainly through an iterative process. When a fast-paced renewable energy growth, with the potential for early goal achievement, is noted, the next iteration step accelerates the target timeline or increases the renewable target. For example, in 2002, the state of California set an initial RPS target of achieving 20% renewable energy supplies from retail sales by 2017. Based on case studies of electricity retail suppliers that showed many utilities were already achieving the 20% target or were soon set to achieve it, the California Energy Commission (2003) suggested accelerating the RPS goal. The proposed goal was to accelerate the target in order to achieve the 20% renewable energy by 2010, rather than 2017. The following year, the Commission recommended further increasing the proposed 20% target to 33% to ensure that the "momentum necessary to reduce costs and push technological innovation" would be kept up (California Energy Commission, 2003). The RPS goal to achieve 33 percent renewable energy retails sale by 2020 was endorsed in 2011. In 2015, Senate Bill 350 was passed to establish California's current RPS goal of 50% of renewable energy retail sale by 2030 (California Energy Commission, 2017). In July 2017, the California Assembly Utilities and Energy Committee approved Senate Bill 100, which proposed a further increase of the current goal to 60 percent renewable energy by 2030, and 100 percent by 2045. Senate Bill 100 has not been passed as law.

The logical methods presented in the proposed AHP process for renewable energy policy formulation intend to shorten the iterative cycle involved in establishing national renewable energy targets for renewable energy portfolios, as well as policy formulation for renewable energy incentives, by starting at calculated renewable energy percentage allocation, rather than an arbitrary value.

The study found that more than half the numbers of states with RPSes (65%) include technology-specific targets in their RPSes. The International Renewable Energy Agency (IRENA, 2015) notes that several renewable energy policies, at a global level, establish technology-specific target structures in order to diversify the renewable energy mix for a more resilient renewable energy supply and uniform expanded growth in multiple renewable energy technologies. The study notes that the decline of solar PV costs, for example, occurred mainly due to prioritized support towards the technology, and the presence of large competing markets, especially in Germany. This led to investments in research and development and subsequently resulted in improvements in solar PV technology, and cost reductions in generation. Considering the vulnerability of renewable energy generation to vary with climatic conditions, such as for solar and wind, resiliency is greatly improved with a diverse renewable energy generation mix, as the renewable energy sources can complement each other. Heide et al. (2010), noted that wind and solar renewable energies complement each other all year round in Europe. In the winter when solar generation is low, wind generation is high and during warmer months, when solar output is high, wind generation is often lower. In addition, geothermal energy can be utilized to provide base load throughout the year, due to its constant supply (Geothermal Energy Association, 2009). Prioritizing favored technologies, through policies, can encourage growth in less advanced technologies that have great potential to be “profitably developed”, by encouraging technology innovation for the favored options. Renewable energy diversification can also prevent saturation or “over-concentration” of a single renewable energy technology (IRENA, 2015).

The current national-level renewable energy policies are not as specific with regards to renewable energy targets and goals. The Energy Independence and Security Act of 2007 has provisions that aim to increase energy efficiency and renewable fuel production, but does not include provisions for renewable electricity targets. The provisions included are based on the Corporate Average Fuel Economy (CAFE) standards, which stipulate the maximum fuel consumption in miles per gallon for vehicles (35 mpg cars and light trucks, by model year 2020); Renewable Fuel Standards

(RFS), which stipulate goals for renewable energy fuel production (36 billion gallons renewable fuel by 2022); and Appliance Lighting and Efficiency Standards (that mandate minimum energy efficiencies for appliances and lighting devices and accessories (Congressional Research Service, 2007). According to the Congressional Research Service, (2007), a national RPS aimed to achieve 15% total electric sales by 2020 was proposed but not included in the Energy Independence and Security Act. While the study does not discuss any shortcomings of the fuel and energy efficiency standards provided by the Act, it instead focuses on providing policy recommendations that focuses on the renewable energy electricity generation aspects that were completely “stripped out”.

In August 2015, former U.S. President Obama and the U.S. Environmental Protection Agency (EPA) announced the Clean Power Plan, proposed to address carbon pollution from power plants. The Clean Power Plan initiatives are based on emission reduction through more efficient fossil fuel plants, increased renewable energy production (resulting to lower-polluting power sources) and increased reliance on natural gas. The proposed plan would allow states to implement the Clean Power Plan using either a mass-based approach (CO_2 emissions) or a rate-based approach (CO_2 emissions per megawatt-hour of electricity produced) to reduce and limit carbon emissions.

In March 2017, current President Trump issued an executive order mandating that EPA review the proposed Clean Power Plan rules to determine whether to revise, suspend or withdraw the rules in order to ensure that they did not impose “regulatory burdens that unnecessarily encumber energy production, constrain economic growth, and prevent job creation” (The White House, 2017). In October 2017, EPA announced its intention to repel the Clean Power Plan Rule and consider a more "modest replacement rule" (New York Times, 2017). Nevertheless, if implemented, in its current or modified version, the standards would establish state-by-state targets for emission reduction by 2030, with a proposed nationwide estimated reduction of approximately 32% from power plants relative to 2005 emissions. This percentage goal would require approximately 1,000 billion kilowatt-hours of net electricity generation from renewable sources by 2030, according to the U.S. Energy Information Administration (EIA) projections (EIA, 2016).

Based on historical data, between 2005 and 2015, renewable energy generation increased by nearly 50% (Figure 1-1). The EIA projections show that the renewable energy generation can double from 546 billion kWh in 2015 to 1088 billion kWh in 2030. The percentage renewable energy generation in 2030 would be at 24% (as a percentage of the total projected energy generation).

Other than the assumption that the Clean Power Plan is in effect, the EIA data projection reflects a "business-as-usual" trend, based on current technology and federal, state, and local laws and regulations in effect as of the end of February 2016. This case therefore assumes that current laws and regulations are maintained throughout the projections. EIA (2016) therefore suggests that "the projections provide policy neutral baselines that can be used to analyze policy initiatives" (EIA, 2016).

While the Clean Power Plan has a national target set for emission reduction, and includes increasing renewable energy generation as one of the strategies, the plan does not set actual national targets for the renewable energy generation to align with the overall emission goal. It is instead left to the states to determine how to meet their individual renewable energy targets.

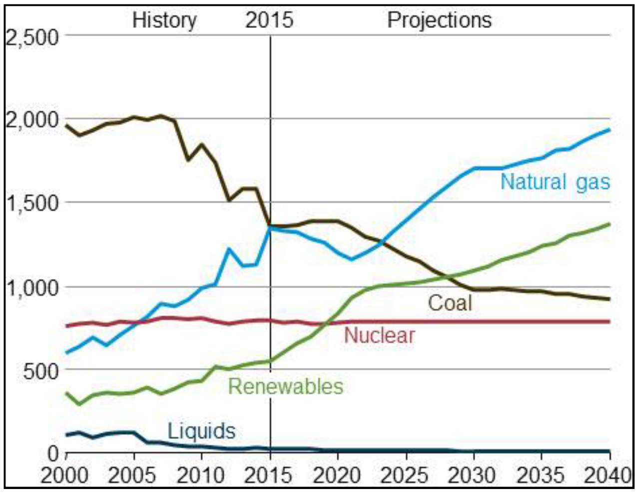


Figure 1-1: U.S. Projected Growth in Net Electricity Generation with CPP (EIA, 2016)

This research proposes the first attempt to recommend technology-specific renewable energy targets for a diverse renewable energy portfolio in the U.S. and towards national-level renewable energy targets. The targets, in this study, are set for different renewable energy sources, such that renewable energy generation from each source is expressed as a percentage of the total renewable energy generation. The percentage targets are thus applied to EIA (2016) projections that assume the Clean Power Plan in place. The percentage is applied to the projected renewable energy to convert the portfolio percentages into actual electrical units of generation (GWh). The results give an indication of the electric targets needed to complement the clean power plan, while ensuring a diverse renewable energy mix.

Case studies that can offer lessons learned in prioritizing technology-specific renewable energy targets for a diverse renewable energy portfolio are reviewed in the sub-sections that follow, to highlight the basis and need for this study.

1.3 Case Studies justifying Multi-criteria Considerations for Technology-Specific Renewable Energy Policies in the U.S

1.3.1 Need for Technology-Specific Renewable Energy Prioritization: Case Study of the United Kingdom Renewables Obligation, and Texas, U.S. Renewables Portfolio Standard

The United Kingdom (U.K.) Renewables Obligation (RO) was introduced in 2002 to increase the supply of electricity from renewable energy sources in the U.K. Similar to the state-level RPSes in the U.S., the U.K. RO standards set renewable energy targets that energy suppliers were to meet, in order to increase the overall renewable energy supply (Garton and Ares, 2016). The U.K. goal was to initially increase renewable energy supply by major utilities by 1% each year, from 3% in 2002/3 to 10.4% in 2010/11. The target was later increased to 15.6% renewable energy generation by 2015/16 (IRENA, 2015). The renewable energy policy required U.K. energy suppliers to purchase Renewable Obligation Certificates (ROCs) from accredited renewable energy generators, build their own renewable energy generation, pay a buy-out for any shortfall, or use a combination of ROCs and buy-outs. The funds collected from the buy-out payments were rewarded back proportionally to all suppliers who presented ROCs. The renewable energy generators would have two sources of income, with the first source generated from wholesale electricity market, which did not differentiate between renewable energy sources and non-renewable sources, and income from the sale of ROCs (Garton and Ares, 2016).

When initially established, one ROC was equivalent to 1 megawatt-hour (MWh) of renewable energy generated across all renewable energy sources, meaning that there was no technology-specific prioritization. However, as a result of the uniformity, only cheaper forms of renewable energy generation, such as wind energy, were mostly developed, with no aim to further advance alternative technologies (IRENA, 2015). In April 2009, the Renewables Obligation Order 2009 introduced "banding" for different technologies, generally stipulating multipliers with varying MWh equivalents per ROC, according to how developed a technology was. The banding would be reviewed every four years for adjustment based on the level of support needed versus the innovation improvements, market conditions and deployment potential.

This case study suggests that technology-neutral policies do not support less-mature renewable energy technologies, even those with potential for improvement and profitable generation. This is true especially when the renewable energy selection is solely based on grounds of being the cheapest.

The RO scheme was later replaced with Contracts for Difference (CFD) in 2017 to ensure security of supply of low carbon sources. In this scheme, generators agree to supply electricity at an agreed fixed "strike" price, such that when wholesale prices for low carbon sources are lower than an agreed fixed price, the scheme tops the amount. When wholesale prices are higher, the surplus is paid back. Prioritization in this case is established by setting higher strike prices for favored resources. Unlike the RO policy, the CFD focuses on "low-carbon" sources of electricity in general rather than only renewable energy sources. Also, prices in the CFD scheme do not fluctuate depending on the amount of renewable electricity generated and this offers a degree of certainty, as perceived by clean energy generators.

Texas offers another example of policies introduced to cut back on wind energy dominating the renewable energy market. Texas was one of the first states in the U.S. to establish an RPS in 1999, when the state mandated an addition of 2000 MW renewable energy generation capacity to be developed by 2010. According to Gulen et al. (undated) since there was no targeted technology in the RPS structure, wind energy took dominance based on the high wind potential in the state, relatively low costs, high maturity, and constructability (large capacities could be constructed within a relatively short time). The wind energy development allowed the RPS target to be reached 4 years earlier than the scheduled year, 2005. The fast-paced wind development put Texas first in wind energy ranking in the U.S, and ahead of California, as the largest wind energy generator in the country. However, this achievement also came at a cost. As a result of the rapid growth of wind energy, and the fact that RECs could only be retired within the state, REC prices significantly dropped. Texas therefore had to go “though cycles and revisions” of the RPS, and ended up including a non-wind voluntary renewable energy goal of 500 MW by 2015 to solve the problem. The current RPS prioritizes non-wind renewable energy generated after Dec 31, 2007, by allowing double the compliance value of electricity generated by wind. This is in order to encourage growth of other renewable energy sources for a more diverse state-level portfolio.

1.3.2 Need for National Level Policies – Case Study of the EU Renewable Energy Directive

The EU has an overall mandatory target of achieving 20% renewable energy consumption by 2020, based on the total consumed energy, and as mandated by the Renewable Energy Directive. Each EU member state has a commitment to a renewable energy initiative to meet this goal, and has individual renewable energy. The member countries report on their progress, measured against the national target, every two years (Euretric, 2011). On 30 November 2016, the European Commission proposed a new renewable energy consumption target of 27% or more by 2030, which member countries have agreed on.

Each member country has a minimum percentage obligation that must be achieved towards the 2020 goal. The obligatory amount was established by first setting a marginal renewable energy consumption target of 5.75% and then applying an additional increase proportionally to the country Gross Domestic Product (GDP) value, also taking into consideration the base level of advancement of renewable energy technologies for each country. While energy potential was not taken into consideration, this methodology allowed a "co-operation mechanism" between states, such that low GDP countries with high renewable energy potentials would transfer renewables to high GDP countries, in order for these countries to meet their high renewable energy targets (Euretric, 2011).

Similar co-operation measures for RPSes between U.S. states would be hindered by jurisdictional boundaries states impose regarding the location of facilities that can contribute to eligible renewable energy. For example the Maryland Renewable Energy Portfolio Standard limits what can be counted as eligible offshore wind facilities to only those located on the outer continental shelf between 10 and 30 miles off the coast of Maryland.

Wyns et al. (2014) observed that in the absence of federal renewable energy targets in the U.S., growth of renewable energy has not been as consistent as it has in the E.U (Figure 1-2). One of the reasons is because the different states do not have the same "pressure" to meet common targets. In addition, because some U.S. states have only voluntary RPSes, there are bound to be varying patterns of renewable energy generation across all the states, towards reaching a common target. National-level renewable energy policies would therefore be needed in the U.S., for predictable and continuous growth of renewable energy. Wyns et al. (2014) also suggested that the lack of federal-level policies and binding targets may cause uncertainties regarding continuation of support mechanisms offered for renewable energy generation.

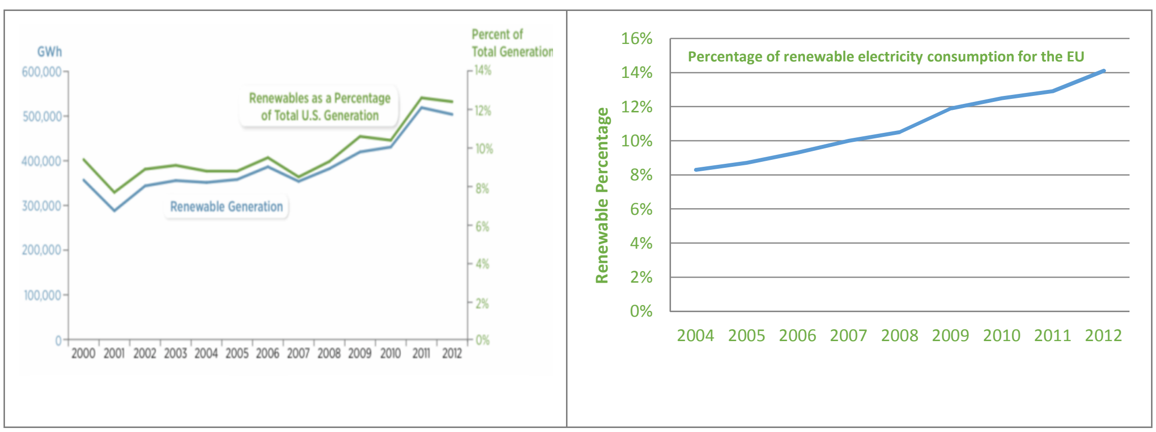


Figure 1-2: Renewable Energy Growth in the U.S. vs. EU

1.3.3 Need for Multi-criteria Consideration for Successful Renewable Energy Implementation – Case Study of California, U.S.

Next to the technical maturity and relatively low costs of wind energy that has led to its growth, is the growing evidence that social and environmental acceptance have become a hindrance to that same continued growth (Wustenhagen, Wolsink and Burer, 2007). Wind energy is thought to be the most mature form of renewable energy, both technically and cost-wise, with the U.S ranking second in the world, after China, on the basis of the total installed capacity (Petrova, 2013). As a result of the increasing population density of wind farms in some U.S. states, "visual intrusion" has become one of the main hindrances to wind energy projects buy-ins (Petrova, 2013). Dear (1992), indicated that the "NIMBY (Not-In-My-Back-Yard) syndrome", is one of the "single greatest barrier to wind project investment". NIMBY refers to the opposition of projects, mainly on grounds of the project siting and its vicinity to the disputer's property, who is mainly concerned about "visual intrusion". NIMBY resistance has also been associated with the noise impacts from operating wind turbines. In addition, environmental concerns regarding a potential extinction of endangered species has caused resistance to wind energy projects. This is based on the mortality of endangered species of birds and bats that get struck by the wind turbine blades. California presents a good case study that highlights the importance of considering social and environmental impacts. According to Petrova (2013), California was the first state in the U.S. to implement wind farms. However, these earlier wind farms were highly protested against, shortly after reports on bird deaths were made available. The turbines ended up idle for "months and years" and had to be eventually shut down. The wind turbines were since replaced with safer models, such as with smaller but more efficient design that received more positive reactions.

A compilation of social and environmental considerations pertaining to renewable energy generation is provided in Appendix 9.2. Potential effects from renewable sources are listed in five main clusters of impacts namely: land-use changes and effects, pollution/emissions, effects on flora and fauna, water demand and general perception based on visual and noise disturbances.

The effort for the wind turbine replacements and improvements in California are an indication of impacts of social and environmental acceptance of renewable energy infrastructure, and the need to incorporate these factors in energy planning.

1.4 Technology-Specific Prioritization Methods for Renewable Energy

Regulatory policies were reviewed to understand the strategies currently used by U.S. states for technology-specific renewable energy prioritization. The quantity of renewable energy generated in states that have implemented RPSes is often tracked using renewable energy certificates (RECs). While different states describe RECs differently, RECs can generally be defined as, "tradable certificates of proof that a unit of power has been generated from a clean energy source" and has been fed into a shared grid (Hamrin, 2014). A REC is equivalent to a unit measure of power generated such as 1 MWh or, in some states like Arizona and Nevada, 1 kWh. RECs are issued to renewable energy certified generators based on the metered amount of renewable energy generated and reported within a defined period. Since grid systems support electricity generated from various sources, it is otherwise impossible to point out the amount that constitutes renewable energy supplied to customers. RECs therefore make it possible for utilities to track renewable electricity purchased for distribution, without necessarily owning a renewable energy generating source. When RECs are purchased by electricity retail suppliers, or otherwise used for RPS compliance, they are retired and cannot be sold again.

Using the DSIRE database, all state renewable energy regulatory policies were reviewed to determine if any of the policies favored or prioritized a particular source of renewable energy. Only the regulatory policies mandating renewable energy generation were reviewed for this purpose, and mostly included RPSes. Energy prioritization in each case was defined by the following methodologies:

1. Using **minimum goals** for the favored renewable energy sources, either set as an addition to the overall goal, or as a carve-out (also known as set-asides, tiers or bands) that is set as a specific portion of RPSes and not an addition. Minimum goals can also be set at varying levels, with higher goals set for favored renewable energy sources
2. Using **varied REC compliance multipliers** for favored renewable energy sources to increase the REC values for the favored technologies. This can also be considered as a Performance-Based Incentive.
3. Using **varied alternative compliance payments (ACP)**, with higher penalty payments made when favored renewable energy goals are not met.
4. Combination of any of the above.

A compilation that summarized the state prioritization methods is found in Appendix 9.1. More than half the numbers of states with RPSes (65%), included prioritization targets in their RPSes. Most included either setting minimum goals for the targeted technologies (Illinois, Connecticut, Maine, Minnesota and Texas); or setting minimum goals with varied ACPs (Ohio, New Jersey, New Hampshire, Maryland, Massachusetts, Pennsylvania, Washington DC.). Three states (New Mexico, North Carolina, and Texas) included policies that used a combination of minimum goals and varied REC compliance multipliers and two states (Nevada and Delaware) had higher order combinations of the prioritization methods listed. The Virginia RPS is voluntary and uses varied REC compliance multipliers.

The renewable energy alternatives prioritized at a state-level were compared to the energies prioritized using the AHP procedure for the U.S. Census Bureau regions that encompass the states. The comparison is detailed in Section 5.

1.5 Renewable Energy Policy Gaps in the U.S

As a review of the problem statement and case studies presented, the following list summarizes current renewable energy policy gaps in the U.S.

1. The U.S. does not currently have any national energy policies aimed at achieving technology-specific renewable energy targets. Predictable and steady renewable energy growth cannot be guaranteed for this reason.
2. The proposed Clean Power Plan has a national target set for emission reduction, and includes increasing renewable energy generation as one of the strategies to reach this goal. However the plan does not give guidelines for renewable energy

generation to align with the overall emission goal. It is instead left to the states to determine how to meet their individual renewable energy targets.

3. There is currently no collaboration between states towards meeting common renewable energy goals. Individual states have varying targets for renewable energy generation and these targets do not align with any national renewable energy mandates.
4. Current state-level RPSes do not all take into account multiple criteria for prioritizing renewable energy sources. Lessons learnt from policies that have allowed renewable energy implementation to focus on cost and level of maturity alone have highlighted problems resulting in oversaturation of a single renewable energy technology, and limitations in advancement of less developed renewable options.
5. Lack of social and environmental considerations in energy planning has also led to renewable energy projects being stalled, or completely rejected, such as in the case presented for wind energy turbines in California.
6. RECs based on state-level RPSes are not usable throughout the country. The current jurisdictional boundaries have made it impossible for states with an overabundance of RECs to transfer and apply the certificates in neighboring states that have less renewable energy potentials. Where REC prices fluctuate, a significant drop in prices can be detrimental to renewable energy growth.
7. It is difficult to apply RECs across the jurisdictional boundaries when there are varying definitions of what counts as eligible sources of renewable energy and

cut off limits of minimum and maximum generation capacities from eligible sources. Definitions of the unit measure of electricity that is equivalent to one REC would also need to be uniform. National policies may enhance standardization to curb these issues.

Based on the discussion in this Section, the research considers the "ideal" renewable energy policy to have the following aspects that are addressed:

1. Multi-Criteria: considering a 'quadruple bottom-line' approach (4P) covering "People" or social aspects, "Planet" or environmental aspects, "Progress" or technical aspects and "Profits" or economical aspects
2. Multi-perspective: Capture varying interests and goals and considering an investor's point-of-view, policy make's point-of-view, and the public's point-of-view covered as part of the criteria consideration.
3. Include technology-specific targets: for a diverse portfolio and growth in multiple Technologies as complementing renewable energy options, can improve overall energy reliability and resiliency.
4. Transparent: with clear procedures for selecting mandates vs. incentives, thus ensuring that technologies do not receive more financial support than is needed for them to deploy, and supporting research and development for emerging technologies.

1.6 Research Objectives

The overall study aims to facilitate decision making and prioritization of renewable energy generation. Energy prioritization was performed for different forms of renewable energies on a regional and national level. The prioritization not only ranked the renewable energy sources but also provided estimates for the percentage goals of each energy alternative. The percentages could be applied to the total renewable energy estimates needed to achieve the Clean Power Plan, or other future policies that target emission reduction through renewable energy generation. Since the recommendations presented are based on percentage values, they would be applicable to any future modifications of the Clean Power Plan.

The specific research objectives are as follows:

i. Prioritize utility-scale renewable energy technologies at a regional and national level, considering benefits offered- technical, social, and environmental benefits, and costs criteria (Multi-criteria).
ii. Develop procedure for national renewable energy policy formulation using Analytic Hierarchy Process (AHP).
iii. Formulate policies that stipulate technology-specific renewable energy targets for the U.S.
iv. Develop procedures for selecting mandates or incentives, based on gaps between targets and current generation.
v. Facilitate selection of targets for low-priority waste-to-energy technologies.

1.7 Research Questions

The study answers the following questions:

i. For each U.S. region, what proportion of renewable energy resources need to be developed for a diverse renewable energy portfolio?
ii. What renewable energy sources should regional/national policies mandate or provide incentives to?
iii. For each renewable energy alternative analyzed, which region(s) would be ideal for investors to focus on for implementation, and which region(s) would benefit from incentives, to attract investment?
iv. What procedure can be used to develop and set energy generation targets for low-priority renewable energy sources?

1.8 Hypothesis

The proposed study will explore the following hypotheses in order to meet the research goals:

i. Decision analysis formulation from a policy maker's point-of-view will differ from the formulation from an investor's point-of-view.

ii. It is worthwhile to develop low-ranking energy sources at a smaller distribution generation scale, rather than at a national level.

1.9 Research Overview and Assumptions

The research establishes national renewable energy targets, by considering renewable energy technical resource potentials in addition to socio-economic and environmental factors using Analytic Hierarchy Process (AHP), a Multiple Criteria Decision Making Model (MCDM). The national-level renewable energy targets were evaluated by first determining regional renewable energy targets, and then translating these regional targets into national goals, following a bottom-up cascading procedure. Since the U.S is a large nation, with diverse geographic and socio-economic composition, and with "numerous state and country components" regional grouping, is often suitable for national-level research and data analysis. The current U.S Census Bureau division, which was selected for the regional grouping, provides 9 divisions that are comparable based on economic characteristics among other factors (U.S. Dept. of Commerce, Economics and Statistics Administration, Bureau of the Census, 1994). The regionalization done for this study allowed energy cost differences and variations of renewable energy resource potentials across the country to be captured, while maintaining a reasonable number of AHP computations.

According to the US Department of Energy, Energy Information Administration (EIA, 2003), the U.S. Census Bureau regions is the most commonly defined regional classification in the U.S. for data collection and analysis. Results based on this classification therefore also provide the opportunity and framework for integration and comparison with other research initiatives. The classification was particularly selected to match the EPA representation of the U.S. energy system, within its MARKet

ALlocation (MARKAL) model structure. The MARKAL model is a "data-driven, bottom-up energy systems economic optimization model" that is used by local and federal governments, for energy use analysis. The regions in the MARKAL database represent varying energy supply, technology, and demand, in order to analyze the environmental impacts of potential changes in energy production and uses (EPA, 2013b).

The AHP model is introduced in Section 4. Only non-hydro renewable energy sources were analyzed to include concentrated solar power (CSP), solar photovoltaic (PV), biomass energy, on-shore wind energy, off-shore wind energy, and geothermal energy. EPA characterizes these sources of energy, in addition to energy generated from small hydropower plants, as having the highest environmental benefits, and subcategorizes them as "green energy" (EPA, undated). Small hydropower energy was however not analyzed as a "green energy" option in this research, due to the varying restrictions of its eligibility as a renewable energy technology. RPSes for example have differing hydropower inclusion criteria based on capacity limits, age restrictions, environmental criteria or technology used. This is such that the same small hydropower facility that is considered a viable renewable energy source in one state may not be eligible in another (Stori, 2013). CSP, solar PV, biomass energy, on-shore wind energy, off-shore wind energy, and geothermal energy were evaluated as the energy "alternatives" in the AHP formulation. These alternatives were ranked to generated technology-specific renewable energy targets in each region.

The AHP "criteria", included the renewable energy technical resource potential (location potential), public perception, equivalent Greenhouse Gas (GHG) emissions, water demand and land requirement. The AHP criteria represented the parameters considered important in establishing the alternatives ranking. The criteria selection was in accordance to the 4P approach, which aims to maintain a balance between "people" or society, "planet" or the environment, "profits" or economics and "progress" or technology innovations . The selection criteria generally matched the criteria that has been recommended and used in previous AHP studies done for energy prioritization (Kabir and Shihan, 2003; Wang, 2009). While the grouping and terminology of evaluation for criteria and sub-criteria differ in the referenced studies, and this research, all generally fall under technical, economic, environmental and social clusters.

The selection criteria utilized quantitative data, which allowed for an objective comparison of alternatives. However, a rank order was used to assign weights for each of the criteria, giving way to some subjectivity in weighing the criteria. This meant that the relative weights given for the location potential values would be highest. The location potential was given the highest ranking due to the impact resource potential has on the technical, economic and market feasibility of an energy option for any given location. For an alternative with a low resource and technical potential, the cost required to develop the renewable energy source may be too high to justify the alternative or allow it to penetrate competing markets. The next criterion was land requirement, considering potential competition with other land uses when renewable energy infrastructure is installed at a commercial scale, followed by emissions due to the impacts on global warming and health, and finally water demand and public perception.

The listed criteria were indirectly expressed as benefits. The state-level alternatives ranking and prioritization based on these benefits were assimilated to establish the national renewable energy portfolio.

The inclusion of costs in AHP can either be done by adding costs as one of the criteria used for evaluating alternatives or represented in the form of a benefits/cost ratio. The latter was preferred for this study.

Costs were not considered in the case of the portfolio ranking but instead used in recommending financial incentives for renewable energy initiatives. Capital costs were used to compute a benefits/cost ratio for the renewable energy alternatives. The financial incentives would ideally be applied in order to promote renewable energy alternatives that ranked high, based on benefits alone, but had a low ranking considering costs. It was assumed that high capital costs were an indication of low levels of technical advancements of the energy options considered, and that the financial incentives would trigger an interest in research and development for those alternatives to lower the costs. It was also assumed that alternatives with high benefits but low benefits/costs ratios would have great potential for profitable development with improved technology. Separating the costs from the benefits criteria therefore allowed for incentives to be rationally recommended where needed.

Separating the benefits from the costs was assumed to offer an additional advantage in policy revisions. Assuming the renewable energy benefits would remain fairly constant with time, in comparison to energy costs, review and updates for energy policy would likely be solely based on cost adjustment, for reprioritization. An example of where this would be advantageous is in the case of solar PV, where the costs have reduced by about 80% since 2008 (IRENA, 2015b). In such cases, only the cost would need to be re-evaluated for computation of new benefits/costs ratios. In addition, cost data are usually based in estimates that may often require revision when better data are obtained.

Lastly, separating the costs would avoid the tendency for costs to dominate the renewable energy prioritization, with a blind-sided view of other benefits, which is the trend the research intends to move away from.

Regional renewable energy goals (both targets and incentives) were obtained using AHP analysis for each region, and based on the criteria established. Technical potential data (location potential) for each renewable energy alternative was available by state. For each region, the state technical potential data for states within the region was summed to obtain the total regional "location potential" values used in the AHP analysis.

A similar procedure was used to develop regional cost data, but by averaging state-level capital cost estimates. The state-level capital costs data were computed from capital cost estimates developed by SAIC Energy, Environment & Infrastructure, LLC for the EIA 2011 (EIA, 2013). Capital cost data were available, by states, for all renewable energy alternatives except for geothermal energy. Further the geothermal capital cost data comprised of estimates for hydrothermal energy, while only 1% of the technical potential data applied to the geothermal energy was attributed to hydrothermal systems. The bulk technical potential was attributed to enhanced geothermal systems (EGS). EGS systems are currently not installed at a commercial scale and cost estimates are therefore subject to many assumptions and uncertainties as the systems are designed for pilot-scale research, not electricity generation. In addition, capital costs estimates for EGS vary significantly from site to site, based on the geological formations and the level of uncertainty factored in risks associated with drilling. Relatively high initial capital costs are therefore typical, while the levelized costs of electricity (LCOE), which includes the capital costs as well as operations and maintenance cost over the useful life of the technology, are often relatively low. Nevertheless, the initial capital costs are expected to decrease over time, as drilling technologies improve (Edenhofer et al., 2011).

EGS capital cost estimates developed by Black & Veatch Holding Company (2012) for the National Renewable Energy Laboratory (NREL) were used for the AHP analysis. The estimates were based on a single-value generic approximation, and were not based on any individual site. Based on the high levels of uncertainty with EGS capital costs, a uniform capital cost was assumed for all regions. In addition, as EGS constituted the majority of the geothermal energy potential, hydrothermal systems were not taken into consideration in the cost analysis.

In addition, it was assumed that public acceptance would remain constant throughout the regions provided the same level of education, public relations and transparency in communications would be invested with a national renewable energy policy. It was also assumed that water demand, land requirement and emissions would mainly be technology-dependent and any difference based on location would be negligible.

In translating portfolio percentage goals into electric units that match the electricity projections with the Clean Power Plan in place, the study makes an assumption that hydropower generation will remain constant. Hydropower is deducted from the total renewable energy generation in 2030, to obtain the same energy mix that is considered for this study. There has generally been little or no hydropower growth, as shown in Figure 1-3, indicating that this assumption is reasonable.

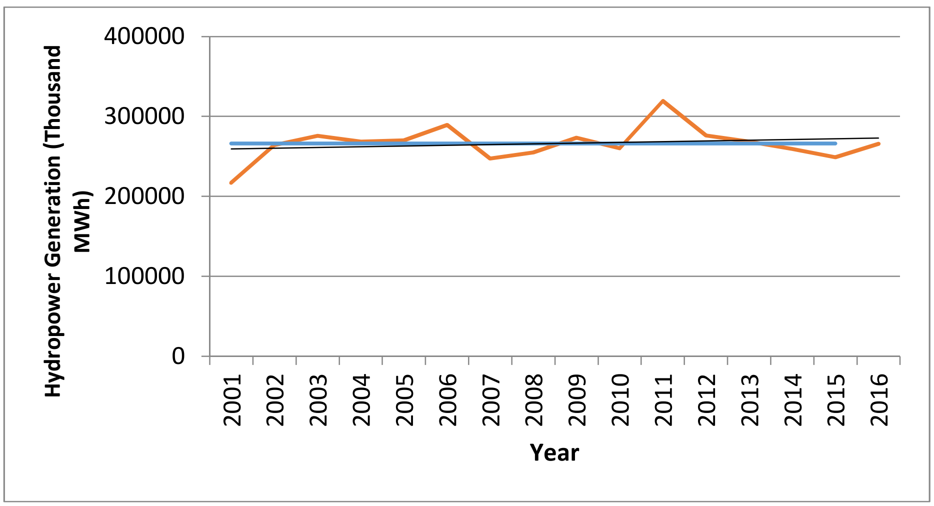


Figure 1-3: Historical Hydropower Generation

Based on the AHP methodology and assumptions made, the prioritization results indicated that on a regional level, electricity generation from biomass energy resources ranked lowest. This was mainly due to the low electricity potential in comparison to the other alternatives, as can be seen in Figure 1-4. Current state-level policies, however, were found to specifically promote biomass waste-to-energy generation, therefore taking advantage of managing waste by using it as a beneficial resource. North Carolina, Virginia and New Hampshire RPSes currently prioritize energy generation from swine and poultry waste, animal waste and wood waste (New Hampshire Public Radio, 2017) respectively. Therefore, rather than disregarding biomass renewable energy sources, which were found least favorable for utility-scale generation, the study assessed how energy targets for these resources could instead be set at a local level. Renewable energy in this case could either be for onsite use within the generating facility or fed back to the electricity grid system as a small-scale distributed energy source.

Biomass energy generated from WWTPs had the least resource potential compared to other biomass sources as shown in Figure 1-5. Therefore, based on energy potential, this source of energy would also be the least attractive for utility scale consideration. As such, the research developed methodologies and recommendations for biogas electrical energy targets at WWTPs. These targets would be established at a local rather than national setting to take advantage of the benefits of waste-derived energy. The study therefore determined the electrical energy potential targets for Combined Heat and Power (CHP) systems based on wastewater treatment capacities. A chart was developed, using a statistical approach, for selecting CHP electricity targets (in kilowatts – kW or megawatts - MW) for wastewater treatment plants. The methodology can be transferred, and modified as need be, to develop charts for other biomass resources.

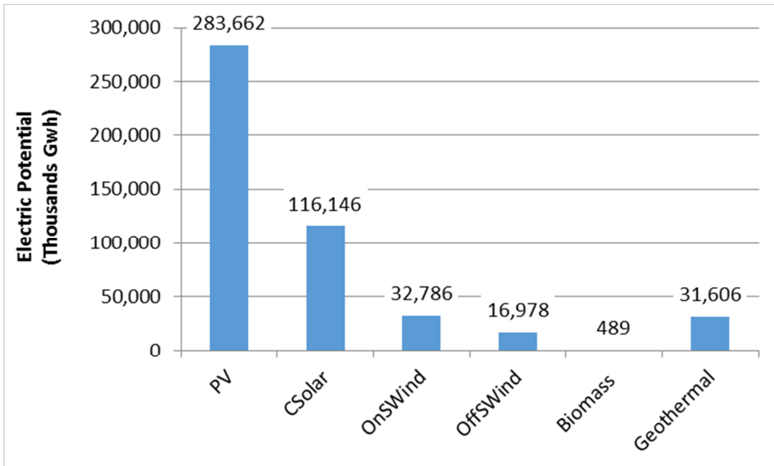


Figure 1-4: Renewable Energy Potentials for Evaluated Alternatives
Data Source: Lopez, A. et al., (2012)

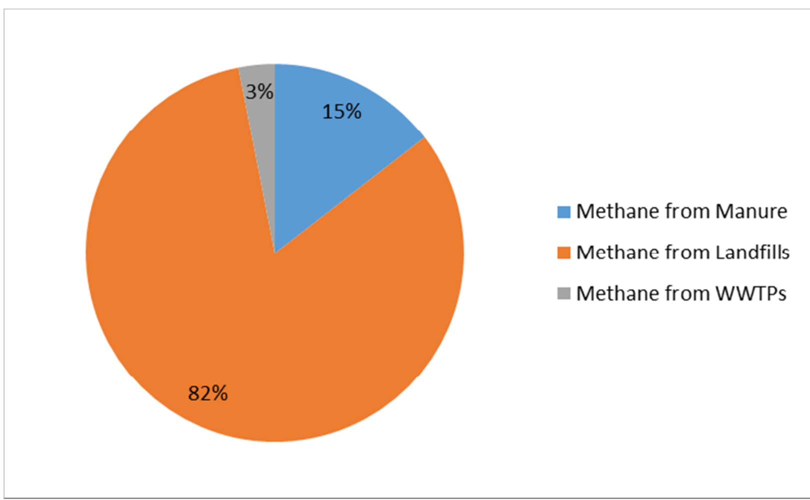


Figure 1-5: Percentage Distribution of Biomass Resource Availability from Methane

2 RENEWABLE ENERGY POLICY FORMULATION AND IMPLEMENTATION IN THE USA

This Section gives an overview of policy formulation in the U.S. in order to demonstrate how federal policies are established and, how state-level Renewable Portfolio Standards (RPSes) are initiated. It reviews how individual states mandate or encourage the implementation of renewable energy development through compliance and voluntary RPSes respectively. Regulatory policies are reviewed to understand the strategies currently used by states for technology-specific renewable energy prioritization, and how energy markets can impact the strategies.

State incentives for renewable energy generation were categorized into financial incentives and regulatory mandates, in order to analyze the driving factors for renewable energy prioritization, where it occurred. The results were compared with the prioritization recommended using the AHP methodology developed in this research in Section 5.

2.1 Policy Formulation and Implementation Cycle

Policy formulation and implementation involves a cyclical and repetitive process in planning that is aimed at achieving certain goals (EU Portal, 2003). Chapman, McLellan and Tezuka (2016) observed, from multiple studies that while the intermediate steps in the policy formulation and implementation cycle may slightly vary, based on the terminology used and/or level of expansion of broader stages into smaller sub-processes, the policy cycle generally begins with an objective problem statement, and ends with evaluation of the policy outcomes against the objectives, before the cycle is repeated, as depicted in Figure 2-1.

The intermediate steps of policy formulation involve reviewing policy proposals and decision analysis to determine if and how the policies will be implemented and translated to rules and regulations.

While policies are not always enforceable before they are implemented as law, which generally sets out mandatory standards and procedures that must be followed, policies can offer voluntary recommendations for meeting certain state or federal objectives, and suggest methods of achieving the objective through adoption into legislature.

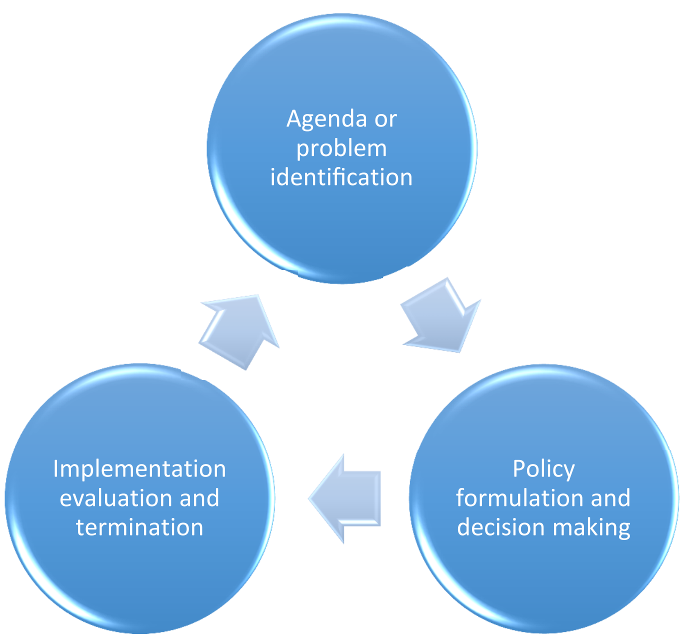


Figure 2-1: Policy Formulation and Implementation Cycle

In the USA federal legislative process, policies are introduced as bills. According to information provided in the United States House of Representatives (undated) website, bills may be initiated as ideas, plans or proposals that must be sponsored by one of the two legislative branches in Congress: the Senate or the House of Representatives (Figure 2-2). The sponsored bills are introduced by any member of Congress during a congress "session". Once the bill is introduced, it is entered in a "House Journal", an official record of the session proceedings, and assigned a legislative number with "HR", indicating a House Bill or "S" indicating a Senate Bill. The bill is then assigned to an applicable Committee depending on the area the bill covers. The Committee votes to report the bill back to the House or Senate for debate if satisfied with the content, or otherwise rejects it. In the case of House Bills, if a majority of the House (218 of 435), are in favor of the bill, the bill moves to Senate and is assigned to another committee for review, amendments and discussion, before it is voted on. When both the House and Senate have passed and signed off the final amended identical bill, it is "enrolled" for presentation to the President. If the President approves the bill and signs it, it becomes law or legislation.

The same procedure is generally followed for state-level policies, with subtle variations in the individual state processes. At a state level, bills may be introduced by a member of the general assembly, reviewed by the appropriate committee, and debated on at different chamber levels. State level bills become state laws when signed by the state governor.

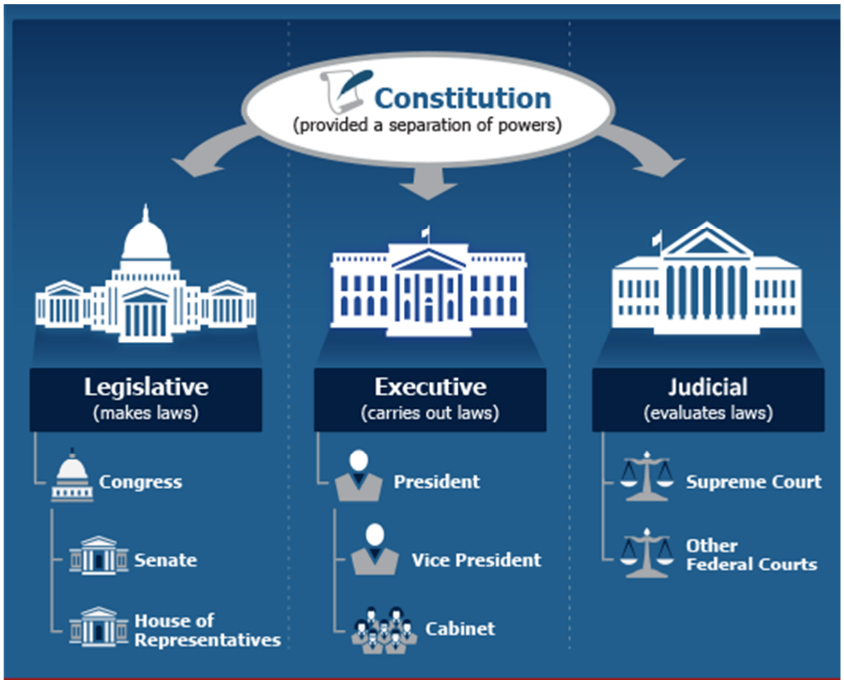


Figure 2-2: Branches of the USA Government

Source: USA Government - *https://www.usa.gov/branches-of-government*

2.2 Renewable energy Policy in the USA

Though the U.S. does not currently have national/federal renewable energy policies precisely aimed at achieving specified renewable energy targets, individual states may mandate or encourage the implementation of renewable energy programs through state initiatives including the RPSes. Other state-level energy regulatory policies, that do not necessarily specify renewable energy generation targets, include policies stipulating design and permitting standards for renewable energy sources, such as for interconnections, line extension, and net metering, as well as standards that govern tariffing, including surcharges added to customer bills as contribution to public benefits funds that support renewable energy programs. Regulatory policies may also include energy efficiency programs and standards such as the Mandatory Utility Green Power options, which require utilities to offer voluntary programs for customers to purchase renewable energy or make voluntary contributions to support development of renewable energy sources. Utilities may charge renewable energy tariffs on top of the regular electricity charge under Mandatory Utility Green Power programs.

Allison and Williams (2010) analyzed the variation of renewable energy laws and regulations of 17 states with the highest populations. Their evaluation excluded Tennessee, due to the inherent influence of the Tennessee Valley Authority (TVA) on the State's energy markets. TVA is a federal corporate agency that provides electricity in Tennessee and parts of Alabama, Georgia, Kentucky, Mississippi, North Carolina and Virginia (TVA, undated).

From the 17 states that were reviewed, 15 had state implemented RPSes that were all initiated from one of the following leads:

1. The public utilities commission, which generally regulates utility services providers, including electric utilities.
2. Legislation-driven and delegated to the public utilities commission, a newly created agency, or both.
3. Citizen-initiative proposed by petition, and enacted into law based on statewide popular vote.

Table 2-1 summarizes the RPS implementation strategies by each of the 17 states. Of the states reviewed, and with the exception of Texas and Michigan, the state RPS goals were generally presented as a percentage renewable energy goal. Texas has a numeral goal, to generate 10,000 MW of renewable energy, by 2025, and Michigan has both a percentage renewable energy goal for the state, and numeral measures for its two largest investor-owned utilities.

Table 2-1: Origins of RPS Programs for Sample States

Originated by state utility commission	Originated by Legislation	Originated by statewide vote
Arizona	California	Missouri
New York	Florida	Washington
	Illinois	
	Massachusetts	
	Michigan	
	New Jersey	
	North Carolina	
	Ohio	
	Pennsylvania	
	Texas	
	Virginia	

Source: Allison and Williams (2010)

2.3 Renewable Energy Policy Mandates and Incentives in the U.S

For this research, all current state-level RPSes were reviewed to determine the type of state incentives applied, and the favored renewable energy options. This was done using the Database of State Incentives for Renewables & Efficiency (DSIRE) records that is operated and maintained by the N.C. Clean Energy Technology Center at the N.C. State University (2017), under funding from the U.S. Department of Energy. The renewable energy programs of interest were filtered to include only state implemented renewable energy technologies, and excluded energy efficiency programs, programs implemented by the federal government and those independently administered by utilities. The resulting state incentives for renewable energy were categorized into financial incentives and regulatory policy mandates, in order to analyze possible driving factors for renewable energy prioritization, where it occurred. The financial and regulatory policies that were reviewed were only applicable to wholesale investor-owned utilities (IOUs), municipal utilities, cooperative utilities, and retail suppliers. The policies were not applicable to residential customers, businesses, contractors or builders, etc. Using examples from the state of North Carolina, investor-owned utilities, such as Duke (Progress) Energy, are operated for-profit and privately owned by stockholders, who may not necessarily be the consumers. Cooperatives, such as Energy United, on the other hand, are owned by local members, and for the benefit of the members, who are also the consumers. Cooperatives therefore are not for profit, providing electric services at a fee that covers the generating, service and improvement costs. Municipal utilities are public power systems, owned by local government entities or by the local community, and operated by local governments (cities or towns), such as the Statesville Electric Utilities, City of Statesville, in Iredell County. Municipal utilities are also non-profit.

The financial incentives were grouped into programs that benefit utilities through corporate tax credits or tax exemptions, and reductions that included sales and property taxes for renewable energy projects, as well as loans, grants, rebates and performance based incentives that offered an incentive amount per unit of renewable energy generated. These are summarized in Table 2-2 to Table 2-8.

Table 2-2: Tax Credit and Exemptions

Tax Incentive Type	State	Policy	Description
Tax Credit	MD	Clean Energy Production Tax Credit (Corporate)	Relief of $ 0.0085/kWh of renewable energy generation against state income tax, for 5 years.
Tax Exemption	WV	Tax Exemption for Wind Energy Generation	Reduction of Business and Occupation (B&O) tax. B&O tax is calculated by multiplying a pre-determined dollar amount by 40% of the nameplate capacity rating of the generating unit. The B&O tax on wind turbines is multiplied by only 12% instead of 40%.

Source: DSIRE Database, Last Accessed September 2017(N.C. Clean Energy Technology Center at the N.C. State University, 2017)

Table 2-3: Sales Tax incentives

State	Policy	Description
NM	Gross Receipts Tax Exemption for Sales of Wind and Solar Systems to Government Entities	New Mexico has a “gross receipts tax structure”, such that businesses are taxed on the gross amount of their business receipts before expenses are deducted. This incentive covers 100% of gross receipts from sale and installation of solar systems used to provide space heat, hot water, or electricity.
NM	Advanced Energy Gross Receipts Tax Deduction	Receipts associated with the sale and installation of an eligible facility are exempt from being added to overall gross receipts. Eligible technologies include Solar and Geothermal: 1 Megawatt minimum and Recycled Energy: 15 Megawatt maximum. The maximum incentive: amount is 60M.
NM	Solar Energy Gross Receipts Tax Deduction	Receipts associated with the sale and installation of an eligible solar facility are exempt from being added to gross receipts.
NV	Renewable Energy Sales and Use Tax Abatement	Systems must have a generating capacity of at least 10 megawatts. Sales and use taxes are fixed at a rate of 2.6%
UT	Alternative Energy Sales Tax Exemption	100% sales tax exemption for 2 MW or greater, or for expansions of 1 MW or greater or renewable energy source at a facility. The facility must have net positive renewable energy generation, that is, it must generate an amount of energy greater than that required for the operation of the facility.
NE	Sales and Use Tax Exemption for Renewable Energy Property	100% sales tax refund. Does not apply to the first 1.5% of sales tax charged by a municipality. Equipment investment must meet or exceed $20,000,000.
NE	Sales and Use Tax Exemption for Community Renewable Energy Projects	100% emption from the sales tax for community renewable energy projects.
CO	Sales and Use Tax Exemption for Renewable Energy Equipment	Exemption of state sales tax and use tax (charged for items bought in another state, but used in Colorado, if the items were not subject to tax in the state bought from), for systems which produce electricity from an eligible renewable resource.

Source: DSIRE Database, Last Accessed September 2017(N.C. Clean Energy Technology Center at the N.C. State University, 2017)

Table 2-4: Property Tax incentives

State	Policy	Description
AZ	Property Tax Assessment for Renewable Energy Equipment	Renewable energy equipment is assessed at 20% of the original after deducting depreciation for Solar Thermal Electric, Solar Photovoltaics, Wind (All), Biomass, and Hydroelectric energy.
NV	Large Scale Renewable Energy Property Tax Abatement (Nevada State Office of Energy)	Up to 55% property tax abatement for 20 years
OH	Qualified Energy Property Tax Exemption for Projects over 250 kW	100% property tax exemption for eligible sources.
IL	Property Valuation for Commercial Wind Energy Equipment	Wind equipment for 500 kW systems and larger are valued at $360,000 per megawatt (MW), equivalent to $360 per kW, of capacity, and annually adjusted for inflation according to the U.S. Consumer Price Index. Allowance for physical depreciation at a depreciation of up to 70%. In comparison, the U.S. Department of Energy (U.S. DOE, 2015) reports that 2015 weighted average installation costs was $1,690 per kW.
TN	Green Energy Property Tax Assessment	Assessed property value may not exceed 1/3 of total installed costs for wind, 12.5% of installed costs for solar, and for other green sources of energy.
WV	Special Assessment for Wind Energy Systems	Property tax reduced to approximately 25% of assessed value by assuming utility-owned wind projects have a value equal to their salvage value.

Source: DSIRE Database, Last Accessed September 2017(N.C. Clean Energy Technology Center at the N.C. State University, 2017)

Table 2-5: Grant Programs

State	Policy	Description
AK	Renewable Energy Grant Program	Grant administered for new renewable energy projects constructed and operated for the public benefit.

Source: DSIRE Database, Last Accessed September 2017(N.C. Clean Energy Technology Center at the N.C. State University, 2017)

Table 2-6: Loan Programs

State	Policy	Description
IA	Alternate Energy Revolving Loan Program	Loan of $1,000,000 for most applicants; $500,000 for rural electric cooperatives and municipal utilities at 0% interest. Maximum term of 20 years. Non-regulated utilities limited to 1 loan every 2 years.
AK	Power Project Loan Fund	Loan Program eligible for cooperatives and government utilities for small-scale (< 10 MW) power production facilities. No maximum loan amount, but loans over $5 million require legislative approval. Term based on useful life of project, with a maximum of 50 years. Interest rates vary based on average yield of municipal bonds.
RI	Energy Revolving Loan Fund	Loans funded by the American Recovery and Reinvestment Act. Loans are offered at terms of 5-10 years, with interest rates ranging between 1% and 3%.

Source: DSIRE Database, Last Accessed September 2017(N.C. Clean Energy Technology Center at the N.C. State University, 2017)

Table 2-7: Rebate Programs

State	Policy	Description
IL	Public Sector Energy Efficiency Programs	Offers rebates and grants that are available for geothermal heat pumps under two programs: Standard Incentive Program – of which the incentives varies, and Custom Incentives of $0.12 per annual kWh savings. Payback period of between one and seven years. Rebates are limited to $150,000, and grants cannot exceed $300,000 per location.

Source: DSIRE Database, Last Accessed September 2017(N.C. Clean Energy Technology Center at the N.C. State University, 2017)

Table 2-8: Performance-Based Incentive

State	Policy	Description
OR	Utility Scale Solar Incentive Program	Performance-Based financial incentive of $0.005/kWh for 2 MW - 10 MW solar PV, paid monthly for a period of five years. Individual owners or operators of solar PV systems may enroll projects up to a cumulative capacity of 35 MW.
NV	Portfolio Energy Credits (PEC)	Renewable energy producers can earn PECs, which can then be sold to utilities that are required to meet Nevada's portfolio standard. One PEC represents one kilowatt-hour (kWh) of electricity generated, with the exception of the multipliers for solar energy which has a higher value.
NY	CHP Performance Program	Incentive Amount of $0.10/kWh annual energy generation from CHP systems.

Source: DSIRE Database, Last Accessed September 2017(N.C. Clean Energy Technology Center at the N.C. State University, 2017)

2.4 Renewable Energy Policy Impacts on Energy Markets

Regulated electric markets are comprised of vertically integrated utilities that generate, transmit and distribute electricity as a single entity. These utilities own or control the power generating plants and the transmission and distribution infrastructure necessary to deliver power to customers over a given service area. Customers within regulated electricity markets do not have the option of selecting the utility that serves them, as all the infrastructure from the source (generating plant) to their service meter is generally owned by a single entity. Fixed rates are set by these utilities and approved by state regulators based on the cost to provide service and a fair profit margin. There is no competitive or market driven pricing. In states that have regulated energy markets, since utilities are simultaneously responsible for the generation, distribution and retail of electricity, the utility companies themselves are "directly" expected to meet state-implemented renewable energy goals from the generation to supply (State of New York Public Service Commission, 2016).

In deregulated markets, utilities serve as retail suppliers as they do not own the generating power plant or transmission mains. Electricity generating companies sell wholesale electricity to the retail suppliers, while transmission companies own and operate the transmission grid. Statewide independent system operator (ISO) or regional transmission organization RTO manage the generation and transmission. The retail suppliers are therefore only responsible for electricity distribution from the grid connection to meter. Retail suppliers can select renewable energy generators based on price, and customer demands. Several retail electricity suppliers are able to sell electricity to a single customer in a free market system that allows competition between the suppliers. The customers, in this case, have an option of determining their retail supplier. Renewable energy goals for deregulated markets can be met by the utilities "purchasing clean energy from independent generators for distribution and retail sale by the utility". RECs can also be purchase to cover state mandated RPSes.

3 DECISION ANALYSIS

This Section reviews the basis of decision analysis and its importance in energy planning, considering that energy planning cuts across multiple sectors and with different groups of stakeholders, all of whom may have varying interests, preferences and goals. Strantzali and Aravossis (2015) suggested that formulating policies without taking into account the multiple parameters involved is not "socially acceptable", as was illustrated with the California case study on the disapproval of wind turbines in Section 1.3.

This Section also highlights why AHP was selected for the Analysis. Though no studies that showcased actual policies being formulated and implemented based on AHP were discovered, literature review of other studies that suggested AHP application, specifically for renewable energy policy formulation or prioritization, were found, as indicated in the sub-section that follows.

3.1 Decision Analysis for Energy and Environmental Planning

Decision analysis is an iterative process, which involves evaluating complex alternatives with uncertain outcomes and difficult tradeoffs in order to make a decision. As illustrated in Figure 3-1, each iteration cycle revises the decision model until no further improvement is needed for the decision to be acted on (Huang et al., 1995). Decision analysis allows for effective decisions to be made consistently by providing tools and techniques for organizing decisions.

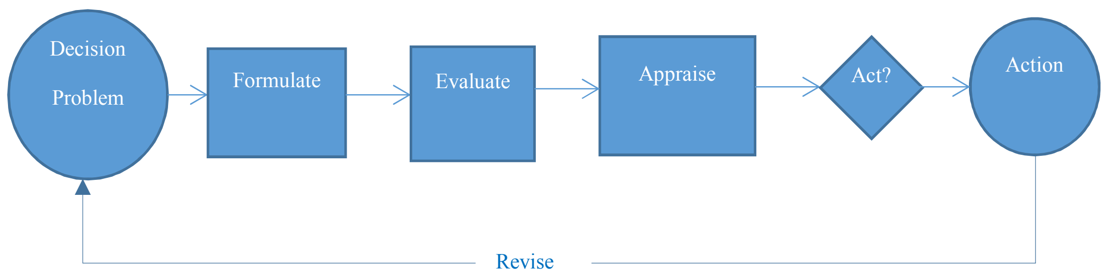


Figure 3-1: Schematics of Decision Analysis Process
Huang et al., 1995

Decision analysis is especially suited for energy and environmental planning, considering the long time frames of projects, and large capital requirements in these sectors. In addition the projects involved are often complex with multiple criteria or objectives, alternatives, and sources of uncertainties. It is no wonder that early applications of decision analysis were mainly carried out for the energy sector, more specifically, for oil and gas exploration in the 1960's, before the application was extended to other sectors (Huang et al., 1995). The focus on decision analysis for energy systems has changed over the years from energy security surrounding the "peak oil" theory concerned with rising oil prices and energy costs in the 1960's, to energy planning for cost optimization in the 1970's (Strantzali and Aravossis, 2015), and towards sustainable energy planning that considers health, social and environmental impacts starting in the 1980's (Løken 2007; Strantzali and Aravossis, 2015).

Recent energy policies in the U.S. that have encouraged clean and renewable energy generation include the RPSes, the Energy Independence and Security Act of 2007 (Clean Energy Act of 2007), and the proposed Environmental Protection Agency (EPA) Clean Power Plan, as described in Sections 1 and 2.

3.2 Decision Analysis Methods

Decision analysis methods can be divided into three main groups, according to Zhou et al. (2006). The main methods include single objective decision making (SODM) methods, multiple criteria decision making (MCDM) methods, and decision support systems (DSS) (Figure 3-2). Though these methods can be further broken down into more specific decision analysis methods, the study does not go into details in comparing the specific methods, but gives a general overview of the grouping and the placement of the AHP methodology that was used, and the basis of its selection.

3.2.1 Single Objective Decision Making (SODM) Methods

SODM methods involve evaluating multiple alternatives with uncertain outcomes under single objective conditions (Zhou et al., 2006) . For example, energy policy objectives could include one of the following objectives: (1) maximize renewable energy generation, (2) minimize investment risks associated with renewable energy, and (3) minimize carbon emissions etc. “Classic” applications include decision trees and influence diagrams. The mathematical foundation of decision trees and influence diagrams is based on the Bayes’ Theorem. The Bayer’s decision theorem quantifies trade-offs between alternatives using probabilities and costs of decisions. According to Huang et al. (1995), decision trees have several drawbacks including large tree sizes for complex problems, and therefore influence diagrams are often used as an alternative to decision trees. Elements of both decision trees and influence diagrams include the decision objective, alternatives, uncertain elements and decision consequences.

3.2.2 Multiple Criteria Decision Making (MCDM) Methods

As the name suggests, MCDM methods are used for decision making involving multiple criteria. MCDM methods can be classified into two broad categories according to Zhou et al. (2006); Pohekar and Ramachandran (2004) and Huang et al. (1995), namely: Multiple Objective Decision Making (MODM) and Multiple Attribute Decision Making (MADM) methods.

In MODM, multiple objectives, which can be complementing or conflicting, are provided or established before the analysis, but the alternatives are not predetermined. There is no single solution, but rather a set of alternative solutions that trade against the different objectives provided and within boundaries of the constraints supplied. The ideal solution is one that cannot further improve any objective without reducing the performance of one or more other objective.

On the other hand, a set of alternatives are first generated for MADM methods and evaluated against various criteria to meet a single objective involving priority ranking.

In addition to life cycle analysis (LCA), which evaluates the overall impacts of a project over its entire life cycle, and benefits-cost analysis, which compares the total costs and benefits associated with projects or policies as a ratio, MCDM are the most frequently used approaches to modelling energy systems (Shmelev, 2012).

3.2.3 Decision Support Systems

Decision support systems (DSS) are based on the application of computer software specifically developed for decision modelling and analysis. These often support decision making for complex problems that would be difficult to analyze using the other methods. Examples of DSS applications specific for energy planning include, Long-range Energy Alternatives Planning System (LEAP), RetScreen, and MARKAL among others. Decision support systems were not used in this research as the complexity of the problems represented did not warrant the need. However, the methods presented in this research can be translated to support systems as a future improvement.

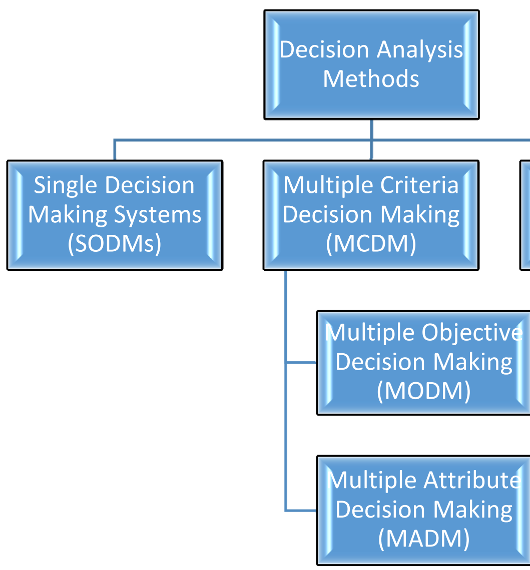


Figure 3-2: Decision Analysis Main Methods

3.3 Basis of AHP Selection for Energy Prioritization

Starting from the main decision making methods, MCDM methods are suitable for this research, as the methods offer the opportunity for decision making involving multiple criteria. Narrowing down further, MADM methods are based on ranking alternatives that have already been predetermined, which was the case for this research, as renewable energy alternatives for analysis were established before the decision making effort. The Analytic Hierarchy Process (AHP) was found particularly favorable for analysis in this study, firstly because it allows for use of both quantitative and qualitative criteria and also for the evaluation of alternatives against criteria that have different units of measurements. Secondly AHP can prioritize /rank alternatives in lieu of generating a single selection. And thirdly AHP can incorporate the computation of a benefits/cost ratio as detailed further in this Section.

According to Huang et al. (1995) and Haddad et al. (2017), the Analytic Hierarchy Process (AHP) is one of the most often used MCDM methods. Pohekar and Ramachandran (2004) reviewed more than 90 published papers and analyzed various MCDM methods and their applicability. Based on the analysis, they determined that AHP was the most popular technique.

Other authors have specifically proposed using AHP for energy development planning and prioritization. Wimmler et al. (2015) provided a detailed review of multi-criteria decision making methods applicable to renewable energy prioritization on islands and concluded that AHP is the most frequently used decision method for energy planning. Wang and Poh (2014) reviewed a database of papers published from 1982 to

2013, which included the application of decision analysis methods in energy and environmental modeling. The study found that the AHP method and its derivatives (i.e. combinations with other methods) were particularly suited for energy planning and policy.

There are several recent energy planning studies which specifically prioritized or ranked renewable energy sources at a country-level using AHP. It was noted, however, that none of the studies reviewed considered the variability of renewable energy potential for large and extensive regions, or countries, such as the U.S. in ranking the energies. In addition, none of the studies addressed the possibilities of conflicting prioritization for renewable energy development based on policy makers' and investors' conflicting points-of-view, to determine where and which policy compromises, specifically incentives, were needed, or where mandatory measures would instead suffice. A comparison of the studies are detailed in Appendix 9.2 and summarized in Table 3-1. In comparison to other studies, this research goes a step closer to policy formulation by reviewing gaps that exist between current renewable energy percentage generation, and the AHP percentage generation for the alternatives considered. As detailed in Section 4, different for the other studies, this research provides an approach for selecting incentives and mandates for high ranking renewable energy sources that offer the most benefits. Other studies merely used AHP to rank renewable energy technologies. The study also looks at both investors' and policy makers' points-of-view to differentiate between the AHP formulations. The study uses the investor's point-of-view to allocate incentives to regions to promote uniform renewable energy development across the U.S. as much as possible, and the policy maker's point-of-view to select between mandates and incentives that would promote a diverse renewable energy portfolio mix.

Table 3-1: Study Uniqueness in Comparison to Others

Author	Country Focus	Energy Ranking	Policy Formulation and Inclusion	Incentives/ Mandates Differentiation	Policy Maker's Point-of-View	Investor's Point-of-View
Ahmad S., and Tahar R.M., 2014	Malaysia	X			X	
Haddad B., Liazid A., and Ferreira P, 2017	Algeria	X			X	
Demirtas O., 2013	Turkey	X			X	
Daniel J., Vishal N.V.R., Albert B., Selvarsan I., 2010	India	X			X	
Kabir A B M Z and Shihan S M A, 2003	Bangladesh	X			X	
Amer M. and Daim T.U., 2011	Pakistan	X			X	
Stein E.W., 2013	United States	X			X	
Okioga, 2017 (This Study)	United States	X	X	X	X	X

Similar to this study, Stein (2013) used AHP to rank renewable energy sources (wind, solar PV, geothermal and hydropower) energy alternatives, together with nuclear, oil, natural gas and coal in the United States. The author found the AHP method especially beneficial for energy policy analysis and formulation, due to the ability to evaluate each energy alternative according to cost, technical, environmental and socio-economic-political criteria, as well as ability to conduct a sensitivity analysis with respect to the criteria weights selected.

Ahmad and Tahar (2014) developed a AHP model to prioritize solar, biomass, wind and hydropower in Malaysia, using investment costs, CO_2 emissions, efficiency, land requirements, job creation, operational life and construction time. Haddad et al. (2017), used AHP to rank solar, biomass, wind, hydropower, and geothermal renewable energy resources using technical, environmental, economic and socio-political criteria for the Algerian electricity system. Demirtas (2013) used AHP to determine the best renewable energy alternative for Turkey, considering technical (production capacity, technological maturity, reliability and safety), economical (investment cost, operation and maintenance cost, service life and payback period), environmental impacts (carbon dioxide emissions), and social (benefits and acceptability) criteria. The renewable energy alternatives that were examined included geothermal, hydropower, wind, solar and biomass. Daniel et al. (2010) considered cost, efficiency, environmental impacts, installed capacity, estimated potential, reliability and social acceptance as criteria to rank solar, wind and biomass renewable energy sources in India. Kabir and Shihan (2003), also ranked solar, wind and biomass (biogas) energy, and considered location criteria based on land requirements, with flexibility (rural or urban suitability) and plant size as sub-criteria, for selecting renewable energy sources in Bangladesh. Other selected criteria included unit cost, technical considerations (equipment and plant design, parts availability, plant safety, maintainability, and training requirements), environment (impact on ecosystem and noise) and social impact (acceptability and quality of life). Amer and Daim (2011) focused on wind, solar and biomass energy for evaluation in Pakistan. The criteria for ranking were based on technical (technology maturity, efficiency/capacity factor, reliability, deployment time/duration, availability of required expert human resource, distribution grid availability, and resource availability), economical (research and development costs, capital cost, operation and maintenance costs, economic value/viability and electricity cost), environmental (land requirement, emissions (greenhouse gasses etc.), stress on eco-system), social (social benefits, job creation, and social acceptance) and political (contribution to national energy security and national economic benefits).

Haddad et al. (2017) provided a list and details of several other studies that have used AHP in combination with other methods, including AHP in combination with SWOT (Strengths, Weaknesses, Opportunities, Threats) analysis (Strantzali and Aravossis, 2016); as well as studies that have used variants of AHP, including Fuzzy AHP (Kahraman et al., 2009; Talinli et al., 2010; Tasri and Susilawati, 2014; Shen et al., 2010; Buyukozkan, and Guleryuz, 2003; and Ribas and da Silva Roch, 2015). AHP variants and combinations are not reviewed in detail for the purpose of this study. However, for this research, AHP was used in combination with Geographic Information System data to evaluate the technological resource potentials in U.S regions. This was done in order to take into consideration, the variability of renewable energy resource potential for the multiple alternatives considered, across the U.S. There are other studies that have used AHP to select renewable energy development sites for specific energies in a selected region. For example, Tahri et al. (2015) used a combination of AHP and GIS to determine suitable locations for solar PV farms in southern Morocco. AHP results were overlaid on GIS maps to highlight the suitable sites for solar PV farms. The criteria used included orography (slope steepness and orientation), land use (distance to road and urban areas) and climate (electricity potential). Climate was defined as the most important criteria, as it described the potential electricity production in a region.

In addition to the general AHP selection basis discussed above, the AHP methodology was found to be ideal as it allows costs to be separated from benefits for a benefits/cost ration computation. Considering renewable energy benefits remain fairly constant with time, in comparison to energy costs, review and updates for energy policy would involve a simple cost adjustment, for reprioritization.

Therefore, not only would the AHP approach facilitate structuring the decision-making process in a logical and consistent manner, but it also would enable efficient updates of policies when costs are updated. Contrary to this ideal scenario, current policies establish renewable energy goals through an iterative process of setting renewable energy targets, and accelerating target timelines or increasing the target goals when early growth is noted. It may be cumbersome to reach ideal energy targets when goals are set without logical reasoning. The easy-to-follow logical methods presented in the AHP process for renewable energy policy formulation are expected to shorten the iterative cycle involved in setting renewable energy goals, by starting at rational/calculated renewable energy percentage allocations, rather than arbitrary values, to set targets needed for a diverse renewable energy portfolio. This allows certainty in setting renewable energy targets, as well as in establishing reasonable mandatory measures to reach the targets. This level of certainty is also bound to increase predictability and confidence in the renewable energy policies, and thereby encourage buy-in and investment into renewable energy development. One of the issues the current

U.S administration is facing is lack of confidence in the formulation of its environmental and energy policies as discussed below.

In October 2017, the U.S. EPA proposed to repeal the “Obama-era” Clean Power Plan, indicating the EPA “determined that the Obama-era regulation exceeds the Agency's statutory authority" (EPA, 2017). The current EPA Administrator, Scott Pruitt indicated that he would consider a more “modest replacement rule for the Clean Power Plan” (New York Times, 2017). Scott Pruitt was also concerned about the plan potentially having a negative impact on jobs and profitable investments (CNN, 2017). He based his doubt on the data supporting regulations on climate change and the environment, and concerns about jobs, and stated: “The citizens just don't trust that EPA is honest with these numbers…. Let's get real, objective data, not just do modeling. Let's vigorously publish and peer-review science. Let's do honest cost-benefit work. We need to restore the trust”.

The AHP method was found to be easily adaptable for comprehensive formulation of national renewable energy policy, taking into consideration public perception, as well as the policy maker’s and investor’s point-of-view. By considering the two differing viewpoints the study was able to suggest how incentives and mandates can be used to tackle differing objectives.

The research applies “real” and “objective” data for the alternatives criteria and a new thought process of AHP for policy formulation, “not just modelling”.

4 USING ANALYTIC HIERARCHY PROCESS (AHP) FOR REGIONAL AND NATIONAL RENEWABLE ENERGY RANKING

This Section details the development of the Analytic Hierarchy Process (AHP) model, which was used for renewable energy ranking and portfolio allocation for U.S regions and the nation. The AHP analysis was uniquely developed to rank and prioritize the renewable energy alternatives based on a multi-perspective view, from the publics, policy makers' and investors' points-of-view. The ranking generated technology-specific targets for renewable energy generation, on a region by region basis, and the regional targets were assimilated into national renewable energy goals.

4.1 Regional Grouping for the AHP Analysis

Similar to other studies that have conducted national-level data analysis and research for the U.S., regional grouping was considered suitable for this study, since the U.S, as a large nation, has diverse geographic and socio-economic composition, and with "numerous state and county components" (U.S. Dept. of Commerce, Economics and Statistics Administration, Bureau of the Census, 1994). Renewable energy parameters, such as costs and resource potential, are therefore expected to vary with respect to different locations in the U.S. The regional grouping done for this study therefore allowed energy cost differences and variations of renewable energy resource potentials across the country to be captured, while maintaining a reasonable number of AHP computations. The current U.S Census Bureau division (Figure 4-1), was selected for the regional grouping. The grouping provides 9 divisions that are comparable based on economic characteristics among other factors (U.S. Dept. of Commerce, Economics and Statistics Administration, Bureau of the Census, 1994).

According to the U.S. Department of Energy, Energy Information Administration (EIA, 2003), the U.S. Census Bureau regions comprise the most commonly defined regional classification in the U.S. for data collection and analysis. Results based on this classification therefore provide the opportunity and framework for integration and comparison with other research initiatives. The classification was particularly selected to match the EPA representation of the U.S. energy system, within its MARKet ALlocation (MARKAL) model structure. The MARKAL model is a "data-driven, bottom-up energy systems economic optimization model" that is used by local and federal governments, for energy use analysis. The regions in the MARKAL database represent varying energy supply, technology, and demand, in order to analyze the environmental impacts of potential changes in energy production and uses (U.S. EPA, 2013b).

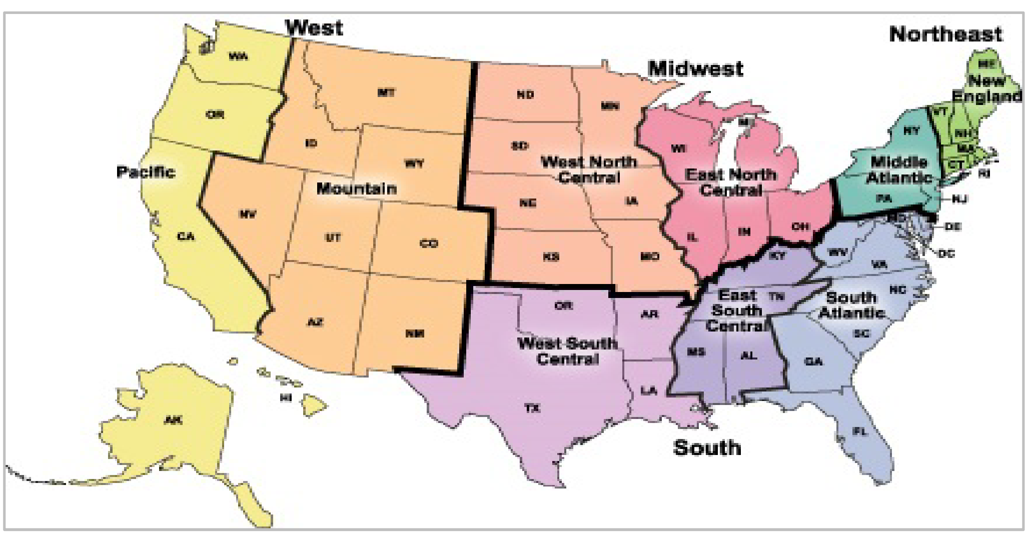


Figure 4-1: Census Bureau: Four Geographic Regions and 9 Sub regions of the U.S.

4.2 AHP Formulation and Structure

AHP is a Multiple Criteria Decision Making Model (MCDM) that allows multiple alternatives to be selected or ranked in order of preference using multiple criteria, by pairwise comparison of criteria and alternatives. Originally developed by Thomas Saaty in the 1970s, the method employs the following steps:

1. Stating the problem and objectives.
2. Listing the alternatives for solving the problem and defining the criteria that influence the selection of alternatives.
3. Hierarchical structuring of the problem to include goals, and the AHP criteria and alternatives.
4. Performing a pairwise comparison of the criteria and entering the comparison results in an n*n matrix, where n is the number of criteria being compared. The Saaty's (1980) scale provided in Table 4-1 can be used for making the pairwise comparison between criteria i and j, in which the diagonal entries result to 1 and entries that mirror the diagonal result in reciprocal values, thus requiring *n(n-1)/2* comparisons.

Table 4-1: Saaty's Scale

Comparison rating between alternative i and j	Description
1	i is equally important to j
3	i is slightly or moderately more important than j
5	i is strongly more important than j
7	i is very strongly more important than j
9	i is extremely more important than j
2,4,6,8	Intermediate values

Saaty (1980)

5. Calculating the geometric mean as successive n-powers of the comparison matrix and the normalized weight (normalized eigenvectors) obtained for each criterion.
6. Calculating the consistency ratio (CR) to determine if the pairwise comparison is consistent and satisfactory, and repeating the process until an acceptable CR is achieved (generally less than 0.1).
7. Computing a rating of the alternatives against each criterion (criteria scores). For quantitative data, normalization can also be carried out by simple weighted calculations, therefore eliminating the need for pairwise comparisons of the alternatives and subsequent consistency checks.
8. Computing the overall scores for each alternative as a product of the criteria weights and scores.
9. Ranking alternatives starting with the highest overall score.

The renewable energy alternatives evaluated for each U.S. region included onshore and offshore wind, solar PV and concentrated solar power (CSP), biomass and geothermal energy. The AHP criteria are the parameters that the alternatives are compared against for ranking or prioritization. The criteria used to rank the alternatives included the renewable energy technical resource potential in each region (location potential), the land requirement and water demand needed to develop and operate the energy, Greenhouse Gas (GHG) emission levels, and public perception. Section 4.3 explains the basis of the criteria selection. Costs for the renewable energy alternatives were not included as part of the criteria. Instead, capital costs were computed for each of the regions and used in establishing benefits/costs ratios as detailed in Section 4.10.The Hierarchical structure of the AHP problem is represented in Figure 4-2.

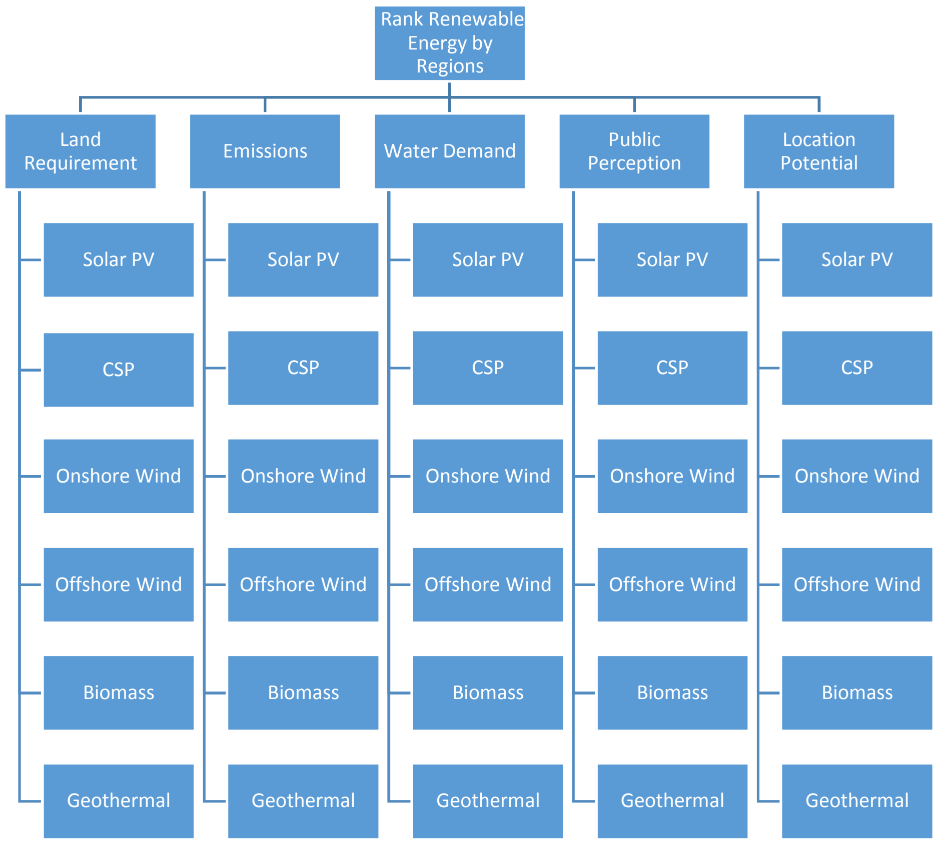


Figure 4-2: AHP Hierarchy

4.3 AHP Formulation: Objectives and Criteria Development

AHP objectives are generally based on the need to make decisions by ranking alternatives for a single selection of the best-ranking alternative, or in order to develop prioritization levels for all the alternatives considered. The AHP objective in this study was to rank, and prioritize renewable energy alternatives, in order to develop a national renewable energy portfolio and policy recommendations. After the problem was defined, and the objectives stated, the alternatives used for solving the problem, and the criteria that would influence the selection of alternatives, needed to be determined.

According to Wang (2009) evaluation of all the possible criteria in AHP planning and decision making does not necessarily imply a better decision model. It is instead recommended to focus on the most important criteria, which can be identified as those which are in line with the project objectives, independent of other criteria used, quantitatively or qualitatively expressed, comparable with the possibility of measurements based on both benefits and costs, and evaluated as a system rather than as individual components.

The evaluation criteria often used for energy ranking can be divided into four main categories according to Wang (2009), namely: (1) Technical criteria, including factors such as equipment design, complexity in technology, equipment and parts availability, installation flexibility, plant safety, estimated potential, efficiency, reliability, maintainability, maturity of the energy technology, and training requirements; (2) Economic criteria, including investment costs, capital costs, and operating and maintenance costs; (3) Environmental criteria including pollutant emissions, noise pollution, water demand, land or space requirements, location suitability and impacts on ecosystems; and (4) Social criteria including acceptability, job creation potential and impact on quality of life. Similarly, these main categories were applied in the AHP criteria selection for this study.

Location potential for renewable energy was considered at a base level for the U.S. regions analyzed, and environmental, economic and social constraints were assessed against the location potential in order to provide a complete analysis of achievable renewable energy opportunities. The environmental constraints or impacts were considered using the lifecycle of carbon dioxide equivalent Greenhouse Gas (GHG) emissions, water demand and land requirements as three separate criteria. Social impacts were considered using the public's perception of the importance of the renewables to the U.S. energy future, and economic impacts were considered using capital costs.

Though the AHP analysis allows alternatives to be evaluated against qualitative criteria, the research selected to use quantitative data, which is less subjective. The attributes that defined the measurable units for the respective criteria included the following: the measure of renewable energy location potential in Gigawatt hours (GWh); public perception based on the percentage of positive responses for the energy alternatives considered the most important; amount in grams of carbon dioxide equivalent greenhouse gas emissions (CO_2 equivalent GHG emissions) per kilowatt hour (kWh) of electricity generated by the energy source(g CO_2 eq/kWh); water demands based on maximum amounts of water consumed in energy generation, including cooling water, in gallons per Megawatt-hours (Gal/MWh); and land requirement ,based on land-use intensity for energy production, and measured in square kilometers of impacted land per terawatt-hour per year (km^2/TWh/yr). An advantage of using the AHP is that the units of measure for comparison between the different criteria did not have to be uniform for all criteria. Data conversions to reflect similar units for electric measures were therefore not required.

The listed criteria were indirectly expressed as benefits, while cost was taken into consideration by computing a benefits/cost ratio. Section 4.10 further discusses the reasons for separating costs from the criteria.

The selection criteria for this research generally matched the criteria used in previous AHP studies done for energy prioritization (Kabir, 2003 and Shihan, 2003). While the grouping and terminology used for the criteria, and sub-criteria where applicable, vary in the comparative studies, the general groupings fall under the technical, economic, environmental and social clusters suggested by Wang (2009). The criteria selection for this study, as well as the comparative studies, generally consider a 'quadruple bottom-line' (4P or QBL) approach, which would aim to maintain a balance between "people" or society, "planet" or the environment, "profits" or economics, and technology innovations or "progress".

4.4 AHP Formulation: Criteria Order of Ranking

The AHP model requires a weight to be established for each criterion being compared. According to Wang J–J et al. (2009), since different weights on criteria have a direct impact on the AHP results, it is necessary to rationally assign criteria weights. The weight is established by performing a pairwise comparison of each of the criteria, and entering the comparison results in an n*n matrix, where n, in this case, is the number of criteria being compared. Determining the values for the pairwise comparison is facilitated by first establishing a rank order of the criteria, starting with the one considered the most important to least important.

The ranking order was established such that it correlated as much as possible with the renewable energy potential pyramid developed by Lopez et al. (2012), shown in Figure 4-3.

Figure 4-3 suggests that the renewable energy potential of a particular technology can be analyzed at different levels. At a base level, the resource potential is the achievable energy generation, considering the renewable resource availability and quality. The technical potential data take into consideration factors that would influence the actual recoverable energy or the technical system performance such as topographic limitations, environmental, and land-use constraints and requirements, among other factors. The amount of energy available based on the technical potential is therefore less than that which is available based on the resource potential.

The technical potential values used to generate the renewable energy potential data in Appendix 9.4were based on the available land area for the energy development, excluding areas deemed unlikely for energy development such as landmarks, recreational parks, wetlands, forests and other protected lands. The technical potential values also factored in energy efficiencies and capacity factors for the renewable alternatives Lopez et al. (2012).

Similarly, for the AHP criteria ranking, the location potential was given the highest rank due to the impact resource potential has on the technical, economic and market feasibility of a renewable energy option. For an alternative with a low resource and technical potential, the cost required to develop the renewable energy source may be too high for investors to justify developing the alternative, or expect it to penetrate competing markets.

The next criterion in the rank order was land requirement, considering possible competition with other land uses, when renewable energy infrastructure is installed at a commercial scale.

The economic potential in Figure 4-3 is the next-level subset of the technical potential, and takes into consideration costs required to generate electricity. The economic potential is higher when the cost required to generate electricity is lower than the expected or available revenue. The market potential goes further to consider competition for energy resources, competing energy alternatives, investor responses, policies and regulations, and demands as shown in Figure 4-3 (Lopez et al., 2012). Policies and regulations may include rules or guidelines related to emissions, due to impacts on health and climate change, as well as water required for non-consumptive uses such as cooling water in geothermal energy production, as well as water demand management and treatment. Similarly, the AHP criteria ranking for emissions and water demand were placed 3rd and 4th respectively due to the impacts on global warming and health. Finally, public perception ranked lowest, as it assumed not all the survey feedback had scientific backing.

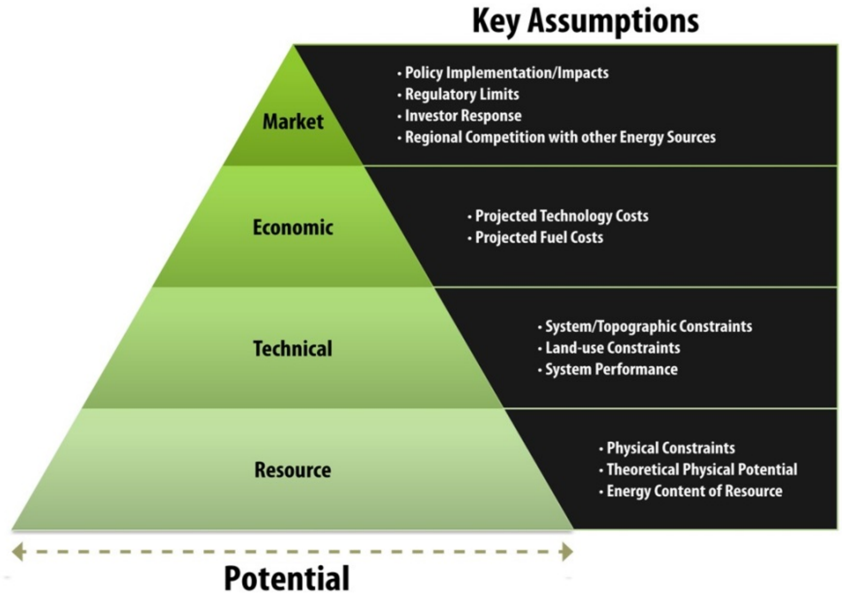


Figure 4-3: Renewable Energy Potential Levels
Source: Lopez et al. (2012)

4.5 AHP Formulation: Criteria Weighing

Criteria weights were obtained by pairwise comparison, that is, two criteria were compared and scaled in a comparison matrix according to the Saaty scale (Saaty, 1980). Intermediate values (even numbers) were not used in order to simplify the process. For example, the pairwise comparison between location potential and public perception in Table 4-2 was given a scale of 9, indicating that location potential scales 9 times as much as public perception or is of "absolute importance" in comparison to public perception. Logically, public perception would scale 1/9 times as much as location potential. The order established in the criteria ranking was used to construct the comparison matrix in Table 4-3, taking into consideration the diagonal entries, or elements compared to themselves, result to 1.

Table 4-2: Relative Ranking of Criteria

Pairwise Comparison	Scale of Relative Importance	Scale Description according to Saaty (Saaty, 1980)
Location Potential and Land requirement	3	Moderate Importance
Location Potential and Emissions	5	Strong Importance
Location Potential and Water Demand	7	Very Strong Importance
Location Potential and Public Perception	9	Absolute Importance
Land requirement and Emissions	3	Moderate Importance
Land requirement and Water Demands	5	Strong Importance
Land requirement and Public Perceptions	7	Very Strong Importance
Emission and Water Demand	3	Moderate Importance
Emission and Public Perception	5	Strong Importance
Water Demand and Public Perception	3	Moderate Importance

Table 4-3: Pair-wise Comparison Matrix of Criteria

	Location Potential	Land requirement	Emissions	Water Demand	Public Perception
Location Potential	1	3	5	7	9
Land requirement	1/3	1	3	5	7
Emissions	1/5	1/3	1	3	5
Water Demand	1/7	1/5	1/3	1	3
Public Perception	1/9	1/7	1/5	1/3	1

4.5.1 Weight Normalization of the Criteria and Comparison Matrix

The geometric mean was calculated as successive n-powers of the criteria comparison matrix (where n is the number of criteria, in this case, 5). The normalized weights (normalized eigenvectors) were obtained for each criteria as a weighted average using calculations shown in Table 4-4 and Table 4-5.

Table 4-4: Criteria Geometric Mean Calculations

	Location Potential	Land requirement	Emissions	Water Demand	Public Perception	Geometric Mean
Location Potential	1	3	5	7	9	$\sqrt[5]{1} \times 3 \times 5 \times 7 \times 9) = 3.9$
Land requirement	1/3	1	3	5	7	$\sqrt[5]{\frac{1}{3}} \times 1 \times 3 \times 5 \times 7) = 2$
Emissions	1/5	1/3	1	3	5	$\sqrt[5]{\frac{1}{5}} \times \frac{1}{3} 1 \times 1 \times 3 \times 5) = 1$
Water Demand	1/7	1/5	1/3	1	3	$\sqrt[5]{\frac{1}{7} \times \frac{1}{5}} \times \frac{1}{3} 1 \times 1 \times 3) = 0.5$
Public Perception	1/9	1/7	1/5	1/3	1	$\sqrt[5]{\frac{1}{9} \times \frac{1}{7} \times \frac{1}{5}} \times \frac{1}{3} 1 \times 1) = 0.3$

Table 4-5: Criteria Normalized Geometric Mean Calculations

	Geometric Mean	Normalized Geometric Mean
Location Potential	$\sqrt[3]{1} \times 3 \times 5 \times 7 \times 9) = 3.9$	3.9/7.7 = 0.5
Land requirement	$\sqrt[3]{\frac{1}{3}} \times 1 \times 3 \times 5 \times 7) = 2$	2/7.7 = 0.3
Emissions	$\sqrt[3]{\frac{1}{5}} \times \frac{1}{3} 1 \times 1 \times 3 \times 5) = 1$	1/7.7 = 0.1
Water Demand	$\sqrt[3]{\frac{1}{7} \times \frac{1}{5}} \times \frac{1}{3} 1 \times 1 \times 3) = 0.5$	0.5/7.7 = 0.1
Public Perception	$\sqrt[3]{\frac{1}{9} \times \frac{1}{7} \times \frac{1}{5}} \times \frac{1}{3} 1 \times 1) = 0.3$	0.3/7.7 = 0.03
	Total = 7.7	

4.5.2 Logical Consistency Check for Criteria

To check for consistency in the pairwise comparison established, a consistency ratio was calculated, and checked to ensure that it was less than 0.1. A consistency ratio greater than this would imply inconsistency in the pairwise comparisons. The consistency ratio was obtained as a ratio of the consistency index (CI) and random consistency index (RI). The formula for obtaining the consistency index is given by:

$$CI = (\lambda_{max} - n) / (n - 1)$$

Equation 4-1

Where n is the size of the matrix (number of criteria) and λ_{max} is the eigenvalue. The random consistency index (RI), which is a function of the number of criteria (n), is obtained from standard tables (Table 4-6).

Table 4-6: Random Consistency Index

n	1	2	3	4	5	6	7	8	9	10
RI	0	0	0.58	0.9	1.12	1.24	1.32	1.41	1.45	1.49

Table 4-7 shows the complete solution for the criteria ranking including the logical consistency check. The criteria weights assigned were 0.51 for location potential, 0.26 for land requirement, 0.13 for emissions, 0.06 for water demand, and 0.03 for public perception.

Table 4-7: Logical Consistency Check for Criteria

	Location Potential	Land requirement	Emissions	Water Demand	Public Perception	Geometric Mean	Normalized Geometric Mean
Location Potential	1	3	5	7	9	3.9	0.51
Land requirement	1/3	1	3	5	7	2.0	0.26
Emissions	1/5	1/3	1	3	5	1.0	0.13
Water Demand	1/7	1/5	1/3	1	3	0.5	0.06
Public Perception	1/9	1/7	1/5	1/3	1	0.3	0.03
Sum	1.79	4.68	9.53	16.33	25.00	7.7	1.0
Consistency Measure, λ	0.91 (1.79 x 0.51)	1.23 (4.68 x 0.26)	1.24 (9.53 x 0.13)	1.04 (16.33 x 0.06)	0.82 (25 x 0.03)		
λ_{max} (Total λ)	5.24						
CI = (λ_{max} -n)/(n-1)	0.06						
CR = CI/RI	0.05						

4.6 AHP Formulation: Criteria Scores

In Section 4.5 weights for each evaluation criterion were established by pairwise comparisons of the criteria. The higher the weight, the more important the corresponding criterion was. The next step was to assign AHP scores for the alternatives according to performance against each criterion. A high score implied high performance of the alternative, with respect to the considered criterion.

For each region, quantitative data for the alternatives were used to establish the performance against each criterion to develop the scores. Technical potential data (location potential) for each renewable energy alternative was available by state (Appendix 9.4). For each region, the technical potential data for all states within the region were summed to obtain the total regional "location potential" values used in the AHP analysis. Figure 4-4, Figure 4-5, Figure 4-6, Figure 4-7, Figure 4-8 and Figure 4-9 depict the regional potential values for each renewable energy alternative.

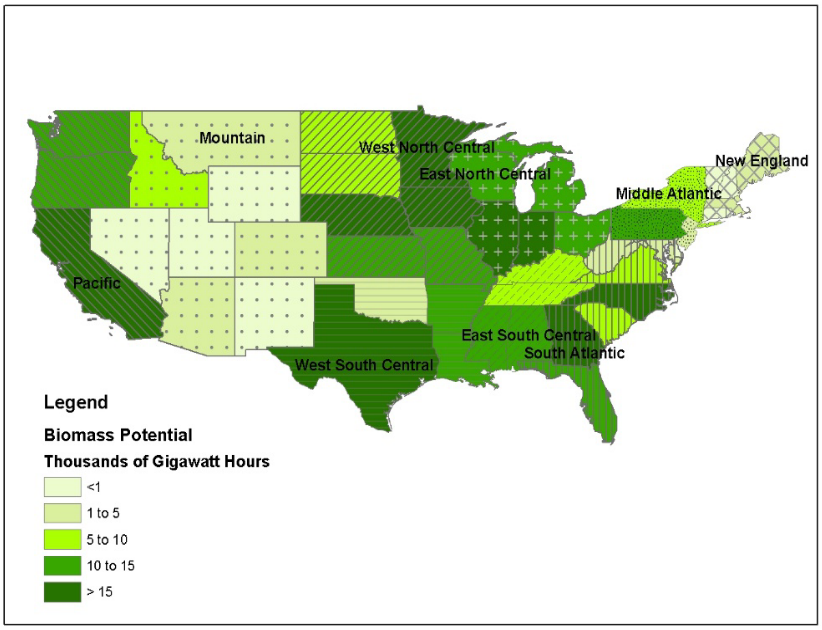


Figure 4-4: Biomass Potential Map

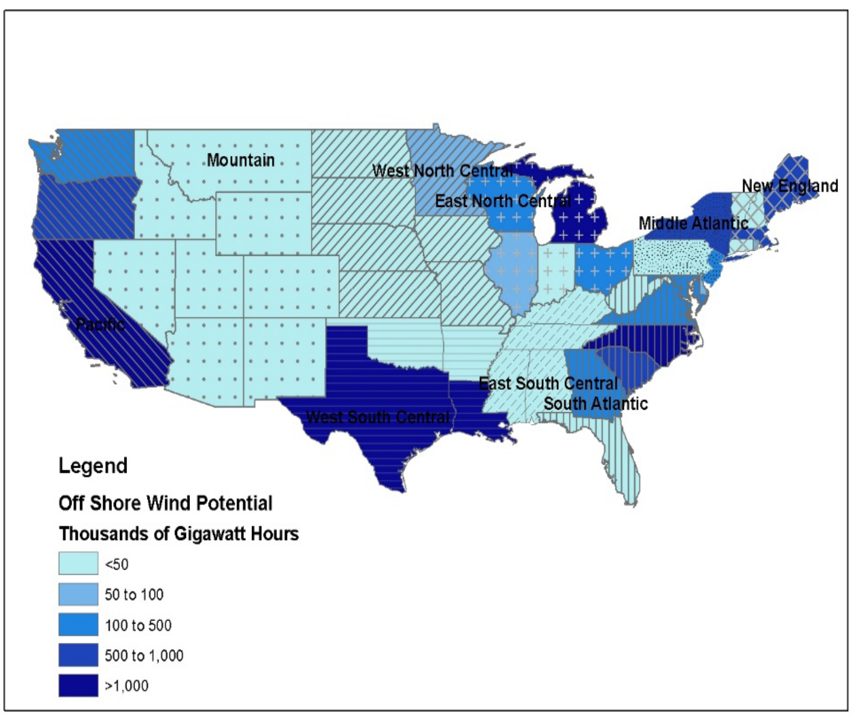


Figure 4-5: Offshore Wind Potential Map

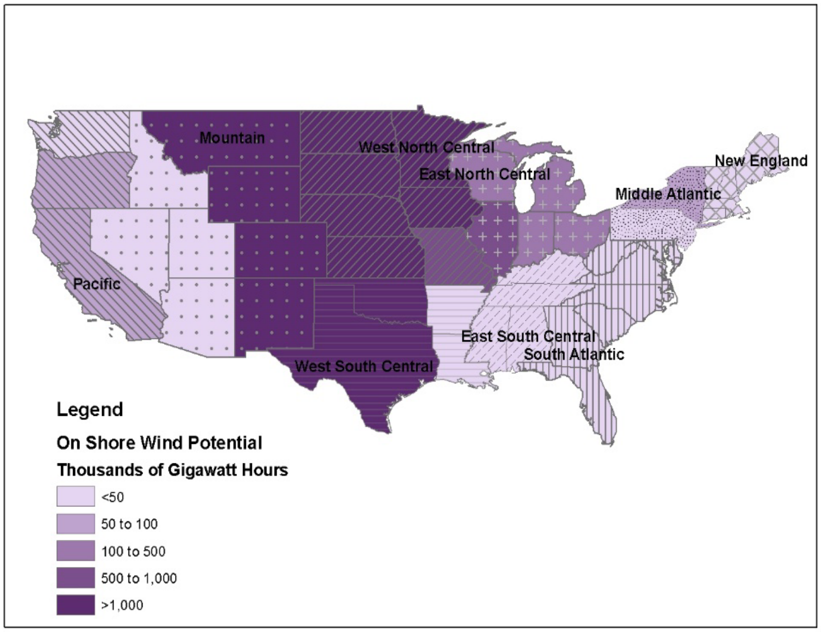


Figure 4-6: Onshore Wind Potential Map

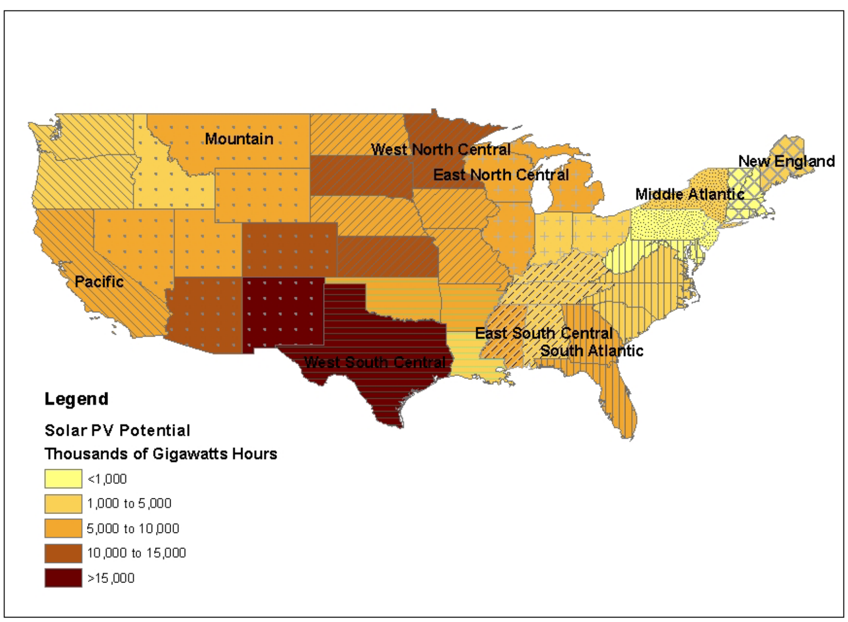


Figure 4-7: Solar PV Potential Map

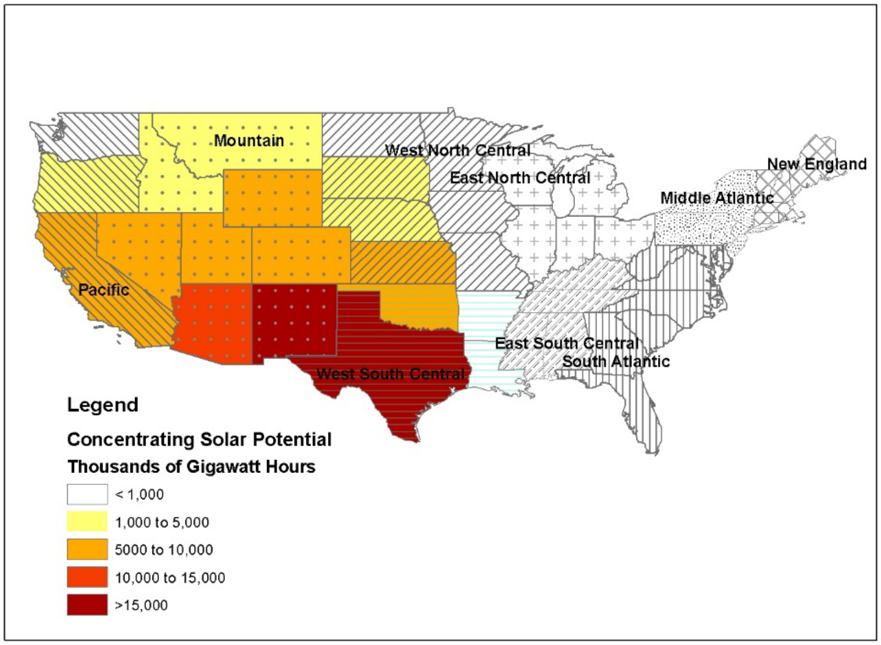


Figure 4-8: CSP Potential Map

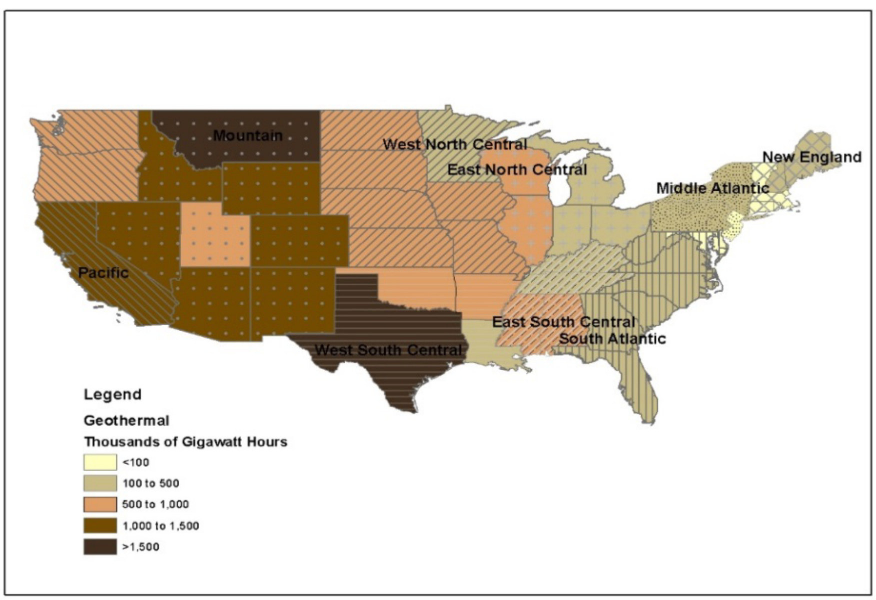


Figure 4-9: Geothermal Potential Map

It was assumed that water demand, land requirement and emissions would mainly be technology-dependent and any difference based on location would be negligible. It was also assumed that public acceptance would remain constant throughout the regions provided the same level or education, public relations and transparency in communications would be invested with a national renewable energy policy. These criteria therefore had uniform measures throughout the U.S. The data that were used are provided and discussed further in Section 4.8.

4.7 AHP Alternatives Ranking – Multi-perspective Views

Qualitative data obtained for the criteria were used to determine the preference (priority vector) of each alternative over the other, using, that is, priority settings for location potential, land requirement, emissions, water demand, and public perception. The alternatives were analyzed considering two main points-of-view:

1. Policy Maker's Point-of-View: It is assumed that the policy maker's goal would be to establish renewable energy portfolio standards for the U.S. regions and the nation, while incorporating all the renewable energy alternatives for a diverse energy mix and to facilitate national policy formulation for renewable energy targets and incentives. This analysis therefore answered the first two research questions listed under "Research Questions" (Section 1.7).
2. The Investor's Point-of-View: It is assumed that the investor's goal would be to determine the ideal location to implement a given form of renewable energy. This analysis, therefore, assumed that the investor would have

already narrowed down on the decision to invest in a particular renewable energy technology and would be required only to determine where to implement the project. For example, a solar developer would look to invest in areas or regions that would bring the highest possible profits, considering factors such as high solar potential and low capital costs for solar-derived electricity. This translates to lower risks for an investor. The analysis therefore answers the third research questions listed under Section 1.7.

4.8 Ranking Based on the Policy Maker's Point-of -Viewpoint

This section focuses on the policy maker's point-of-view for renewable energy prioritization and ranking. It explains how the normalized weights for prioritizing/ranking of renewable energy alternatives were determined and how renewable energy portfolios were generated. The AHP formulation combined the normalized criteria weights with the normalized criteria scores for the location potential, land requirement, emissions, water demand, and public perception, in order to obtain combined regional "benefit scores" for the renewable energy alternatives. The normalized criteria weights and scores were combined as a product of matrices for each region. The state-level alternatives ranking and prioritization, based on the benefit scores, were assimilated to establish the national renewable energy portfolio. The section starts by illustrating how quantitative values that were used for the evaluation criteria were normalized.

4.8.1 Normalized Location Potential

Regional renewable energy potentials were obtained from state data compiled by the National Renewable Energy Laboratory (Lopez et al., 2012). The data included energy potential for urban utility-scale solar PV, rural utility-scale solar PV, and rooftop solar PV, which were totaled to obtain the solar PV potential by state. The biomass potential was a total of both solid and gaseous biopower, and the geothermal potential was a total of hydrothermal geothermal and enhanced geothermal systems (EGS). Concentrated solar power and onshore and offshore wind energy values were used as provided in the referenced report. Energy potential maps (Figure 4-4, Figure 4-5, Figure 4-6, Figure 4-7, Figure 4-8 and Figure 4-9) were generated using the aforementioned data. The regional resource potentials are shown in Table 4-8 . The state data is included in Appendix 9.12 and the assumptions made in arriving at the technical potential values are summarized in Appendix 9.13.

For each renewable energy considered, the relative renewable energy rating, $U(x)$ values were calculated using the formula:

$$U(x) = \frac{x - E_{min}}{E_{max} - E_{min}}$$

Equation 4-2

where E_{min} was the minimum regional energy potential and E_{max}, the maximum potential.

From the policy maker's point-of-view, the analysis was done horizontally across the values shown in Table 4-8, to obtain the energy rating values in Table 4-9.

The energy ratings were then normalized to obtain the percentage benefits scores shown in

Table 4-10 and Figure 4-10, using the formula,

$$\frac{U(x)}{\sum U} \times 100$$

Equation 4-3

Table 4-8: Energy Resource Potentials (Thousand GWh)

Policy Maker's Point-of-View →

Investor's point-of-view →

(Energy Potential, GWh x 1000)	Geothermal	Onshore Wind	Offshore Wind	CSP	Solar PV	Biomass	Total	E_{max}	E_{min}
Mountain	9,933	7,015	-	62,324	70,480	21	149,773	70,480	-
West North Central	5,471	15,396	100	14,487	66,836	111	102,401	66,836	100
West South Central	4,923	7,098	2,302	27,855	57,980	57	100,215	57,980	57
East North Central	2,711	1,555	2,295	-	27,361	89	34,011	27,361	-
Pacific	2,973	1,587	6,951	11,480	23,093	59	46,143	23,093	59
South Atlantic	2,175	16	2,691	-	20,885	72	25,839	20,885	-
East South Central	2,007	1	10	-	12,933	44	14,995	12,933	-
Middle Atlantic	737	72	1,068	-	2,706	26	4,609	2,706	-
New England	676	46	1,561	-	1,388	10	10	1,561	-
Total	31,606	32,786	16,978	116,146	283,662	489			
E_{max}	9,933	15,396	6,951	62,324	70,480	111			
E_{min}	676	1	-	-	1,388	10			

Table 4-9: Energy Rating, U(x),Values – Policy Maker's Point-of-View

	Geothermal	Onshore Wind	Offshore Wind	CSP	Solar PV	Biomass	Total ($\sum \boldsymbol{U}$)
Mountain	0.14	0.10	NA	0.88	1.00	0.00	2.12
West North Central	0.08	0.23	0.00	0.22	1.00	0.00	1.53
West South Central	0.08	0.12	0.04	0.48	1.00	0.00	1.72
East North Central	0.10	0.05	0.08	NA	1.00	0.00	1.23
Pacific	0.13	0.07	0.30	0.50	1.00	0.00	1.99
South Atlantic	0.10	0.00	0.13	NA	1.00	0.00	1.23
East South Central	0.16	0.00	0.00	NA	1.00	0.00	1.16
Middle Atlantic	0.27	0.02	0.39	NA	1.00	0.00	1.67
New England	0.43	0.02	1.00	NA	0.89	0.00	2.34

Table 4-10: Normalized Percentage Scores for Location Potentials (equivalent to the Recommended Percentages of Renewable Energy)

	Geothermal	Onshore Wind	Offshore Wind	CSP	Solar PV	Biomass
Mountain	7%	5%	NA	42%	47%	0%
West North Central	5%	15%	0%	14%	66%	0%
West South Central	5%	7%	2%	28%	58%	0%
East North Central	8%	4%	7%	NA	81%	0%
Pacific	6%	3%	15%	25%	50%	0%
South Atlantic	8%	0%	10%	NA	81%	0%
East South Central	13%	0%	0%	NA	86%	0%
Middle Atlantic	16%	1%	23%	NA	60%	0%
New England	18%	1%	43%	NA	38%	0%

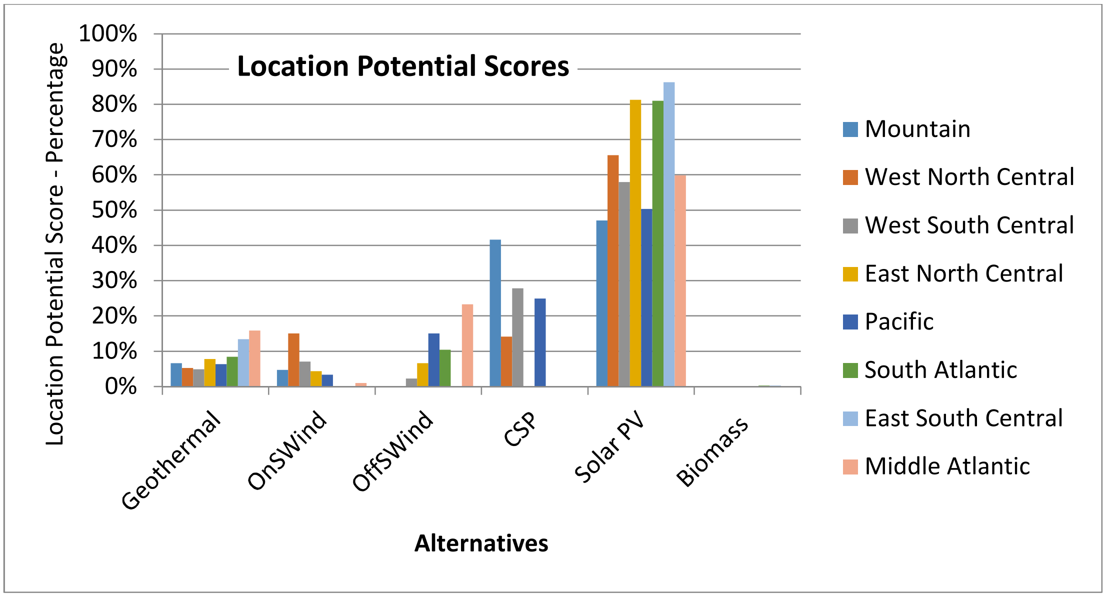


Figure 4-10: Renewable Energy Benefits Scores for Location Potentials – Policy Maker's Point-of-View

4.8.2 Normalized CO_2 Equivalent Greenhouse Gas (GHG) Emissions

Lifecycle of CO_2 equivalent greenhouse gas (GHG) median emissions data, obtained from the Intergovernmental Panel on Climate Change (IPCC, 2012), were used for computing emission scores. In this case, since it was desired that the lesser emissions result in higher scores, the energy rating $U(x)$, for each region was calculated using the formula given in Equation 4-4.

$$U(x) = \frac{E_{max} - x}{E_{max} - E_{min}}$$

Equation 4-4

where E_{min} is the minimum median emission expressed as grams of CO_2 equivalent per kilowatt-hour of generation (g CO_2 eq/kWh) and E_{max}, the maximum median emission. Again, the energy ratings based on the median values of emissions were normalized to obtain the results tabulated as follows.

Table 4-11and Figure 4-11 show that onshore wind energy scored highest with a 22% normalized criteria score and biomass lowest with a 0% score, based on emissions.

Table 4-11: Emissions Normalized Scores

Technology	Median Lifecycle of CO2 equivalent GHG emissions (g CO2eq/kWh)	Relative Score	Normalized Weighted Scores
Geothermal	38	0.877	0.189
Onshore Wind	11	1.000	0.216
Offshore Wind	12	0.995	0.215
CSP	27	0.927	0.200
Solar PV	48	0.831	0.179
Biomass	230	0.000	0.000

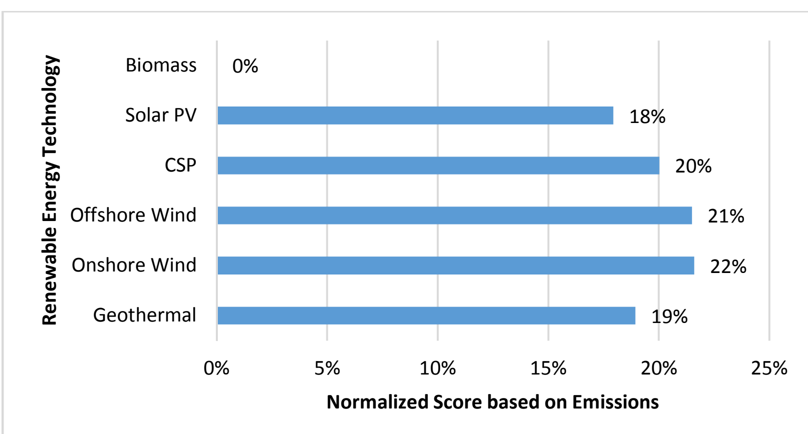


Figure 4-11: Normalized Scores based on Emissions

4.8.3 Normalized Land Requirement

Normalized scores for land requirement were calculated using land-use intensity data for energy production and conservation techniques, measured in square kilometers of impacted land per terawatt-hour per year (km^2/TW hr/yr) as projected for 2030 by McDonald et al. (2009). It was thus assumed that current land-use intensity was equal to the 2030 projected land-use intensity ratios, or the intensities would vary proportionally with time, such that the normalized score and ranking stayed the same. The mid-points of the intensities were used to compute the normalized scores.

Using the same methodology previously discussed for normalizing scores, the normalized land requirement score values shown in Table 4-12 and Figure 4-13 were obtained. The normalized data indicated that geothermal energy scored highest with 21.3% and biomass energy lowest with a 0% normalized land requirement score.

Table 4-12: Land Requirements Normalized Scores

Technology	Median Land-use Intensity (km2/TW hr/yr)	Relative Score	Normalized Weighted Score
Geothermal	7.5	1.000	21%
Onshore Wind	72.1	0.879	19%
Offshore Wind	72.1	0.879	19%
CSP	15.3	0.985	21%
Solar PV	36.9	0.945	20%
Biomass	543.4	0.000	0%
Max =	543.4	4.689	100%
Min =	7.5		

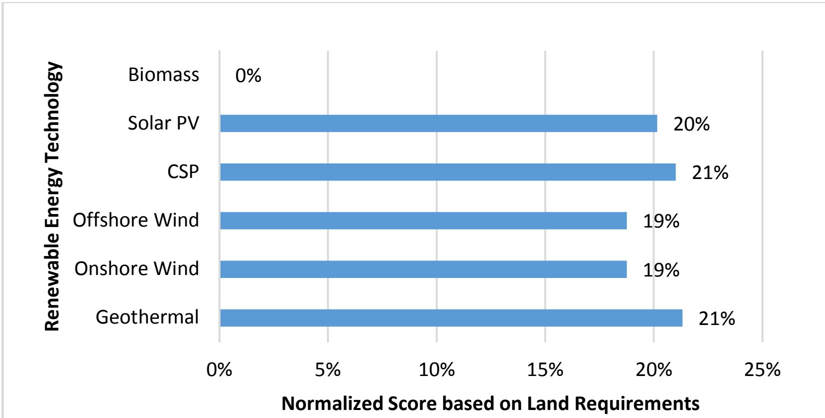


Figure 4-12: Normalized Scores based on Land Requirements

4.8.4 Normalized Public Perception

Normalized scores for public perception were calculated using the poll results of a 2015 national online survey of 1,400 randomly selected U.S. homeowners, completed between January 20 and January 22, 2015, and conducted by SolarCity and Clean Edge (2015), with the aim of understanding the homeowners' attitudes towards a range of energy options. The specific question in the survey asked "*Which energy sources do you believe are most important to America's energy future (Pick up to Three)?*".

Wind and solar were not differentiated as onshore and offshore, or solar PV and CSP, respectively in the survey, and therefore the same score was assumed for both solar technologies as well as both wind technologies. The results for the computed scores are shown in Table 4-13 and Figure 4-13.

Table 4-13: Public Perception Normalized Scores

Technology	Considered Most Important in Survey Response [19]	Relative Score	Normalized Weighted Score
Geothermal	10%	0.070	2%
Onshore Wind	42%	0.814	22%
Offshore Wind	42%	0.814	22%
CSP	50%	1.000	27%
Solar PV	50%	1.000	27%
Biomass	7%	0.000	0%
Max =	0.5	3.698	100%
Min =	0.07		

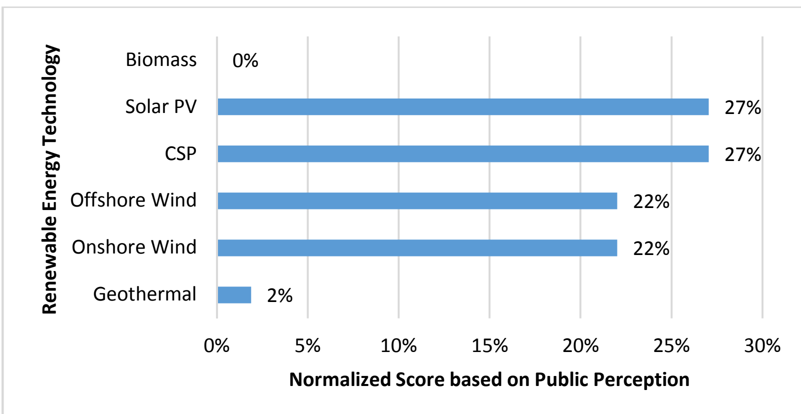


Figure 4-13: Normalized Scores based on Public Perception

4.8.5 Normalized Water Demands

Normalized scores for water demand were calculated using the maximum volumes of water consumed in generating, and cooling, where applicable. Water consumed in growing plant-based biomass was not taken into consideration, as it would be highly variable depending on the plant species and whether or not irrigation would be required. The data used were obtained from a summary compilation based on the U.S. Department of Energy (DOE, 2006) data. Using the same methodology for normalizing scores, as was done for previous criteria, computed normalized scores shown in Table 4-14 and Figure 4-14 were obtained. The data indicated that wind energy scored the highest (most favorable) with 26% and geothermal energy the lowest with a 0% water demand score.

Table 4-14: Water Demand Normalized Scores

Technology	Max Water Consumed (Cooling and Generation. Gal/MWh)	Relative Score	Normalized Weight
Geothermal	1400	0.000	0%
Onshore Wind	0	1.000	26%
Offshore Wind	0	1.000	26%
CSP	1000	0.286	7%
Solar PV	5	0.996	25%
Biomass	510	0.636	16%
Max =	1400	3.918	100%
Min =	0		

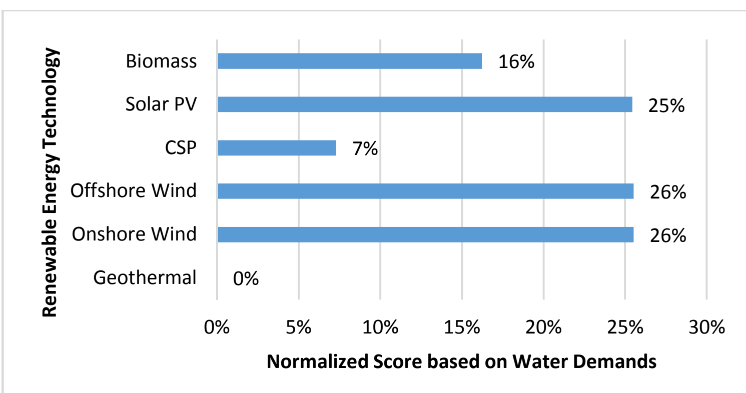


Figure 4-14: Normalized Scores based on Water Demand

4.9 Combined Benefit Scores for Regional and National Energy Portfolios Targets

In order to obtain the combined regional benefit scores of the renewable energy alternatives, the normalized criteria weights and scores were combined as a product of matrices for each region. The matrix product for each alternative was considered as the "benefit score" that was later used in the benefit/cost computations. As an example of the matrix product computation, the Mountain region calculations are shown in Table 4-15. Note that for regions where the technical potential of a given renewable energy alternative was zero, such as offshore wind energy in the Mountain region, the alternative was completely ruled out. The same procedure was repeated for the other 8 regions to obtain the results shown in Table 4-16. The results demonstrate the recommended approach towards establishing national renewable energy targets by first establishing regional goals for renewable energy development. At a minimum, this approach would account for variability in renewable energy resource potential across the nation.

The weighted averages for the regions were calculated to obtain the national renewable energy percentages (last column of Table 4-16 and as shown in Figure 4-15)

This study suggests that these national renewable energy percentages can be considered as the recommended renewable energy portfolio targets. These targets take the benefits associated with the renewables into consideration and the associated energy is ranked based on the benefits. The costs were not considered in the case of the portfolio ranking, but instead taken into account in determining financial incentives or mandates requirements. This approach encourages the adoption of new renewable energy technologies with high non-cost benefits and ensures that RPSes do not focus mainly on the least cost option. Following this approach would therefore more likely lead to a diverse renewable energy portfolio, with incentives logically allocated to less mature high-cost, high-benefits alternatives, and also ensure that technologies do not receive more financial support than is needed for them to deploy. Separating the costs from the benefits criteria therefore allowed for incentives to be rationally recommended to bring down costs for technologies that have potential for profitable deployment.

Table 4-15: Overall Benefits Scores for Renewable Energy Alternative – Mountain Region

	Location Potential	Land requirement	Emissions	Water Demand	Public Perception		Criteria Ranking		Benefits Score
Geothermal	0.0662	0.2625	0.2412	0.0000	0.0242		0.510039		14%
Onshore Wind	0.0467	0.2308	0.2751	0.3427	0.2823		0.263834		15%
Offshore Wind	0.0000	NA	NA	NA	NA	x	0.129574	=	NA
CSP	0.4163	0.2586	0.2550	0.0979	0.3468		0.063636		33%
Solar PV	0.4708	0.2481	0.2286	0.3415	0.3468		0.032918		37%
Biomass	0.0000	0.0000	0.0000	0.2179	0.0000				1%

Table 4-16: Overall Benefits Scores for Renewable Energy Alternatives – All Regions and National Level

	Mountain	West North Central	West South Central	East North Central	Pacific	South Atlantic	East South Central	Middle Atlantic	New England	National
Geothermal	14%	11%	11%	13%	11%	13%	16%	17%	18%	14%
Onshore Wind	15%	18%	14%	13%	12%	11%	11%	12%	12%	13%
Offshore Wind	NA	10%	11%	15%	18%	16%	11%	23%	33%	15%
CSP	33%	17%	24%	NA	22%	NA	55%	42%	NA	21%
Solar PV	37%	44%	40%	53%	36%	53%	NA	NA	31%	32%
Biomass	1%	1%	1%	6%	1%	7%	7%	6%	6%	4%
Totals	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%

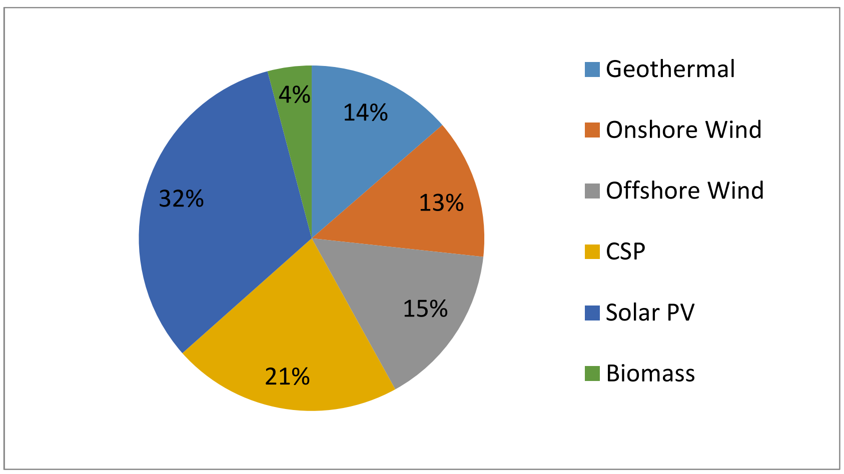


Figure 4-15: Recommended National Renewable Energy Portfolio for Policy Formulation

The percentage values for the recommended national renewable energy portfolio were compared to historical and current renewable energy generation percentages at a utility scale using data obtained from EIA (EIA, 2017). Comparison with the most recent (2016) data indicated that the recommended renewable energy portfolio suggests an increase of solar PV energy generation from 10% to 32%, concentrated solar energy from 1% to 21% and geothermal energy from 5% to 14%, based on the total renewable energy currently generated (Figure 4-16). The recommended increase in energy generation was compared to the historical energy production trend.

Historical values showed an increasing percentage generation of solar PV and concentrated solar energy, but a decreasing percentage generation of geothermal energy (Figure 4-17). This may be an indication that incentives for geothermal energy need to be considered for the targeted growth.

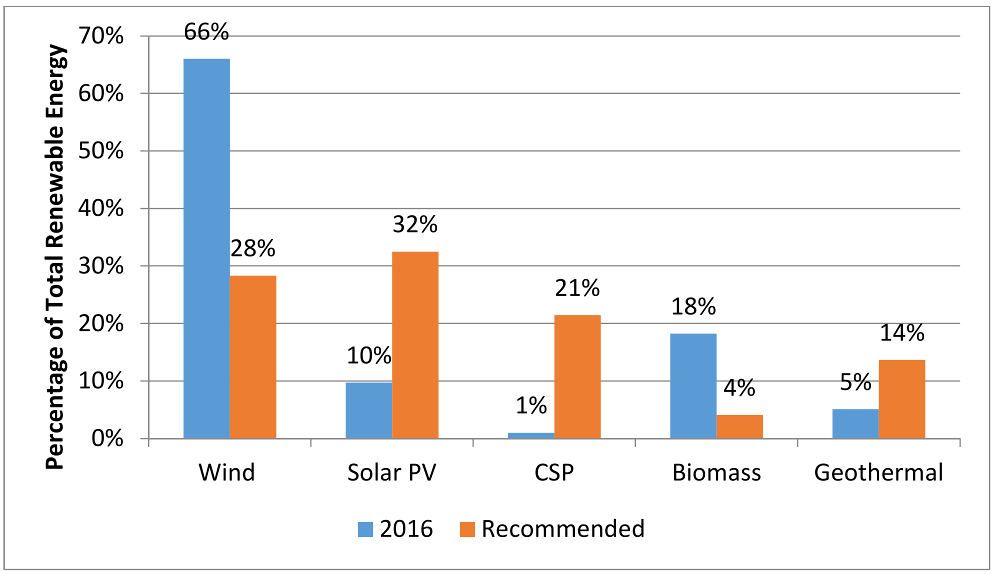


Figure 4-16: Recommended National Renewable Energy Portfolio for Policy Formulation Comparison with 2016 Data

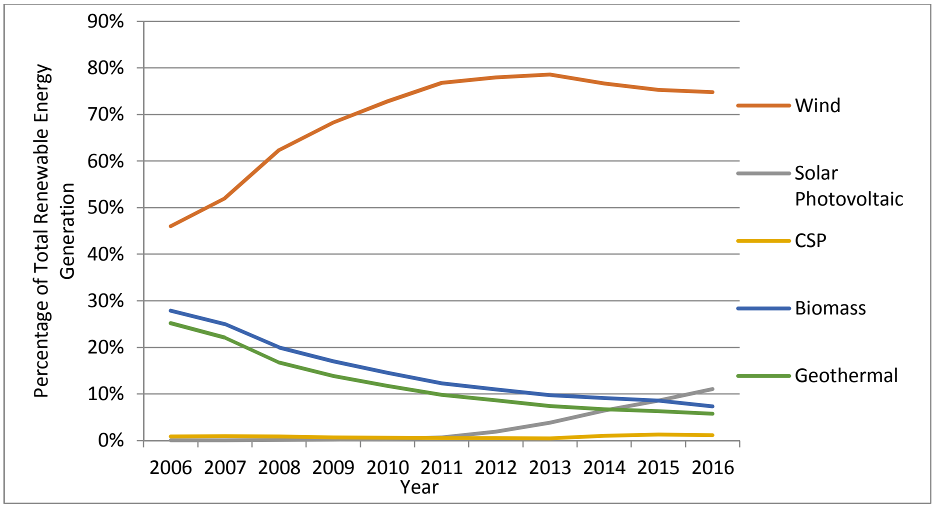


Figure 4-17: Historical Percentage Renewable Energy Generation Nationwide

4.10 AHP Formulation: Factoring in Cost

4.10.1 Benefits/Cost Analysis

The inclusion of costs in AHP can either be in the form of a benefits/cost ratio, or represented as one of the criteria used to evaluate alternatives. For this research, cost was factored in by computing a benefits/cost ratio using capital costs for the renewable energy alternatives. Separating the costs from the criteria for evaluation was expected to avoid the tendency for costs to dominate the renewable energy prioritization, with a blind-sided view of non-cost benefits. Separating the benefits from the costs was assumed to offer an additional advantage in policy revisions. Assuming the renewable energy benefits would remain fairly constant with time, in comparison to energy costs, review and updates for energy policy would likely be solely based on a cost adjustment, for reprioritization based on a benefits/cost analysis. An example of where this would be advantageous is in the case of solar PV, where the costs have reduced by about 80% since 2008 (IRENA, 2015b). In such cases, only the cost would need to be re-evaluated for computation of new benefits/costs ratios. In addition, cost data are usually based on estimates that may often require revision when better data are obtained.

While costs were not considered in the case of the portfolio ranking, cost data was instead used in recommending financial incentives or mandates for renewable energy initiatives. The financial incentives would ideally be applied in order to promote renewable energy alternatives that ranked high, based on benefits alone, but had a low ranking considering costs. It was assumed that high capital costs were an indication of low levels of technical advancements of the energy options considered, and that the financial incentives would trigger an interest in research and development for those alternatives to lower the costs. It was also assumed that alternatives with high benefits but low benefits/costs ratios would have great potential for profitable development with improved technology. Separating the costs from the benefits criteria therefore allowed for incentives to be rationally recommended where needed. 2012 capital investment costs data were used for the benefit/cost analysis. The 2012 cost data were identified as potentially outdated, and as a weakness in the research, especially considering rapidly declining costs of renewable energy technologies, such as for solar PV.

4.10.2 Capital Cost Data Collection and Analysis

In 2010, EIA appointed an external consultant, SAIC Energy, Environment & Infrastructure, LLC, to develop cost estimates for utility-scale electric generating plants (EIA, 2013). In generating the cost estimates, generic facilities in a location with no unusual constraints or infrastructure requirements, were assumed. When construction cost data were available, the actual known construction costs were applied to develop the estimates. The regional capital costs for solar PV, CSP, off-shore wind, on-shore wind, and biomass, used for the AHP benefits/cost analysis, were computed from capital cost estimates developed for states in this study. The geothermal energy cost estimates from the referenced study were not used as they did not capture the data required for this study. The geothermal energy costs developed for the referenced study were based on hydrothermal geothermal facilities and considered only 12 states that had actual hydrothermal installation data, namely: Alaska, Arizona, California, Colorado, Hawaii, Idaho, Nevada, New Mexico, Oregon, Utah, Washington, and Wyoming. These states all fall in the Pacific and Mountain regions, where, in addition to Montana, the hydrothermal energy potential is estimated to be highest (Lopez et al., 2012). However, the referenced study did not evaluate costs for enhanced geothermal systems (EGS) that are estimated to constitute more than 90% of the geothermal energy potential estimates (Figure 4-18). Furthermore, the state-level hydrothermal potentials used in this research were based on hydrothermal systems with greater than 1 GWh technical potential. This reduced the hydrothermal systems technical potential to contribute to approximately 1% of the total geothermal energy potential estimates used for this study. In addition to the estimated energy potential from hydrothermal systems being relatively insignificant, the cost estimates for hydrothermal systems would also have a negligible effect toward the average cost estimates for geothermal systems needed for the benefits/cost computation. Cost estimates for EGS systems were therefore needed.

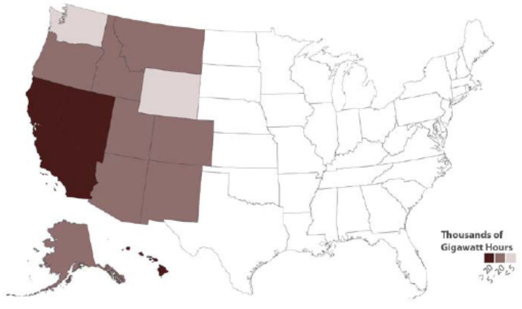
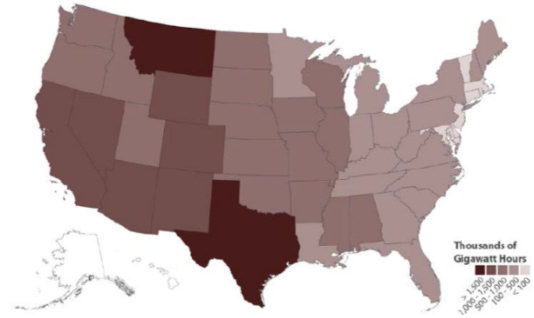
	
Total estimated technical potential for hydrothermal power in the United States (300 TWh)	Total estimated technical potential for enhanced geothermal systems in the United States (31,300 TWh)

Figure 4-18: Hydrothermal and EGS Technical Potential Comparison
Source: (Lopez et al., 2012)

However, according to Edenhofer et al. (2011), EGS systems are currently not installed at a commercial scale and cost estimates are therefore subject to many assumptions and uncertainties. The current EGS facilities are designed for pilot-scale research, not full-scale electricity generation. In addition, capital costs estimates for EGS vary significantly from site to site, based on the geological formations and the level of uncertainty factored in risks associated with drilling. Relatively high initial capital costs are typical, while the levelized costs of electricity (LCOE), which includes the capital costs as well as operations and maintenance costs over the useful life of the technology, are often relatively low. Nevertheless, the initial capital costs are expected to decrease over time, as drilling technologies improve.

EGS capital cost estimates developed by Black & Veatch Holding Company (2012) for the National Renewable Energy Laboratory (NREL) were instead used to develop cost estimates for the AHP analysis. The estimates were based on a single-value generic approximation, and not for a particular site. Based on the high levels of uncertainty with EGS capital costs, and the higher technical potential in comparison to hydrothermal systems, cost estimates developed by Black & Veatch (2012) were used to assume a uniform geothermal capital cost for all regions. The capital cost for 2012 (9,828 $/kW) was obtained by interpolation (Table 4-17). Future EGS costs were also estimated in the Black & Veatch report by assuming improvement in pumping technologies, and the ability to develop multiple EGS units for a single site, thus reducing costs based on economies of scale.

Table 4-17: EGS Estimated Costs and Projections

Year	Capital Cost ($/kW)
2008	10,400
2010	9,900
2015	9,720
2020	9,625
2025	9,438
2030	9,250
2035	8,970
2040	8,786
2045	8,600
2050	8,420

Source: Black & Veatch Holding Company (2012)

4.10.3 Normalized Costs – Policy Maker's Point-of-View

Regional renewable energy capital costs were normalized by taking the capital cost value of a particular source of energy in each region and dividing it by the total unit cost of all energy sources (bottom row of Table 4-18) to obtain values shown in Table 4-19. The normalized capital costs represented the "costs score", used in the benefit/cost analysis as described in sections that follow.

Table 4-18: 2012 Capital Costs of Energy by Regions with Totals ($/kW)

	Mountain	West North Central	West South Central	East North Central	Pacific	South Atlantic	East South Central	Middle Atlantic	New England
Geothermal	9828	9828	9828	9828	9828	9828	9828	9828	9828
On-shore Wind	2291	2285	2094	2268	2601	2190	2114	2412	2345
Off-shore Wind	NA	6635	5686	6384	6856	5960	NA	7072	6472
CSP	4823	4924	4359	5164	5812	4682	4455	5817	5172
Solar PV	3831	3865	3536	3938	4443	3711	3584	4261	3984
Biomass	3841	3977	3699	4239	4766	4118	3757	4598	4359
Sum	24613	31515	29202	31820	34306	30489	23738	33990	32160

Table 4-19: 2012 Normalized Capital Costs (Cost Scores) by Regions

	Mountain	West North Central	West South Central	East North Central	Pacific	South Atlantic	East South Central	Middle Atlantic	New England
Geothermal	0.40	0.31	0.34	0.31	0.29	0.32	0.41	0.29	0.31
On-shore Wind	0.09	0.07	0.07	0.07	0.08	0.07	0.09	0.07	0.07
Off-shore Wind	NA	0.21	0.19	0.20	0.20	0.20	NA	0.21	0.20
Solar Thermal	0.20	0.16	0.15	0.16	0.1694	0.15	0.19	0.17	0.16
Solar PV	0.16	0.12	0.12	0.12	0.13	0.12	0.15	0.13	0.12
Biomass	0.16	0.13	0.13	0.13	0.14	0.14	0.16	0.14	0.14

4.11 Benefits/Cost Ratio Computations for Energy Ranking

The benefits/cost ratios were computed using the “benefits scores” (Table 4-16) and “cost scores” (Table 4-19). Each of the values in Table 4-16 was divided by the corresponding cost score in Table 4-19 to obtain the benefits/cost ratios shown in Figure 4-21.

It is expected that, in comparison to the other criteria used for the AHP formulation, costs would vary the most with time and therefore recurring policy reviews and updates would most likely be triggered by the magnitude of the change in technology costs. For example, IRENA (2015b) estimates that solar PV costs have reduced by nearly 80% between 2008 and 2015. Separating costs from other criteria to analyze alternatives using a benefits/cost ratio would help with policy review for updates when only the cost factors needed to be re-evaluated. In such cases, the benefits criteria do would remain fairly unaltered.

Incorporating the costs into the benefit/cost ratios, rather than evaluating it as a criteria, also facilitated the possibility of promoting energy sources that ranked high based on benefits alone. Renewable energy alternatives with high benefits and high costs would benefit the most from financial incentives, while those with high benefits and low costs would require mandates. High -benefits alternatives were considered as those that had at least one region with a benefits score value equal to or higher than the average score. Figure 4-19 shows that geothermal, offshore wind, onshore wind, CSP and Solar PV were high-benefits alternatives. Biomass energy was the only low-benefits alternative. Similarly, "high-costs" alternatives were based on average costs score values. Figure 4-20 shows that high cost scores included geothermal, offshore wind, and CSP, while low cost energy alternatives included onshore wind, solar PV, and biomass.

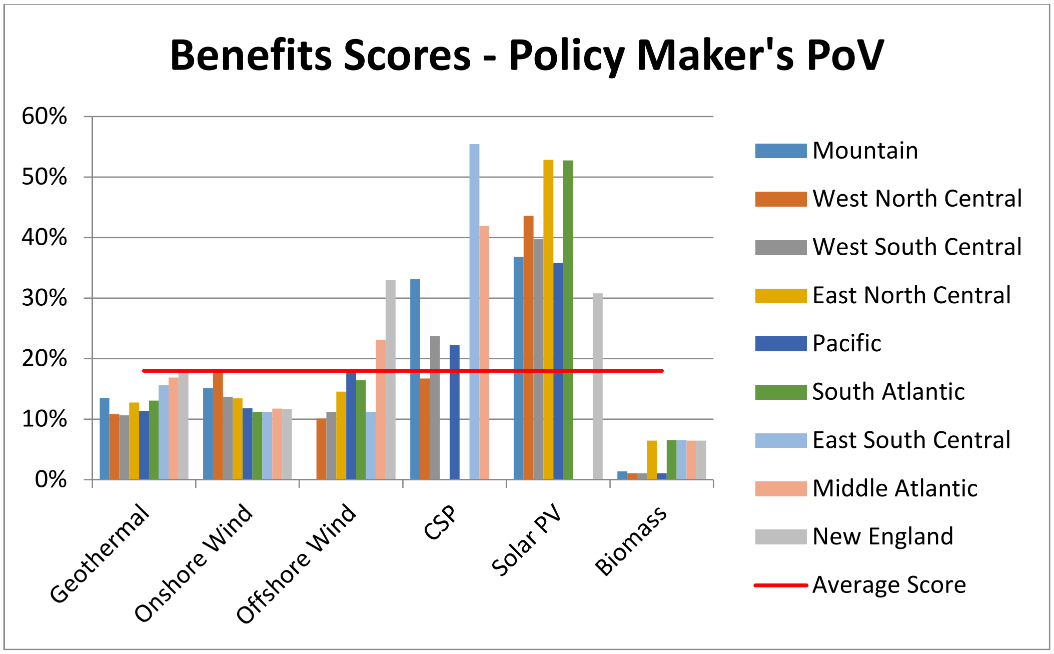


Figure 4-19: AHP Results – Policy Maker's Point-of-View – Average Benefits Score

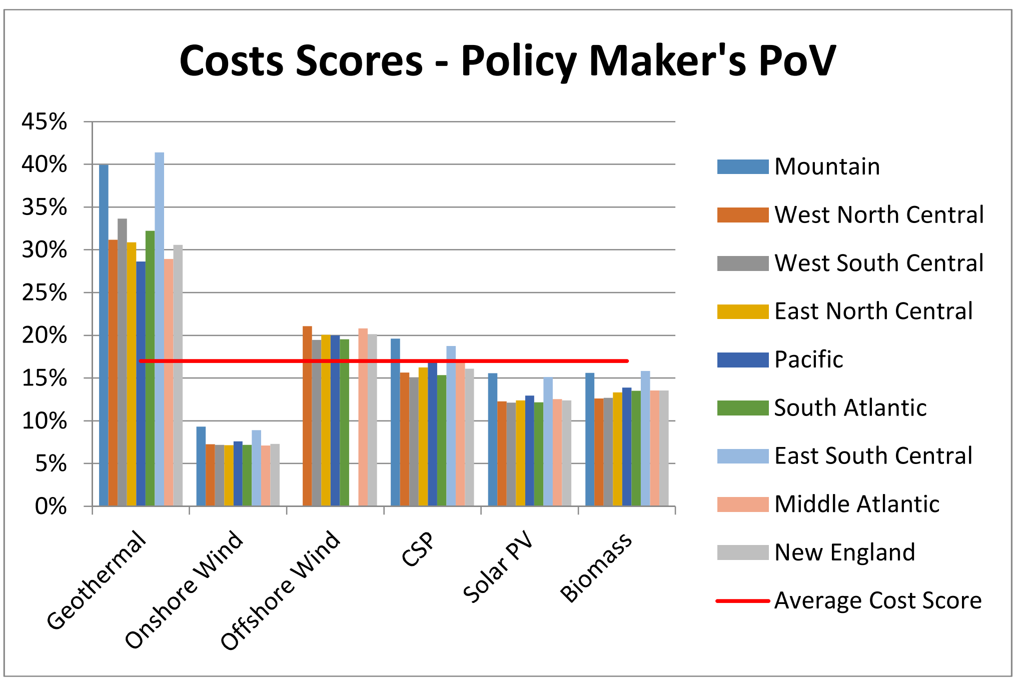


Figure 4-20: AHP Results — Policy Maker's Point-of-View – Average Cost Score

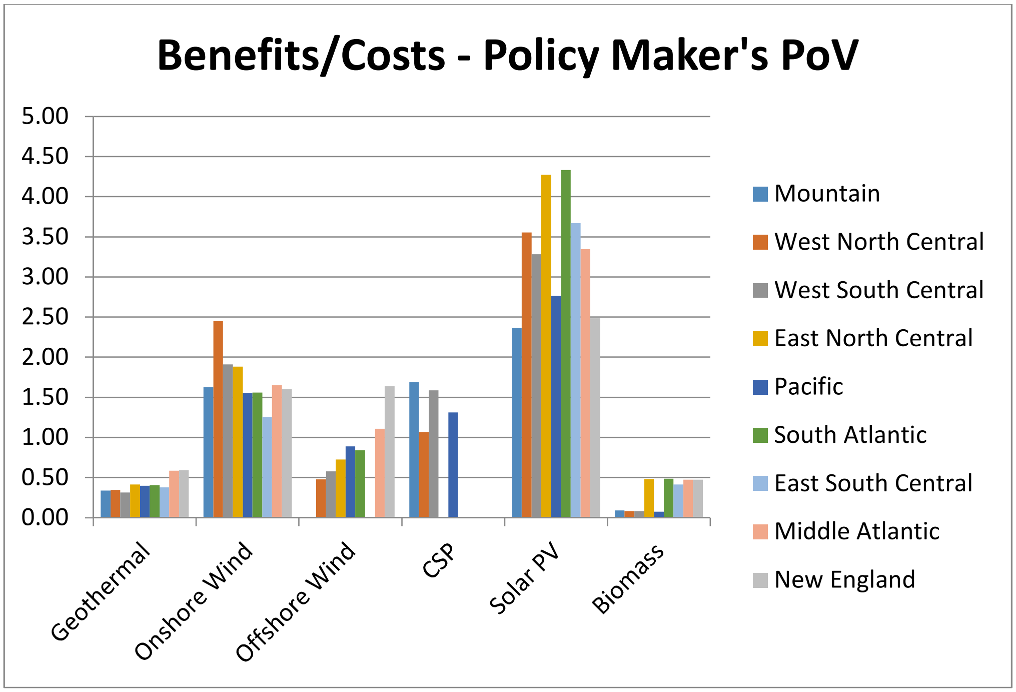


Figure 4-21: AHP Results — Policy Maker's Point-of-View – Benefits/Cost Analysis

4.11.1 Benefit/Costs Incentives/Mandates (BCIM) model

In order to simplify incentives and mandates selections, based on the previous discussion, a visual model considering the benefits and costs for selecting incentives and mandates was developed. The Benefits/Costs Incentives/Mandates (BCIM) model focused on high-benefits alternatives that required an increase in portfolio contribution, based on current percentage generation. No increase in wind (offshore and onshore combined) and biomass energy generation was needed since the current percentage generation exceeds the target portfolio percentage. These options could therefore be eliminated from incentives/mandates consideration. Biomass was also eliminated as a low-benefits technology. The BCIM model is shown in Figure 4-22. The results show that, with wind energy ruled out, mandates would ideally be issued for solar PV and incentives for geothermal and CSP alternatives.

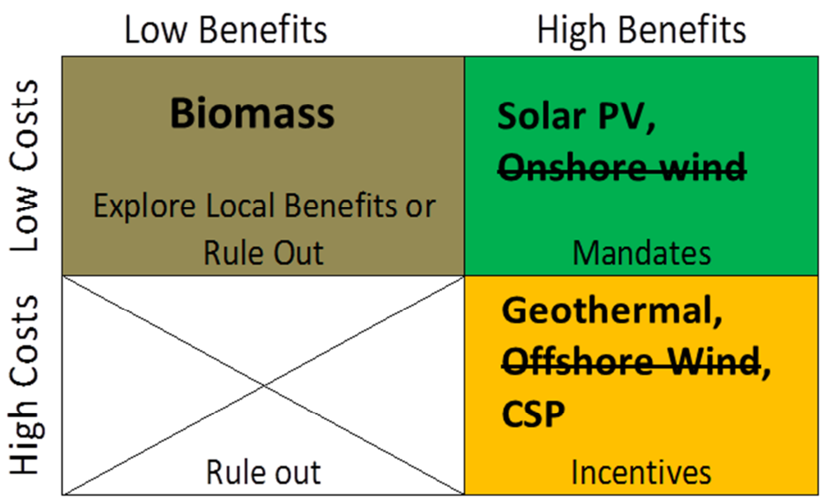


Figure 4-22: AHP Results — Benefits/Costs Incentives/Mandates Model

4.12 Ranking Based on the Investor's Point-of-View

It is assumed that an investor's main goal would be to maximize production and revenue for a single renewable energy alternative by determining the ideal location to implement the given form of renewable energy. Therefore, since the investor's point of view aims at selecting regions for investment, the AHP problem was formulated as a transpose of the policy maker's point of view formulation. For the investor's point-of-view, the analysis was done vertically along the energy resource potentials values shown in Table 4-8. That is, the regions were analyzed as the alternatives from an investor's point-of-view and the benefits scores were also instead formulated as the criteria. Also, because the location potential component of the benefits score would be the only score that varied with the regions, the other benefits score components, i.e. land requirement, emissions, water demand, and public perception could be eliminated from the investor's point-of-view. The overall benefits score was therefore equal to the location potential score values (Figure 4-23). As in the previous case, a benefit/cost analysis was also computed to obtain the ratios illustrated in Figure 4-24.

An ideal location for the energy alternatives would be one that had a high location potential and low costs. Regions that would benefit the most from financial incentives were identified as those that were not ranked as ideal for any renewable energy option from an investor's point-of-view.

Based on the benefits/cost analysis, the Mountain region was found to be the most attractive for investment in geothermal, concentrated solar and solar PV energy, while the West North Central for onshore wind, solar PV and biomass energy. The East North Central region was found to be most suitable for biomass energy, the West South Central region for Solar PV and the Pacific region for offshore wind energy. The South Atlantic, East South Central, Middle Atlantic and New England regions would benefit from policy-related renewable energy incentives as, based on the investor's point-of-view, these areas did not rank as high for any of the renewable energy alternatives considered.

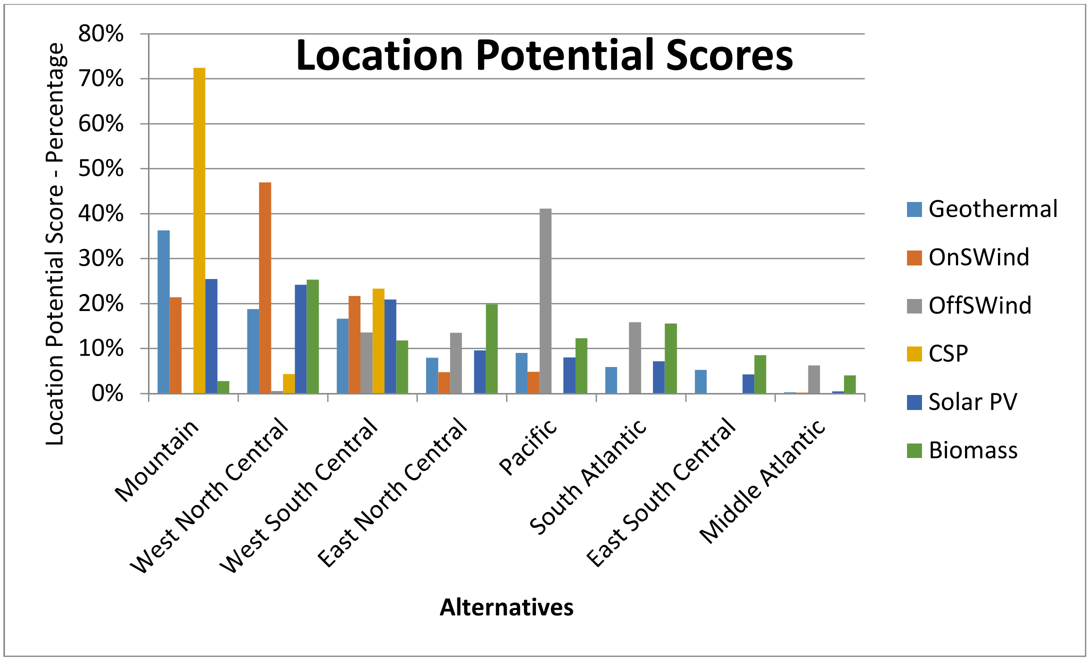


Figure 4-23: Renewable Energy Scores – Investor's Point-of-View

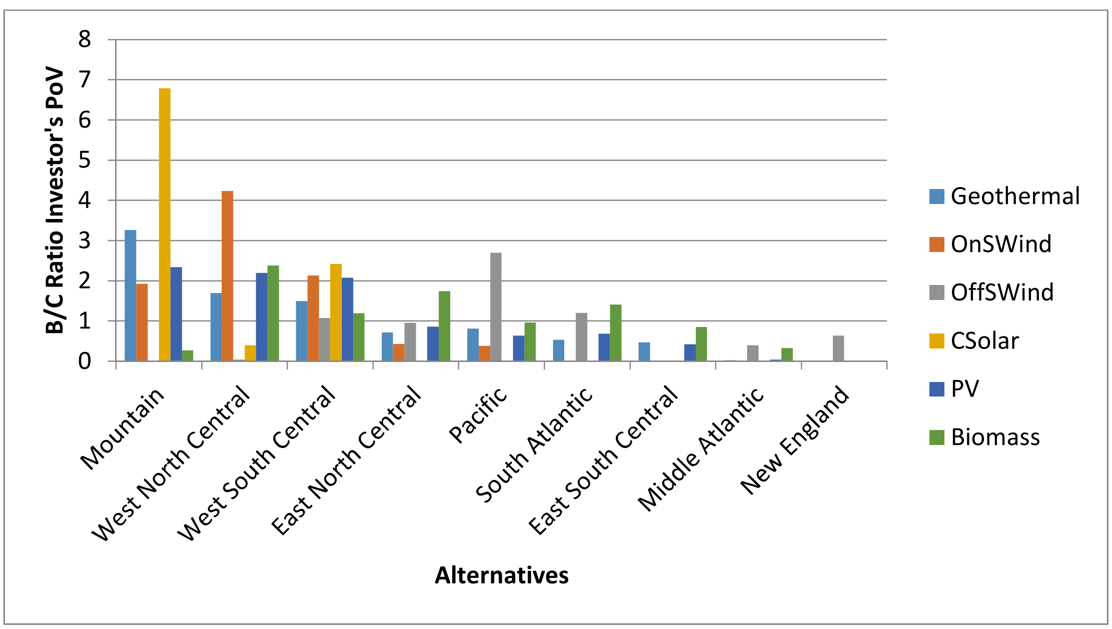


Figure 4-24: Benefits/Cost Ratio – Investor's Point-of-View

4.13 Translating Portfolio Percentage Goals into Electric Units

The previous Subsections of Section 4 recommended technology-specific renewable energy targets for a diverse renewable energy portfolio in the U.S. and towards national-level renewable energy targets. The targets were set for different renewable energy sources, such that renewable energy generation from each source was expressed as a percentage of the total renewable energy generation.

In this Subsection, the percentage targets are applied to EIA (2016) projections that assume as scenario in which the Clean Power Plan is passed as law. The percentages computed are applied to the projected renewable energy values to convert the portfolio percentages into actual electrical units of generation (GWh). The results therefore give an indication of the electric targets needed to complement the clean power plan, while ensuring a diverse renewable energy mix.

The Clean Power Plan would establish state-by-state targets for emission reduction by 2030, with a proposed nationwide estimated reduction of approximately 32% from power plants relative to 2005 emissions. This percentage goal would require approximately 1,000 billion kilowatt-hours of net electric generation from renewable sources by 2030, according to the EIA (2016) projections. The referenced EIA data is included in Appendix 9.11. Based on the historical data provided, renewable energy generation increased by nearly 50% between 2005 and 2015. The EIA projections show that the renewable energy generation could double from 546 billion kWh in 2015 to 1088 billion kWh in 2030. The percentage renewable energy generation in 2030 would be at 24% (as a percentage of the total projected energy generation).

Other than the assumption that the Clean Power Plan is in effect, the EIA data projection reflects a "business-as-usual" trend, based on current technology and federal, state, and local laws and regulations in effect as of the end of February 2016. This case therefore assumes that current laws and regulations are maintained throughout the projections. EIA (2016) therefore suggests that "the projections provide policy neutral baselines that can be used to analyze policy initiatives".

While the Clean Power Plan has a national target set for emission reduction, and includes increasing renewable energy generation as one of the strategies, the plan does not set actual national targets for the renewable energy generation to align with the overall emission goal. It is instead left to the states to determine how to meet their individual renewable energy targets. This Subsection computes estimates of the electric targets that correlate with the 2030 renewable energy projection that can help close this gap.

In translating portfolio percentage goals into electric units that match the electricity projections with the Clean Power Plan in place, the study makes an assumption that hydropower generation will remain constant. Hydropower is deducted from the total renewable energy generation in 2030, to obtain the same energy mix that is considered for this study. There has generally been little or no hydropower growth, as previously discussed and as shown in Figure 1-3, indicating that this assumption is reasonable.

The results from this analysis are shown in Table 4-20. The total technical potential energy is the location potential energy that was used as criteria in the AHP ranking. The 2016 actual generation values were obtained from EIA (2017b), and they reflect the actual electricity generation in 2016. The ideal 2016 generation, reflects the actual 2016 total generation, distributed according to the AHP portfolio that was established in this research. The 2030 CPP target generation, reflects the EIA (2016) renewable energy projection, distributed according to the AHP portfolio. A graphical representation of the results is shown in Figure 4-25. The graphics show how close the recommended generation mixes rely on the technical potential. The percentage generation increases with increase in technical potential, but at the same time, other criteria, namely emissions, land requirement, public perception and water demand influence this relationship. This is especially evident with the comparison between wind and CSP. While wind energy has a lower technical potential than CSP, wind energy has a higher percentage allocation in the targeted electricity generation.

Table 4-20: Electricity Generation in Thousands GWh

Alternative	Total Technical Potential	2016 Actual Generation	Ideal 2016 Generation	2030 CPP Target Generation
Geothermal	31,606	17	47	112
Wind	49,764	227	97	233
CSP	116,146	3	74	176
Solar PV	283,662	33	112	267
Biomass	489	63	14	34
Hydro	258,953	266	266	266
Total	740,620	610	610	1088

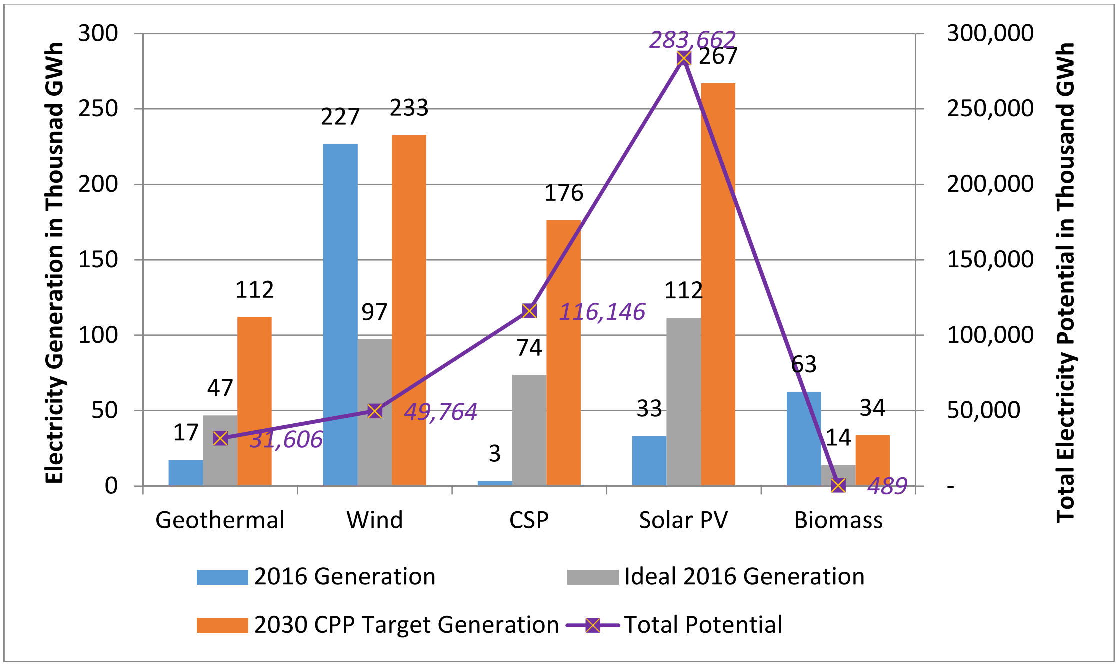


Figure 4-25: Renewable Energy Mix in Electric Units

5 A COMPARISON OF CURRENT STATE-LEVEL RPS PRIORITIZATION WITH PRIORITIZATION USING THE AHP PROCEDURE

In the previous Section, the percentage renewable energy mix for U.S. regions was determined though AHP, based on the benefits evaluation from a policy maker's point-of-view. The analysis used location potential, land requirement, emissions, water demand and public perception for the ranking criteria to obtain renewable energy proportions for both a regional and state-level renewable energy portfolio.

This Section demonstrates a comparison of the current renewable energy alternatives prioritized at a state-level, based on the RPSes, to those prioritized using the AHP procedure in this study, for the U.S. Census Bureau regions that encompass the respective states.

Section 2 discussed individual states' current mandates for the implementation of renewable energy through compliance and voluntary RPSes. The state-level RPSes were separately reviewed to understand the strategies currently used by each state for technology-specific renewable energy prioritization. State incentives for renewable energy generation were then categorized into financial incentives and regulatory mandates, in order to analyze the criteria for renewable energy prioritization, where it occurred.

An investigation of state prioritization methods was summarized in Appendix 9.1. It was noted that more than half the U.S. states with RPSes (65%) included prioritization targets in their RPS mandates. Most encompassed either setting minimum goals for the favored technologies, minimum goals with varied ACPs , minimum goals and varied

REC compliance multipliers, or minimum goals and varied ACPs and REC compliance multipliers.

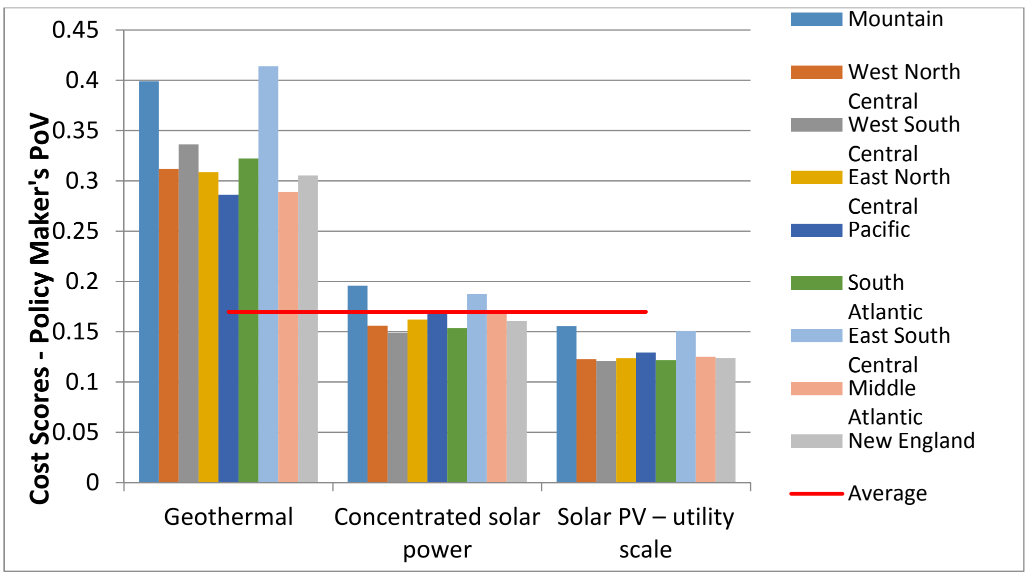
Section 4 established a Benefits/Cost Incentive/Mandate (BCIM) model for selective incentives or mandates for energy alternatives that needed to “grow”, based on the gap that existed between current percentage generation (as a percentage of the total renewable energy) and the portfolio generated using AHP. Only high-benefits energies were considered for mandates and incentives, that is, solar PV, geothermal and CSP.

The compiled state-level RPS energy prioritization was compared with the prioritization result that were recommended using the AHP methodology developed in this research as shown in

Table 5-1. The Regional BCIM spectrum shown in Figure 5-1could be applied for prioritization.

Based on this, the results implied that solar PV would ideally have mandatory targets nationally; and CSP in the West North Central, West South Central, East North Central, South Atlantic, and New England regions.

Analysis for each region is discussed in more detail in the Sub-sections that follow.



High Costs Scores for only High-benefits Technologies

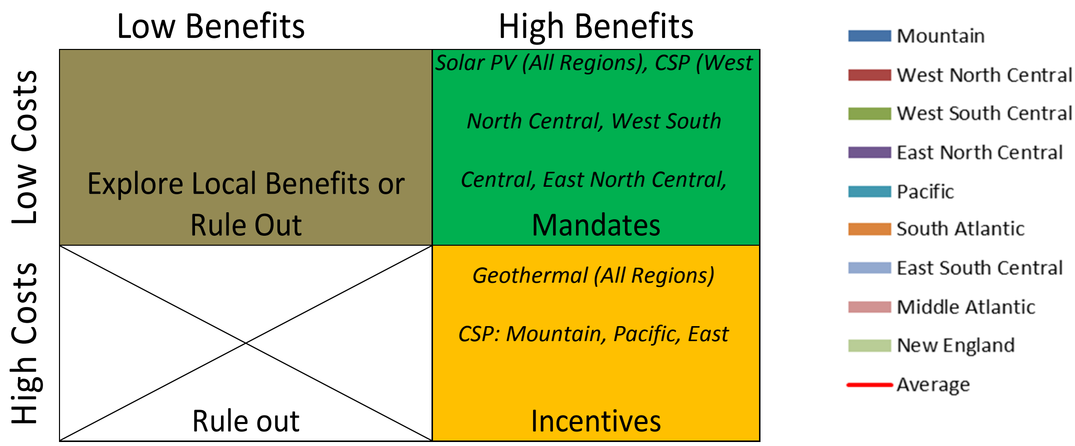


Figure 5-1: Regional BCIM

Table 5-1: Comparison Current Regional Renewable Energy Prioritization with Research

Region	Recommended Prioritization Order from AHP	Current Target Prioritization
Mountain	Solar PV (37%) CSP (33%) Geothermal (14%) Onshore wind (15%) Offshore wind (NA) Biomass (1%)	Solar (Nevada 6%) and New Mexico- 20%) Solar PV (Nevada) Wind (New Mexico – 30%) Geothermal (New Mexico – 5% in combination with other renewables - biomass and certain hydro facilities
West North Central	Solar PV (44%) Onshore wind (18%) CSP (17 %) Geothermal (11%) Offshore wind (10%) Biomass (1%)	Solar (Minnesota) Solar PV (Missouri) Wind (Minnesota)
West South Central	Solar PV (40%) CSP (24 %) Onshore wind (14%) Geothermal (11%) Offshore wind (11%) Biomass (1%)	Non Wind (Texas)
East North Central	Solar PV (53%) Offshore wind (15%) Geothermal (12%) Onshore wind (13%) CSP (NA Biomass (6%)	Solar PV (Illinois and Ohio) Wind (Illinois)
Pacific	Solar PV (36%) CSP (22%) Offshore wind (18%) Onshore wind (12%) Geothermal (11%) Biomass energy (1%)	None
South Atlantic	Solar PV (53%) Offshore wind (16%) Geothermal (13%) Onshore wind (11%) CSP (NA) Biomass energy (7%)	Solar (Delaware, Maryland, North Carolina, Virginia, Washington DC) Wind (Delaware, Maryland, Virginia) Biomass (North Carolina, Virginia)
East South Central	Solar PV (55%) Geothermal (16%) Onshore wind (11%) Offshore wind (10%) CSP (NA Biomass (7%)	None

Region	Recommended Prioritization Order from AHP	Current Target Prioritization
Middle Atlantic	Solar PV (42%) Offshore wind (23%) Geothermal (17%) Onshore wind (12%) CSP (NA) Biomass energy (6%)	Solar (New Jersey- ACP of $300 per MWh) Solar PV (Mid Atlantic) Offshore wind (New Jersey - ACP of $50 per MWh)
New England	Offshore wind (33%) Solar PV (21%) Geothermal (18%) Onshore wind (12%) CSP (NA) Biomass (6%)	Wind (Maine- higher priority for offshore) Solar (New Hampshire) Biomass (New Hampshire) Solar PV (Massachusetts) Geothermal- CHP (Massachusetts, 5% in combination with biomass)

5.1 Mountain Region

The AHP prioritization for the mountain region matched the current prioritization for Solar. Solar PV (37%), followed by Solar CSP (33%) ranked highest, using the AHP methodology. Solar is also currently prioritized in Nevada and New Mexico. Onshore wind and geothermal energy had nearly the same ranking and percentage allocation (15 and 14% respectively), based on AHP results. Wind energy is currently prioritized in New Mexico, most likely because of the high onshore wind potential energy on the eastern part of the region where the state falls. However, geothermal energy is not currently prioritized in any of the RPSes for states within the Mountain Region, yet it is nearly at the same level of wind energy based on the AHP results. It may, therefore, be worthwhile developing criteria to prioritize geothermal energy development, and at the same level as wind energy, in this region.

5.2 West North Central

Solar is currently prioritized in Missouri and Minnesota, and wind energy in Minnesota. Similarly, Solar PV (44%), onshore wind (18%) and CSP (17 %) alternatives ranked highest for this Region based on the AHP results.

5.3 West South Central

Solar PV (40%), CSP (24 %), and onshore wind energy (14%) rank highest in the AHP results. Texas currently has a voluntary non-wind minimum that intends to dilute the wind energy saturation in the State, in an effort to diversify its renewable energy mix.

5.4 East North Central

Based on AHP results, solar PV results in more than half (53%) of the renewable energy share, and therefore minimum mandatory targets would suffice for this region. Offshore wind energy (15%), onshore wind (13%) and geothermal (13%) rank fairly close to each other. The current prioritization in this region only target solar and wind energy, although energy ranking for geothermal is nearly at the same level as onshore wind energy. It may, therefore, be worthwhile to develop criteria to prioritize geothermal energy development, and at the same level as wind energy, in this region.

5.5 Pacific

There are currently no prioritization targets for any renewable energy in this region. Solar PV (36%), CSP (22%) and wind energy (18%), ranked highest in this region using AHP, and could very well have mandatory minimum targets established for them.

5.6 South Atlantic

Based on AHP results, solar PV results in more than half (53%) of the renewable energy share and therefore mandatory minimum targets would suffice for this region. Offshore wind is second in ranking (16%). The research results correspond to the current target prioritization of these energies. Biomass energy (from animal waste) is also prioritized in the state of North Carolina, most likely based on beneficial waste-to-energy conversion of animal waste products.

5.7 East South Central

There are currently no prioritization targets for any renewable energy in this region. Based on AHP results, solar PV results in more than half (55%) of the renewable energy share and therefore mandatory minimum targets for solar PV would suffice for this region.

5.8 Middle Atlantic

The high AHP ranking of solar (42%) and offshore wind (22%) energies in the research results correspond to the current target prioritization of these energies. Mandatory minimum targets would be suitable for both alternatives.

5.9 New England

The high AHP ranking of wind (33%), solar PV (31%), and geothermal energy (18%) in the research results correspond to the current target prioritization of these energies. Biomass energy is also prioritized in New England. The biomass prioritization may have been placed in order to sustain the state's six wood-waste biomass plants, one of which was recently on the verge of shutting down as biomass could not compete with natural gas as a fuel for electricity generation (New Hampshire Public Radio, 2017).

5.10 Overall Review

The AHP method developed and applied for renewable energy ranking were comparable, based on the observation that the regional AHP rankings were similar to the current RPSes prioritization. Biomass energy was prioritized in two regions on the basis of waste-to-energy conversion. Biomass energy prioritization at local levels is reviewed further in the Section 6.

It was, however, noted that even though the AHP results showed favor for geotechnical energy is some regions, none of the state RPSes have mandates that prioritize geothermal energy development in those regions. New Mexico is the only state that somewhat attempts to prioritize geothermal energy, but the current 5% target generation by 2020 is lumped together with a cluster of renewable energy alternatives including biomass and certain hydro facilities, all that can contribute to the 5% target.

Geothermal energy is ideal as a base load renewable energy source, when compared to other sources, since the energy supply can be maintained at a fairly constant level without being influenced by seasonal or climatic variations (Geothermal Energy Association, 2009). NREL (2009) indicates that one of the barriers with geothermal energy development at state levels have included the large extent of research and development, as well as capital investments needed to develop the energy, such that individual states are not able to implement research and development without federal funding. California is reported to be the only state that funds its own research and development program for geothermal energy.

In addition to incentives and mandates being called for geothermal energy based on its benefits/costs values, declining energy generation, and gap between the current and ideal portfolio contribution, the identified R&D barriers would call for both minimum targets and federally administered financial incentives, specific to geothermal energy. This would be ideal for this energy alternative, in regions where it is feasible.

6 BIOMASS ENERGY SAVING GOALS FOR COMBINED HEAT AND POWER SYSTEMS AT WASTEWATER TREATMENT PLANTS

AHP results from Section 4 showed that on a regional basis, electricity generation from biomass energy resources ranked lowest considering renewable energy prioritization at a national level. A limitation with the AHP analysis therefore is that it did not promote biomass resources that offered waste-to-energy benefits, as current state-level policies do. Rather than establish national mandates for biomass energy, this Section explores how voluntary targets can be set at a local-scale, or smaller distribution-generation scale, for waste-to-energy resources. This analysis is conducted using biomass energy from wastewater treatment plants (WWTPs).

A statistical approach is used to determine the range of electrical energy potential targets for Combined Heat and Power (CHP) systems at WWTPs, based on wastewater treatment capacities. Since waste-to-energy resources are usually developed as a means of managing waste disposal, rather than the intention of extracting the full energy potential, goals established for biomass energy generation are expected to be well under the actual potential.

Gohlke and Martin (2007) conducted a study to determine the main drivers for waste-to-energy resource development. One of the main drivers noted was the necessity to divert waste from landfills due to costs associated with landfill taxes and tipping fees. The study concluded that “innovation in the waste-to-energy industry is driven by competition with other waste treatment options”. That is, the main waste-to-energy development driver is the waste-component and not necessarily the energy component.

Therefore, rather than selecting CHP targets based on the full energy potential, this Section develops a reference chart for CHP target selection based on data listings of successful installations. The chart serves as a one point reference to be used in lieu of individual case studies for selecting electrical goals for CHP systems installed at WWTP. The methodology can be modified, as need be, and potentially transferred to develop charts for other biomass resources.

6.1 Energy Demand and CHP Potential at Wastewater Treatment Plants

According to the U.S. Department of Energy (2006), approximately 4% of the U.S. energy production is used in water / wastewater treatment and water supply, and nearly 75% of municipal water / wastewater processing costs are attributed to electricity. Energy represents a significant percentage of cost in wastewater treatment as it is required in all stages throughout treatment. Despite the high energy costs, many existing WWTPs are not energy efficient and do not utilize renewable energy alternatives that could be cost saving and more sustainable in the long run. According to the Water and Environment Research Federation (WERF, 2011), wastewater has nearly ten times as much stored energy as what is needed for treatment.

For those WWTPs that incorporate *anaerobic digestion* (a biological breakdown of organic matter in the absence of oxygen), one significant method to capture this energy is through combined heat and power (CHP). CHP, also known as *cogeneration*, is a form of distribution generation that involves the process of simultaneously generating heat and electricity from a unit fuel source such as biogas, natural gas or fuel oil. In WWTPs, biogas, which primarily contains a mixture of approximately 40% carbon dioxide and 60% methane, is produced as a byproduct of anaerobic digestion.

Brown and Caldwell (2010) stated that the use of biogas alone from anaerobic digestion in WWTPs can offset up to 40% brown energy consumption through the production of CHP, which is the most common application of biogas in WWTPs.

However, despite WWTPs' potential to produce renewable energy through CHP systems, according to the Environmental Protection Agency Combined Heat and Power Partnership (U.S EPA CHPP, 2011), more than 20% of WWTPs with anaerobic digestion in the U.S. do not utilize CHP. In 2012, WERF and the New York State Energy Research and Development Authority (NYSERDA) published a report based on a survey study conducted in 2011 and that covered 209 wastewater utility personnel and 36 non-utility stakeholders including consulting engineers, government agencies, private project developers and product vendors to determine and rank the barriers WWTPs faced in implementing CHP Systems and to identify ways to overcome these barriers (WERF, 2012). The study categorized the CHP barriers into 10 hypothesized sub-categories, 9 of which were verified to be actual. The barrier sub-categories were further divided into three main groups namely: (1) economic barriers, which ranked highest, (2) barriers resulting from policy factors, and (3) barriers resulting from human factors including lack of experience and knowledge. According to the North East Biosolids and Residuals Association (NEBRA, 2012), lack of strong baseline data of biogas production and utilization in WWTPs was identified as a factor that has slowed the growth of CHP in WWTPs.

This study attempts to compile, summarize and simplify data that quantify CHP electrical energy potentials and installations at WWTPs in the U.S., in order to facilitate selecting achievable CHP electrical goals and targets at a local/facility setting.

6.2 Definitions – Electrical Potential vs. Electrical Capacity

For the purpose of this analysis, the "electrical potential" of a CHP system will be used when referring to the theoretical or computed maximum recoverable electrical energy based on biogas production at wastewater treatment plants, while the "electrical capacity" will be used when referring to the maximum total electrical energy output of all biogas-based energy generating unit installations at the WWTPs considered. The installed electrical is usually specified by the manufacturer of the generating equipment.

6.3 Background for Analysis of CHP at WWTPs

In 2007, U.S EPA CHPP published a guide entitled "Opportunities for and Benefits of Combined Heat and Power at Wastewater Treatment Facilities", which was later updated in 2011 (EPA CHPP, 2011). In addition to providing information for assessing energy potential for CHP at WWTPs that have anaerobic digesters, the guide also provides basic WWTP CHP data such as the number of WWTPs utilizing digester gas for CHP in the U.S., the total CHP electrical capacities and electrical potentials by state. However, according to the North East Biosolids and Residuals Association (NEBRA, 2012), "industry experts" have found that the data included in the report are both incomplete and contain errors. In July 2011, the Water Environment Federation (WEF) sought ways to improve the data available to WWTPs by initiating and funding The National WWTP Biogas Data Project, "Preparation of Baseline of the Current and

Potential Use of Biogas from Anaerobic Digestion at Wastewater Plants." The project was awarded to a team of companies comprising InSinkErator, NEBRA and Black & Veatch. Data captured in this phase included: facility name, location and contact information; wastewater flows; type of digestion and CHP technology used, application of biogas generated; indication if outside waste is fed to digester; whether electricity is generated and if it is fed to the grid (NEBRA, 2012-2013). The database was available online through the biogasdata.org website. Although the database did not have information such as the biogas production at each plant, CHP capacities and estimated energy potentials that WWTPs planning for CHP systems may deem useful, it was anticipated that such information would be provided in the second phase of the project.

In order to obtain CHP capacities that were not included in biogasdata.org, the study used a second online database maintained by ICF international - www.eea-inc.com/chpdata/index.html, currently transferred to https://doe.icfwebservices.com/chpdb/. In addition to listing CHP capacities at various industries in the USA including WWTPs, the ICF international database also indicates the CHP prime mover (type) and the fuel types, as not all the industries included in the database use biogas (ICF International, 2013).

6.4 Methodology for Establishing Biomass Energy Saving Goals for CHP at WWTPs

The sub-sections below first describe the EPA CHHP (2011) report and the additional literature search performed for this study. Then, it explains the methodology used for this Section and summarizes how the research builds on the EPA CHHP report.

6.4.1 CHP Electrical Potential in Wastewater: The EPA CHHP Study (2011)

The U.S. EPA Combined Heat and Power Partnership (EPA CHPP, 2011) estimates that approximately 26 kilowatts (kW) of electrical energy can be produced for every 1 million gallons per day (mgd) of wastewater treated, based on modelling the average energy produced using microturbines, reciprocating engines/Internal Combustion Engines (ICE) and fuel cells, the most commonly used prime movers at WWTPs, and assuming a typical wastewater loading rate of 9.1 mgd (resulting to approximately 91,000 cubic feet of biogas production per day). By analyzing tabulated data included in the U.S. EPA CHPP report (2011), it was noted that the modelled CHP electrical potential of each prime mover under consideration was obtained as a product of the biogas volume production, energy content of biogas higher heating value (HHV) and the electrical efficiency of the generating equipment obtained from manufacturer data. The average value of all prime movers was then obtained and divided by the modelled flow of 9.1 mgd in order to obtain 26 Kw/mgd (Table 6-1).

Based on the relationship between wastewater flow and electrical energy potential from WWTP CHP systems (26 kW/mgd), it is apparent that the higher the plant flow, the greater the electrical potential. According to the U.S EPA CHPP (2011), the greatest 'economic potential', defined as one having a payback period less than or equal to 7 years, are realized for larger plants with flows equal to or higher than 30 mgd. Further, a study conducted by the Electric Power Research Institute (EPRI, 2002), shows that the electrical intensity (kilowatt-hour per million gallon – kWh/mg) for larger WWTPs is lower than for smaller plants utilizing the same treatment technology as can be seen in

Figure 6-1, indicating that further benefits, in terms of percentage savings from CHP systems, can be realized by larger plants. Larger WWTP will generally have lower energy intensities due to economies of scale.

Nevertheless, smaller WWTPs can boost their biogas production, by adding nonhazardous high‐strength wastes (HSW), such as fats, oil, and grease (FOG), or where feasible, incorporating thermophilic digestion, which utilizes higher temperatures ranging between 124°F and 138°F that facilitate faster gas yields.

Table 6-1: CHPP Model Summary for Estimating CHP Electrical Potentials

	ICE/ Rich Burn	ICE/ Lean Burn	Micro Turbine CHP	Fuel Cell
Total WWTP Flow (MGD)	9.1	9.1	9.1	9.1
Biogas Volume (Cubic Feet)	91,000	91,000	91,000	91,000
Electrical Efficiency	0.291	0.326	0.260	0.423
Biogas Higher Heating Value (HHV) (Btu/day) HHV	1.71 E+07	1.92 E+07	1.53 E+07	2.49 E+07
Electric Energy Potential (kW)	209	234	187	304
Average Electrical Potential (kW)			234	
Average Electrical Potential per mgd (kW/mgd)			26	

As can be expected, energy intensity also increases as the level of treatment increases. For example, considering an arbitrary selected 10 mgd WWTP with tricking filters (energy intensity of about 850 kW/mgd) and comparing with a 10 mgd plant with nitrification (energy intensity of about 1800 kW/mgd) we find that the WWTP with nitrification uses 2.1 times the energy used in the WWTP with trickling filters.

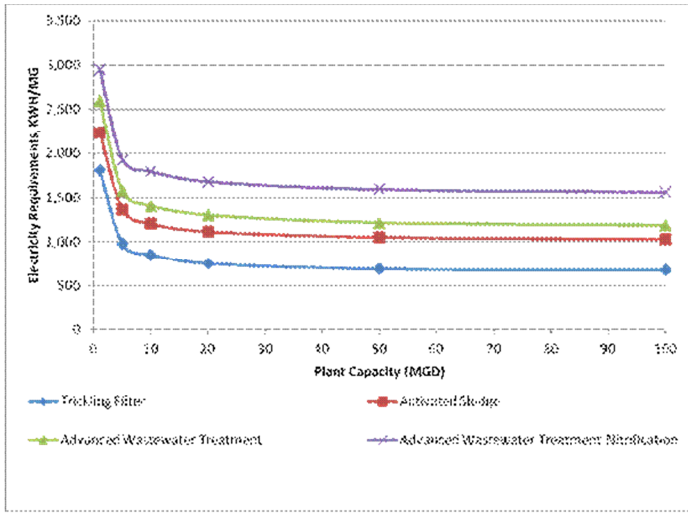


Figure 6-1 Electricity Demand for Wastewater Treatment by Size of Plant and Treatment Type Source: EPRI (2002)

6.4.2 Energy Saving Goals and Target Setting for CHP Systems Based on Survey of WWTP Case Studies – Additional Literature Search

WWTPs may have several facility-driven energy related targets and performance indicators, which may include, but are not limited to, reduction in brown energy consumption and increase in renewable energy sources, reduction in energy cost, reduction of peak load demand, and reduction in greenhouse gas emission in treatment processes as well as in utility vehicle use . These energy goals may be defined based on an organization’s energy policies. According to U.S EPA (2013), an energy policy can be defined as a commitment endorsed by management to meet specified energy improvement targets based on a defined plan of action or “framework”. These goals can be determined by reviewing case studies to compare what similar facilities have been able to achieve and setting goals similar to those achieved in the past. The Massachusetts Department of Environmental Protection (2011) has identified a set of notable case studies with different goals, motivations and reasons for setting CHP systems including, among others, the Sheboygan WWTP in Wisconsin, Gloversville Johnstown Joint WWTP in New York and the East Bay Municipal Utility District (EBMUD) in California.

Recognized as a leader in energy efficiency in the U.S. wastewater sector, the Sheboygan WWTP implemented a 300 Kilowatt (kW) capacity Combined Heat and Power (CHP) system and is an example of a facility that implemented CHP to reduce energy consumption, with the ultimate goal of becoming a net-zero or energy neutral facility. The plant, which has a treatment capacity of about 18 mgd, is currently able to achieve between 70% and 90% energy sufficiency from its CHP system, resulting in an annual savings of approximately $78,000 from the electricity generated and approximately $60,000 based on heat generated (ACEE, 2011).

The Gloversville Johnstown Joint WWTP in New York is an example of a facility that highly benefited from energy cost savings due to installation of CHP systems. The plant was expanded in 1992 to 13 MGD in order to treat both domestic wastewater (30%) and industrial wastewater (70%) from fishing and leather and tanning industries in the cities of Gloversville and Johnstown. Through the early 2000s, after the leather and tanning industries within the service areas closed down, the Gloversville Johnstown Joint WWTP experienced a reduction in revenue and excess capacity at the facility. The implementation of a CHP system made it possible for the facility to reduce operating costs and control their financial situation. The current location of the WWTP and its proximity to dairy processing facilities further enabled the facility to incorporate dairy waste into its processing stream thus generating more biogas and energy, as well as utilizing the unused treatment capacity. The WWTP is able to produce between 90% and 95% of the electricity required to operate the facility though a 700 kW capacity CHP system (Cogeneration and On-site Power Production, 2011).

According to the Massachusetts Department of Environmental Protection (2011), the EBMUD is the first facility in the U.S, which, in addition to having a wastewater stream, also has a separate food waste stream and a FOG stream in its treatment process. The 168 mgd capacity plant is a good example that demonstrates the benefits of adding food waste and FOG streams in digesters for greater methane production. Like the Gloversville Johnstown WWTP, EBMUD experienced excess capacity of more than 50% due to industries it served moving away. EBMUD was able to accommodate food waste redirected to the plant after a ban on organics in landfills was enacted and was able to generate approximately 90% of its total energy needs through CHP.

6.4.3 Data Collection

According to EPA (2008), even though there are various case studies of CHP systems at WWTPs that can be used to set energy goals by comparing with what similar facilities have been able to achieve, there are no standard energy objectives and targets that can be directly selected to suit individual plants that plan to implement energy improvement programs. This study compiled and analyzed data of installed CHP electrical capacities at WWTPs, which could be used in lieu of individual case studies that are often needed for selecting reasonable CHP electrical goals and targets. The installed CHP electrical capacities were compared to calculated CHP electrical potentials obtained by methodology developed by the EPA CHPP (2011). Comparing the data would verify the accuracy of the EPA CHPP model, which is a simplified and direct method for obtaining CHP electrical potentials using wastewater flows as the only variable and therefore enabling operators to set energy goals for CHP systems in WWTPs in a simplified manner. In order to carry out the analysis on a complete set of data, CHP electrical capacity data were collected for all the WWTPs in the USA using the online biogas database accessed from biogasdata.org (NEBRA, 2012-2013) and from the ICF International database (ICF International, 2013), accessed from www.eea-inc.com/chpdata/index.html.

Where possible, data retrieved from the two databases was verified using the WWTP utility websites and online reports on the respective CHP installations. A spreadsheet with a total of 126 WWTPs that utilize CHP using biogas for electrical energy was created from the two online sources. Of the 126 WWTPs, 12 WWTPs that incorporate CHP systems with combustion turbines, stream turbines and boilers were eliminated in order to limit the analysis to include only those plants with CHP prime movers most commonly used in wastewater treatment, namely: microturbines, reciprocating engines and fuel cells.

Two plants with thermophilic digestion were also eliminated in order to limit the analysis to only those with mesophilic digestion. The higher temperatures under thermophilic conditions facilitate faster gas yields and more significant destruction of pathogens, but the increased energy requirements make this option more expensive than mesophilic digesters. Thermophilic digesters are also highly sensitive to fluctuating environmental conditions. Due to these drawbacks, as well as the fact that there are more anaerobic mesophiles (mesophilic methane-forming bacteria) than there are thermophiles (thermophilic methane-forming bacteria) in nature, most digesters at wastewater treatment plants are mesophilic (Geradi, 2003).

It was not possible to obtain missing CHP data from two of the remaining 112 WWTPs under the scope of this study, and therefore CHP data from a total of 110 plants, with flows ranging from 1.5 mgd to 160 mgd, were used for analysis.

The total number of WWTP in each state and total capacity by state obtained in this study was compared to the numbers obtained by U.S. EPA CHPP (Table 6-2).

Table 6-2: Number of WWTP CHP Systems Utilizing Biogas and Total Capacity by State: Comparison of EPA CHPP (2011) Data

State	EPA CHPP (2011)		THIS STUDY	
	Number of WWTP	CHP Capacity (MW)	Number of WWTP	CHP Capacity (MW)
AR	1	1.73	1	1.73
AZ	1	0.29	1	0.29
CA	33	62.67	39	67.26
CO	2	7.07	1	0.07
CT	2	0.95	2	0.88
FL	3	13.5	3	13.5
IA	2	3.4	1	3.4
ID	2	0.45	2	0.53
IL	2	4.58	2	4.58
IN	1	0.13	1	0.13
MA	1	18	2	**0.37**
MD	2	3.33	2	3.33
MI	1	0.06	1	0.06
MN	4	7.19	4	2.19
MT	3	1.09	3	1.09
NE	3	5.4	3	5.4
NH	1	0.37	1	0.37
NJ	4	8.72	4	6.2
NY	6	3.01	9	3.03
OH	3	16.29	2	**0.16**
OR	10	6.42	11	8.17
PA	3	1.99	3	2.11
TX	1	4.2	1	4.2
UT	2	2.65	2	2.65
WA	5	14.18	3	11.70
WI	5	2.02	6	1.18
WY	1	0.03	0	0.00
Total	104	189.7	110	144.5

Because data from the US EPA CHPP study (2011), was based on the ICF International Database, one of the two primary databases used in this study, many of the parameters in both studies have similar values. However a few major discrepancies worth noting are as follows:

MA - Deer Island Wastewater Treatment (16 MW) may have possibly been included in the U.S EPA CHPP study (2011) and was not include in this study. Based on ICF

International (2012) database the WWTP CHP system utilizes boiler/steam turbine prime movers, which should have been eliminated from both studies.

OH – Based on the Public Utilities Commission of Ohio Database of CHP Systems (undated), this study did not include Bay View Wastewater Treatment Plant that utilizes combustion turbines (10MW) and Toledo Wastewater Treatment Plant that utilizes combustion turbines (6.2 MW). Also 0.09 MW was used for the Lima WWTP in this study instead of 0.155 MW indicated in the ICF database. This study also includes the City of Twinsburg Wastewater Treatment Plant (0.065 MW) assumed to have been left out in the U.S EPA CHPP analysis.

6.5 Data Analysis

6.5.1 Establishing Categories

The 110 WWTPs considered were categorized into initially 5 classes, so as to simplify analysis. In order to approximate an equal number of WWTPs in each of the 5 classes, the total number of WWTPs was divided by the predetermined number of classes (5) to obtain approximately 22 WWTPs per class. The WWTP flows were then ranked in order of increasing flows and a cut-off flow determined based on where every 22nd ranking fell. The flows were rounded to more reasonable upper and lower limits in each class interval to obtain 5 categories of WWTPs with average flows ranging from 1 to 5 mgd (22 plants), 5 to 10mgd (21 plants), 10 to 20 mgd (28 plants), 20 to 50 mgd (20 plants), 50 to 160 mgd (19 plants).

The 50 to 160 mgd category was further divided into two categories of 50 to 100 mgd (11 WWTPs) and > 100 mgd (8 WWTPs) so as to limit the distortion of data (potentially concealing important variation of CHP electrical capacities) caused by the larger interval range of average flows in the 50 to 160 mgd class. This resulted into six WWTP categories (Figure 6-2).

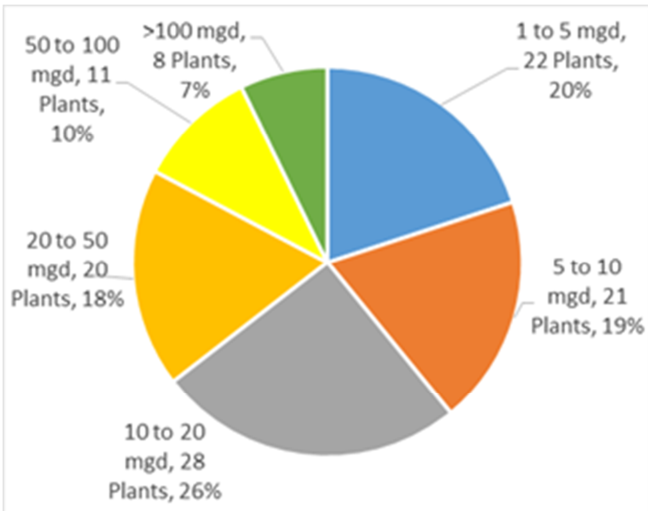


Figure 6-2: WWTP Categories

6.5.2 Constructing Confidence Intervals in Each Flow Category

1) Criteria for Selection of Mean or Medium

A 95 percent confidence interval was selected for establishing CHP electrical limits in each of the six flow categories.

In order to determine whether to use the mean or median to give a reflection of the 'average' value of the installed CHP electrical capacities, the data distribution in each of the six categories was checked for normality by plotting histograms and observing the plots for symmetry. The results are shown in Figure 6-3 to Figure 6-8.

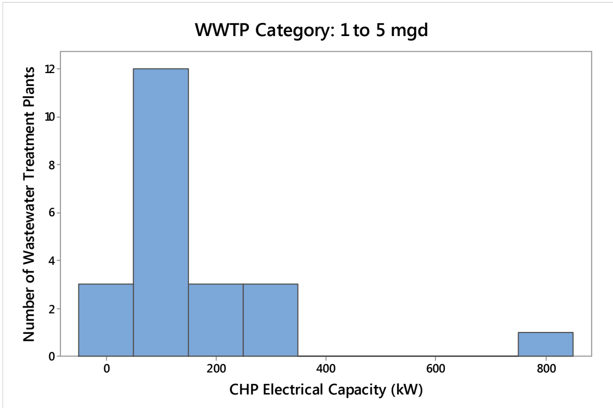


Figure 6-3: Histogram of WWTP CHP Electrical Capacities for WWTPs with Average Flows of 1 to 5 Mgd

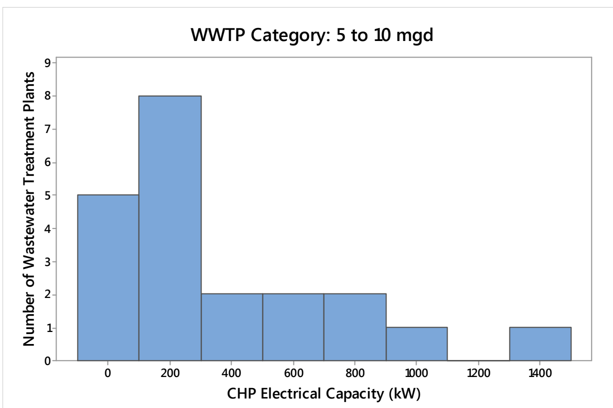


Figure 6-4: Histogram of WWTP CHP Electrical Capacities for WWTP with Average Flows of 5 to 10 Mgd

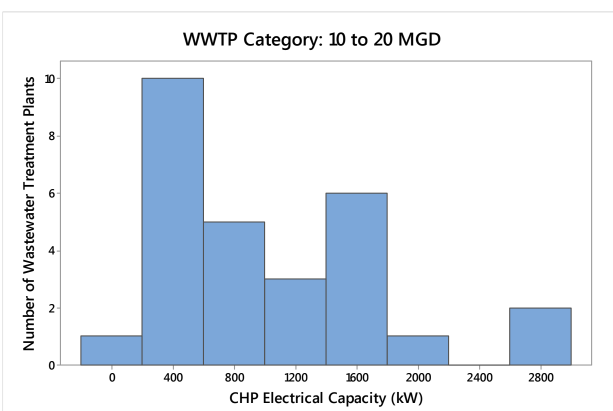


Figure 6-5: Histogram of WWTP CHP Electrical Capacities for WWTP with Average Flows of 10 to 20 Mgd

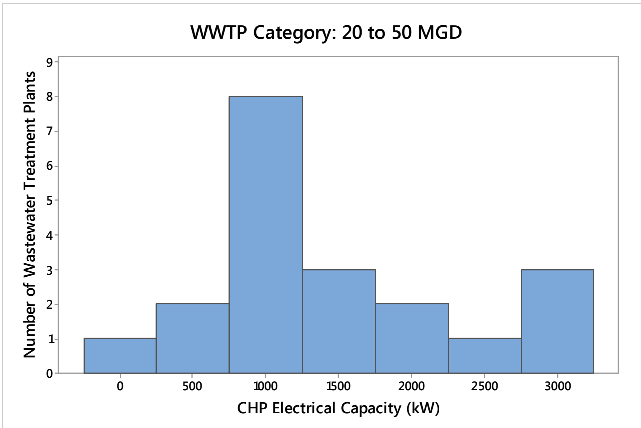


Figure 6-6: Histogram of WWTP CHP Electrical Capacities for WWTP with Average Flows of 20 to 50 Mgd

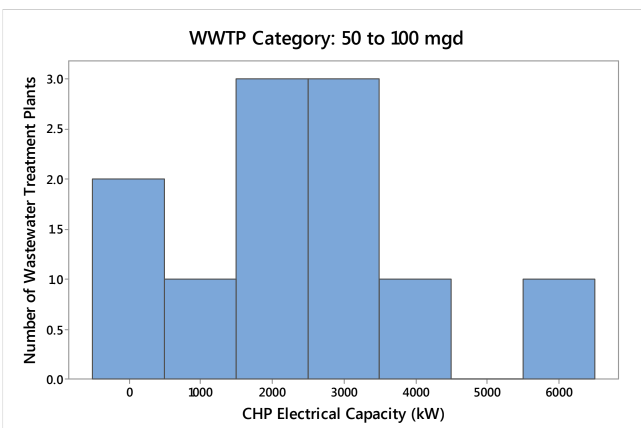


Figure 6-7: Histogram of WWTP CHP Electrical Capacities for WWTP with Average Flows of 50 to 100 Mgd

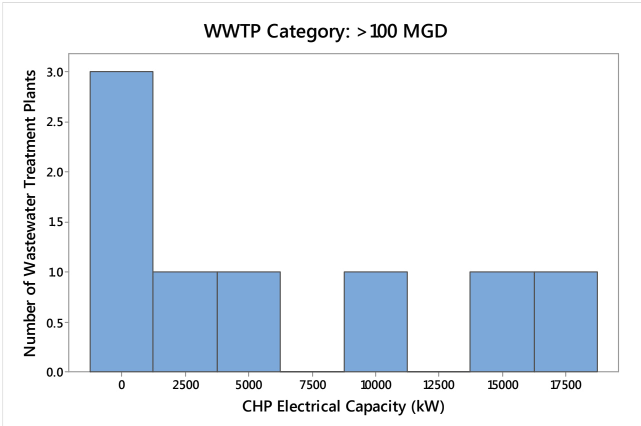


Figure 6-8: Histogram of WWTP CHP Electrical Capacities for WWTP with Average Flows > 100 Mgd

Since none of the histograms showed symmetry, and generally skewed to the right, the medians in each class were selected to represent the 'average' value. The confidence intervals for each median was obtained using 1-Sample Sign Analysis, a non-parametric tests, which does not require the data used to be of any particular kind of distribution. The 1-Sample Sign analysis constructs confidence intervals from the actual data by selecting a ranked value based on data sorted in increasing order (University College London, 2010).

Since the calculated CHP electrical potential assumes a linear relationship between WWTP flows and the electrical potential (given by 26 kW/mgd), the mean value was used to reflect the 'average' of the computed electrical potentials in each flow category.

2) Obtaining Confidence Intervals for the Median Values of the CHP Electrical Capacities

In order to obtain the lower 95 % confidence limit (LL_1) for a sample with m values, the rank number of the value to be used is given by the formula $m/2 - [1.96(m)^{1/2}]/2$ and the rank number for the upper 95 % confidence limit (UL_1) by the formula $1 + m/2 + [1.96(m)^{1/2}]/2$ (University College London, 2010).

In instances where the rank obtained is not a whole number, an approximation of the 95% confidence interval is obtained by rounding off the rank decimal or by interpolating between the two whole numbers on either side of the decimal.

The analysis in this study was conducted using Minitab, a statistical software, which utilizes the latter option. The computed lower limits (LL_1) and upper limits (UL_1) together with the respective median for each flow category are listed in Table 6-3.

3) Obtaining Confidence Intervals for Mean Values of the Calculated CHP Electrical Potentials

CHP electrical potentials, based on assuming 26 kW/mgd, were calculated using the lower and upper flow limits of the respective WWTP category. For the 1 to 5 mgd category, the limits were defined by 1 mgd and 5 mgd, for the 5 to 10 category the limits were defined by 6mgd and 10 mgd, for the 10 to 20 category by 11 mgd and 20 mgd and so on. The resulting kW values, obtained by multiplying the flow limits by 26 kW/mgd, were therefore used to define lower limit (LL_2) and upper limit (UL_2) in each class as shown in Table 6-3.

Table 6-3: Actual CHP Electrical Capacities and Calculated CHP Electrical Potentials

Flow mgd	Actual CHP Electrical Capacity (1-Sample Sign analysis of Confidence Limits)			Calculated CHP Electrical Potentials		
	LL_1	UL_1	Median	LL_2	UL_2	Mean
1-5	60	150.7	88	26	130	78
5-10	130	473.1	250	156	260	208
10-20	442	1333	675	286	520	403
20-50	854	1906	1223	546	1300	923
50-100	951	3282	1800	1326	2600	1963
>100	300	15193	3900	>2600	-	-

The values in Table 6-3 are shown graphically in Figure 6-9. The dashed center line (blue) in Figure 6-9 represents the median CHP electrical capacities, while the two solid lines (red) on either side of the median represent the 95% upper and lower confidence intervals. The vertical lines represent the range of calculated CHP potentials for each flow category, with the mean value shown for each case.

Figure 6-9 shows that CHP electrical capacities increase as WWTP average flows increase. The variability in CHP electrical capacities also increases with increase in flow as shown by the increase in interval range (difference between upper and lower confidence intervals). This may be based on the fact that although large WWTPs can support larger CHP units and thus generate more power, not all facilities will maximize their electrical potential due to various reasons such as need to pilot test, lack of adequate capital costs and/or the desire to install CHP units in phases, lack of a clear direction for setting achievable energy targets among other reasons.

Figure 6-9 also indicates that the calculated CHP electrical potentials fall close to the lower limit and median of the actual CHP electrical capacities, possibly indicating that the U.S EPA CHPP (2011) model offers a simple and conservative methodology for setting energy targets for CHP systems at wastewater treatment plants.

Figure 6-9, which represents a summary of CHP electrical capacities of systems installed in the U.S, can also be referenced when selecting CHP electrical goals based on the 95% confidence intervals of goals that have been achieved in the past in lieu of analyzing individual selected case studies, which can be time consuming. This alternative has the advantage of offering WWTP operators an opportunity to decide whether to be conservative, for example when selecting short term energy goals, by setting CHP capacity targets closer to the lower limits, or more aggressive, for example for long term strategic energy planning, by selecting CHP capacity targets closer to the upper limits.

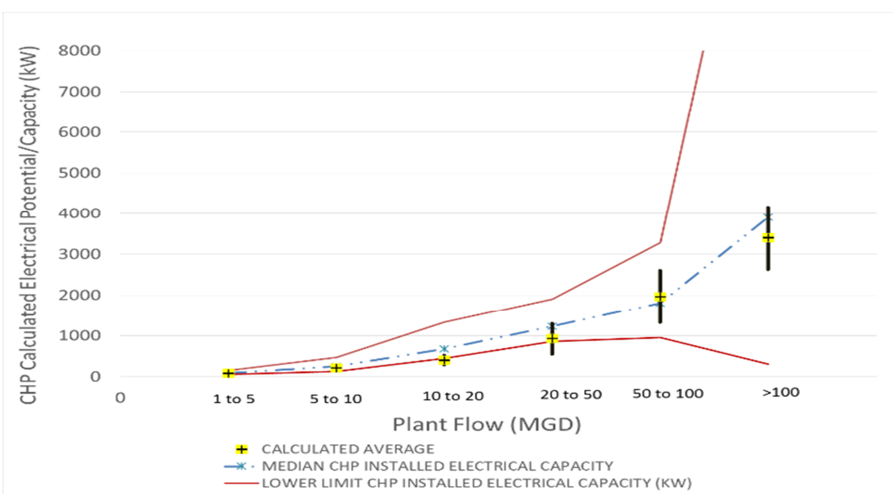


Figure 6-9: Wastewater Flow versus Actual and Calculated Electrical Capacities

6.6 Results and Discussion for CHP Goals at Wastewater Treatment Plants

Wastewater CHP data, mostly obtained from available online databases was collected and assimilated to generate a single database. The total number of WWTP utilizing biogas for CHP and the total CHP electrical capacity by state was obtained from the compilation and compared to those provided by the EPA CHPP report (2011). 110 WWTPs were analyzed in this study, while 104 WWTPs in the EPA CHPP (2011) study. With the exception of minor discrepancies caused by the inclusion or exclusion of WWTPs between the two studies, two major discrepancies were noted for the state of MA (difference of 17.63 MW between the values reported) and OH (difference of 16.13 MW) based on the total CHP electrical capacities by state. For MA, Deer Island Wastewater Treatment (16 MW) may have possibly been included in the U.S EPA CHPP study (2011) and was not include in this study. Making reference to the ICF International database (2012,) the Deer Island WWTP CHP system utilizes boiler/steam turbine prime movers, which should have been eliminated from both studies. For OH, based on the Public Utilities Commission of Ohio Database of CHP Systems (undated), this study did not include Bay View Wastewater Treatment Plant that utilizes combustion turbines (10MW) and Toledo Wastewater Treatment Plant that also utilizes combustion turbines (6.2 MW). Also 0.09 MW was used for Lima WWTP in this study instead of 0.155 MW indicated in the ICF Database (2012). In addition, this study also included the City of Twinsburg Wastewater Treatment Plant (0.065 MW) assumed to have been left out in the U.S EPA CHPP analysis.

CHP electrical potentials for WWTPs (given by 26 kW/mgd) was compared against actual values of CHP electrical capacities. The WWTPs considered were first grouped into 6 categories, based on flow, to simply the analysis. Since the calculated electrical potential assumes a linear relationship between WWTP flows and the computed electrical potential, the mean value was used to reflect the 'average' value for the computed electrical potentials in each flow category.

Histograms for the installed CHP electrical capacities were developed for each WWTP category to determine if the electrical capacities were normally distributed. The resulting histograms indicated non-normal distribution. For this reason, the median values in each class were selected to represent the 'average' value and the confidence intervals for each median obtained using 1-Sample Sign Analysis.

In addition to observing that CHP electrical capacities increased with WWTP average flows, it was determined that the variability in installed CHP electrical capacities also increases with increase in flow. This was assumed to potentially be based on the fact that although large WWTPs can support larger CHP units and thus generate more power, not all facilities maximize their electrical potential due to various reasons such as need to pilot test, lack of adequate capital and/or the desire to install CHP units in phases, lack of a clear direction for setting achievable energy targets among other reasons

An observation was made showing that the calculated CHP electrical potentials fall close to the lower limit and median of the actual CHP electrical capacities, indicating that the U.S EPA CHPP model offers a simple and conservative methodology for setting energy targets for CHP systems at WWTPs. A strength in this study therefore is that it allows WWTP operators to determine if they want to be conservative, such as in selecting short term energy goals, by selecting lower limits based on the 95% confidence interval of the median electrical capacities; to be less conservative and select "average" goals by choosing to install capacities close to the median or to be more aggressive, for example in long term strategic energy planning, by selecting CHP capacities based on the upper limits presented.

The study also offers a one point reference to be used in lieu individual case studies as it represents a summary of electrical capacities derived from most WWTPs in the U.S, therefore serving as quick guide for selecting electrical goals for CHP systems installed at WWTP.

It was realized that each wastewater treatment plant has its own unique characteristics and numerous variables that may impact the amount of biogas generated. These variables include the wastewater flows, sludge composition, treatment processes and mixing methods, as well as use of alternative feed stocks such as fats, oil and grease (FOG) among other factors that cannot all be captured and synthesized for reference. In this study, the only variable that was taken into consideration was the wastewater flow therefore presenting a weakness in the study. Another weakness in the method is that is does not provide information on the thermal energy available from CHP systems for the anaerobic digester heat load and additional thermal energy available for other applications such as space heating. Including this information as part of the study could have been more beneficial than limiting the scope to cover only electrical energy. This information would especially be beneficial for WWTP setting other related CHP goals related to total brown energy reduction (for example goals to reduce both electricity and natural gas consumption) and reduction in greenhouse gas emissions. Including information on the thermal energy output would have also provide a more comprehensive view of all benefits expected from utilizing CHP systems in WWTPs.

7 CONCLUSIONS, RECOMMENDATIONS AND FUTURE STUDIES

7.1 Decision Making and Prioritization for National Renewable Energy Policy Formulation

The percentage renewable energy mix for U.S. regions was determined using AHP, from a policy maker's point-of-view. Location potential, land requirement, emissions, water demand and public perception were the ranking criteria used to obtain renewable energy proportions as follows:

- Mountain region: 14% geothermal, 15% onshore wind, 33% CSP, 37% solar PV, and 1% biomass energy.
- West North Central Region: 11% geothermal, 18% onshore wind, 10% offshore wind, 17 % CSP, 44% solar PV, and 1% biomass energy.
- West South Central Region: 11% geothermal, 14% onshore wind, 11% offshore wind, 24 % CSP, 40% solar PV, and 1% biomass energy.
- East North Central: 13% geothermal, 13% onshore wind, 15% offshore wind, 53% solar PV, and 6% biomass energy.
- Pacific: 11% geothermal, 12% onshore wind, 18% offshore wind, 22% CSP, 36% solar PV, and 1% biomass energy.
- South Atlantic: 13% geothermal, 11% onshore wind, 16% offshore wind, 53% solar PV, and 7% biomass energy.
- East South Central: 16% geothermal, 11% onshore wind, 11% offshore wind, 55% solar PV, and 7% biomass energy.

- Middle Atlantic: 17% geothermal, 12% onshore wind, 23% offshore wind, 42% solar PV, and 6% biomass energy.
- New England: 18% geothermal, 12% onshore wind, 33% offshore wind,31% solar PV, and 6% biomass energy.

The results above answered the research question, *"For each U.S. region, what proportion of renewable energy resources need to be developed for a diverse renewable energy portfolio?"*

Ideally, RECs would be tradable, at minimum within the regions listed above, to allow member states to collectively meet the targets presented. Removing geographic boundaries in trading would allow RECs to be retired faster, avoiding a situation where REC prices significantly drop, due to overabundance of a renewable energy source, such as in the case presented for wind energy in Texas. The cross trading would also allow a "co-operation mechanism" between states, such states with high renewable energy potentials are able to transfer RECs to those with lower potentials allowing renewable energy targets to be met nationally.

Weighted percentage average values for the regional portfolios were used to obtain the national renewable energy portfolio, and to identify the renewable energy sources that the nation should prioritize. This analysis assumed the policy maker's point-of-view aimed for a diverse renewable energy mix. The national renewable energy portfolio obtained for the U.S was 14% geothermal, 13% onshore wind, 15% offshore wind, 21% CSP, 32% solar PV, and 4% biomass energy. Relative to current generation percentages, the recommended renewable energy portfolio would stipulate an increase of solar PV generation from about 10% to 32%, concentrated solar power from about 1% to 21% and geothermal energy from about 5% to 14%. The renewable energy policies would not need to prioritize on development of wind or biomass energy as the percentages generated from these sources currently surpass the AHP percentages computed. However, the achieved targets would regularly need to be reviewed against the intended goals, to ensure that both wind and biomass energy contributions do not fall below the recommended levels.

Historical renewable energy data showed an increasing trend in the percentage generation of solar PV and concentrated solar energy, but generally a decreasing trend in geothermal energy. This was an indication that greater incentives for geothermal energy may be needed for the recommended growth from 5% to 14%. In addition to incentives being called for geothermal energy, based on its declining energy generation and the gap between the current and ideal portfolio contribution, it was noted that research and development of geothermal energy at state-levels has been limited and should be promoted.

Incorporating the costs into the benefit/cost ratios, rather than evaluating it as a criteria, facilitated the possibility of promoting energy sources that ranked high based on benefits alone. Renewable energy alternatives with high benefits and high costs would benefit the most from financial incentives, while those with high benefits and low costs would require mandates. High -benefits alternatives were considered as those that had at least one region with a benefits score value equal to or higher than the average benefits score. These included geothermal, offshore wind, onshore wind, CSP and Solar PV. Biomass was the only low-benefits alternative. Similarly, high-costs alternatives were based on average costs score values. High-cost alternatives included geothermal, offshore wind, and CSP, while low-cost energy alternatives included onshore wind, solar PV, and biomass. In order to simplify incentives and mandates selections, based on this discussion, a visual model considering the benefits and costs for selecting incentives and mandates was developed. The Benefits/Costs Incentives/Mandates (BCIM) model focused on high-benefits alternatives that required an increase in portfolio contribution, relative to the current percentage generation. No increase in wind (offshore and onshore combined) and biomass energy generation was needed since the current percentage generation exceeds the target portfolio percentages. These options could therefore be eliminated from incentives/mandates consideration. Biomass was also eliminated as a low-benefits technology. The BCIM results showed that mandates would ideally be issued for solar PV and incentives for geothermal and CSP alternatives.

The financial incentives recommended above could be similar to current state-level renewable energy incentives including tax credits or sales tax exemptions, and property tax incentives for eligible renewable energy sources, including generating equipment and systems, as well as grant and loan programs. Mandatory policies would similarly include defining minimum targets and prioritization using varied goals, REC compliance multipliers and alternative compliance payments, which are currently applied by some states. Incentives would have to be reevaluated periodically to ensure that regional targets do not decrease to lower than ideal levels when incentives are taken away or reduced as a result of shifting priorities and targets.

The BCIM model identified where incentives towards research and development needed to be facilitated, to bring down costs for technologies that have potential for profitable deployment. On a regional basis, the model would allow high-cost, low-benefits alternatives to be ruled out. Mandating high-cost, low-benefits renewable energy alternatives would potentially result in high electricity rates, in order to allow utilities to profit or break even. The BCIM model would therefore encourage the adoption of new renewable energy technologies while balancing the potential for rising near-term electricity rates for consumers. It would also ensure that RPSes do not lead to growth of just one type of technology – the highest-benefit, least-cost technology.

The investor's point-of-view assumed an investor's main goal would be to maximize energy production for a single renewable energy alternative by determining the ideal location to implement the given option for renewable energy, also taking into considering low capital costs. Based on these conditions, the South Atlantic, East South Central, Middle Atlantic and New England regions would potentially benefit from having policy-related renewable energy incentives, as these areas did not rank high for any of the renewable energy sources from an investor's point-of-view.

Renewable energy for biomass ranked lowest from a policy maker's point-of-view mainly due to the low resource potentials, relative to other sources. However, this does not mean the energy source should completely be disregarded. Development of biomass energy, as a low-cost renewable energy alternative, should instead be considered at a local, rather than national setting. This is in order to better realize the benefits of biomass energy, especially when generated as a waste energy product within a facility, and in general, where the local potential is high. Waste-to-energy biomass is currently targeted through RPSes in the North Carolina (swine and poultry waste), Virginia (animal waste) and New Hampshire (driven by wood waste according to New Hampshire Public Radio, 2017).

Since it may not be feasible to locally develop biomass energy resources to their full potential, the goals established for generation are expected to be well under the actual potential. Using the case of CHP generation at WWTP, the study used statistical methods to develop a simplified reference chart for selecting voluntary energy targets for CHP systems based on successful installation capacities. The statistical methods can be modified, and appropriate data collected, to create charts for other biomass resources.

7.2 Review of the Research Objectives

A review of the research objectives indicates that all the research objectives were met as follows:

7.2.1 Objective (i)

The first objective was to prioritize utility-scale renewable energy technologies at a regional and national level, considering benefits offered- technical, social, and environmental benefits, and costs criteria.

The research recommends policy targets for renewable energy generation to achieve a national renewable energy mix comprising of 14% geothermal, 13% onshore wind, 15% offshore wind, 21% CSP, 32% solar PV, and 4% biomass energy, as a percentage of the total renewable energy generation. Based on the current renewable energy deployment, the research recommends policy mandates for minimum solar PV nationwide, in order to reach the proposed national goal. Policies should include both financial incentives and mandatory measures for CSP and geothermal energy generation for regions where it is feasible.

The policies recommended above were also reviewed for alignment with potential investors' points-of-view. Benefits/cost analysis results from this point-of-view indicated investors would potentially choose the Mountain region for investment in geothermal, concentrated solar and solar PV energy; the West North Central for onshore wind, concentrated solar, solar PV and biomass energy; the West South Central region for Solar PV, the East North central region for biomass energy, and the Pacific region for offshore wind energy. These research findings answered the question, *" For each renewable energy analyzed, which region(s) would be ideal for investors to focus on for implementation, and which region(s) would benefit from incentives, to attract investment?"*

7.2.2 Objective (ii)

The second research objective was to develop a procedure for national renewable energy policy formulation using Analytic Hierarchy Process (AHP).

The AHP methodology presented in this research organized the renewable energy problem and the selection and prioritization criteria in a structured and logical way that facilitated a thorough study of the benefits and costs of the alternatives. The selection criteria used were quantitative, allowing for less subjectivity in the process. However, a rank order was used to assign weights for the criteria, that is, criteria were first ranked from the most important to least important to facilitate assigning weights. This ranking may be considered subjective, and a sensitivity analysis on the rank order as well as the weights assigned for the pairwise comparison is recommended to evaluate the effects on the AHP results. Expert input may also be required in ranking the criteria.

The AHP method developed and applied for renewable energy ranking resulted to comparable current state-level policy prioritization.

The procedure below was followed for this research, and is recommended for the U.S. National Renewable Energy Policy Formulation.

1. Select renewable energy alternatives for evaluation.
2. Establish the selection criteria.
3. Formulate the AHP model considering the policy maker's point-of-view to first set regional goals based on benefits alone.
4. Translate the regional goals into national goals by weighing the regional goals collectively, for a bottom-up cascaded national goal formulation.
5. Review current generation and note gaps between current generation and established portfolio.
6. Where gaps exist, use a benefits/cost ratio to select mandatory policy drivers for renewable energy targets or determine financial incentives, focusing on alternatives with high benefits.
7. Reformulate the AHP model considering an investor's point-of-view to be able to promote renewable energy investment in low-ranking areas for uniform renewable energy growth in the U.S.

8. Review low-cost, low-ranking energies at a local rather than national setting and establish guidelines for setting local-level renewable energy goals.
9. Rule out high-cost, low-ranking technologies.

CHP electrical generation from wastewater treatment plant processes was studied to answer the research questions, *"What criteria should be used to develop and set energy generation targets for low-priority renewable energy sources?"*

Based on the statistical analysis and procedure followed, the final research question was answered, as summarized in the *Objective v* review.

7.2.3 Objective (iii)

The third objective was stipulate technology-specific renewable energy targets for the U.S. This was achieved by developing the renewable energy portfolio.

7.2.1 Objective (iv)

The fourth objective was to develop procedures for selecting mandates or incentives, based on gaps between targets and current generation. A benefits/costs incentive/mandate (BCIM) model was developed to meet this objective.

7.2.2 Objective (v)

The fifth objective was to facilitate selection of targets for low-priority waste-to-energy technologies. The selection of targets for low-priority waste-energy biomass alternatives was recommended at local rather than at a national setting, specifically considering biomass electricity generated from CHP at WWTPs. To meet the objective, the study used a statistical approach to determine the range of electrical energy potential targets for Combined Heat and Power (CHP) systems at WWTPs, based on wastewater treatment capacities. The methodology involved compiling wastewater CHP generation data, listing CHP capacities of successful installations, in order to develop a simplified reference chart for selecting the energy targets for CHP systems at WWTPs. Through this analysis, this research offers a one point reference chart and quick reference guide for CHP target selection, which could be used in lieu of individual case studies for setting CHP electric targets. The methodology can be modified, as need be, and potentially transferred to develop charts for other biomass resources. In other words, while only biomass energy generated from WWTPs was considered, a similar statistical approach can be followed for the analysis of other biomass energy sources, provided the necessary data are readily available.

7.3 Review of the Research Hypothesis

The proposed study explored the following hypotheses in order to meet the research goals:

i. "It is worthwhile to develop low-ranking energy sources at a smaller distribution generation scale, rather than at a national level."

The study found that it is worthwhile to develop only low-ranking energies that have low costs and at a local level. Low-benefits energies with high costs can be ruled out since they would most likely not be feasible. Mandating low-benefits, high-cost alternatives would have negative impacts on customers, based on resulting electricity rate increases.

The study suggested that low-cost waste-to-energy resources could be further developed with the combined purpose of energy generation and waste management, for beneficial re-use. While a low-priority energy source may not seem feasible for implementation when analyzed at a national level, in comparison to other renewable resources, at a smaller and more specific local or facility setting, the benefits may be better realized and the source therefore maybe worth developing at a smaller distribution generation scale, especially where the renewable energy is used on-site where it is generated.

ii. "Decision analysis formulation from a policy maker's point-of-view will differ from the formulation from an investor's point-of-view."

The study found that since the investor's point-of-view aims at selecting regions for investment, the AHP problem formulated from a policy maker's point-of-view would be transposed, and the formulation therefore changes. The regions became the alternatives from an investor's point-of-view. The benefits scores (consisting of only location potential scores) were instead also formulated as the criteria from the investor's point-of-view. Like the formulation from a policy maker's point-of-view, the cost scores remained separated from the criteria, for a benefits/cost analysis.

7.4 Research Uniqueness

In comparison to other studies, this research goes a step closer to policy formulation by reviewing gaps that exist between current renewable energy percentage generation, and the AHP percentage generation for the alternatives considered. The research provides an approach for selecting incentives and mandates for high ranking renewable energy sources that offer the most benefits. In comparison, other studies merely used AHP to rank renewable energy technologies. The study also looks at both investors' and policy makers' points-of-view to differentiate between the AHP formulations. The study uses the investor's point-of-view to allocate incentives to regions to promote uniform renewable energy development across the U.S. as much as possible, and the policy maker's point-of-view to select between mandates and incentives that would promote a diverse renewable energy portfolio mix.

7.5 Future Studies

While this research offers a general framework for structured and logical renewable energy policy formulation, the methods and finding may be further enhanced. Recommended future studies to further improve on the research and the methods developed, firstly, include the addition of more AHP scenarios. Forecasting for future energy potential scenarios would include assessing the environmental or infrastructural/human-driven impacts on energy potential, such as climate change, in order to project and phase future changes to the recommended policies. Policy recommendations also could be used as input data in the U.S. EPA MARKAL model to assess the environmental impacts of varying the renewable energy supplies based on the research recommendation. In addition, additional AHP scenarios that would consider sensitivity analysis for criteria ranking are recommended. Using permutations, n! (factorial) defines the number of different criteria ranking possibilities, where n is the number of criteria. This assumes that no criterion has the same rank order as another. For this study, there were 5 criteria, which would require 120 different formulations (5x4x3x2x1). Simulating scenarios that would develop phased timelines for achieving renewable energy targets is also recommended. Further, fine tuning benefits/cost criteria for wider range of values for the "BCIM" spectrum of values would be ideal since the average scores were used as cut-off for defining high-benefits and high-cost scores. Similarly varying incentives and penalties for mandates would match the wider spectrum.

Secondly, while the location potential and capital costs varied by region, land requirements, emissions, water demand, and public perception for each renewable energy alternative were assumed to remain constant for all the regions. Future studies to evaluate regional variations of these parameters are therefore also recommended to fine-tune the recommendations of this research. In addition, the expansion of criteria/sub-criteria used for evaluation may further improve the results. An Analytic Network Process (ANP) model could be explored to consider the interaction of criteria.

Thirdly, it is also recommended that future studies consider developing guidelines for grid capacity planning. This would ensure that any increase in renewable energy can be integrated into the grid. Such studies can also consider phasing targets for renewable energy goals that correspond to capacity improvement projects for grid systems; in order to ensure that the transmission needs to meet the renewable energy phased targets can be met.

Fourthly, it was noted that the states used varying methods of prioritization, including setting minimum (or varied goals), varied ACPs, varied REC compliance multipliers, and different combinations thereof, respectively. Further studies which evaluate the relative effect of each method on performance outcomes are recommended. Other variabilities noted between state RPSes included criteria for determining eligible renewable energy. While the study narrowed down the list of eligible renewable energy resources to include “green” energy options that excluded hydropower alternatives, studies that dwell deeper into recommending viable standard national definitions of eligible renewable energy may be needed.

Finally, the study recommends formulating local or institutional targets for low-ranking, waste-to-energy renewable sources that would uniquely be beneficial depending on the generating source and the local potential. A statistical approach for selecting voluntary targets was developed and used for electrical energy targets from CHP systems at wastewater treatment plants. It is recommended that future studies test the approach for other biomass sources. It is also recommended that future studies build on this research, by considering cost implications for each level of CHP electric targets. Future studies should also consider benefits derived from the thermal waste energy produced by CHP systems.

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9 Appendixes

9.1 Renewable Energy Prioritization Methods

Region	State	Policy Name	Policy Type	Targeted Renewables	Prioritized Renewable	Prioritization Method	Prioritization Goals, Mandates and ACPs
East North Central	Illinois	Renewable Portfolio Standard	Renewables Portfolio Standard	Solar Thermal Electric, Solar Photovoltaics, Wind (All), Biomass, Hydroelectric, Landfill Gas, Wind (Small), Anaerobic Digestion Landfill Gas, Anaerobic Digestion, Biodiesel.	Wind and Solar PV	Minimum Goal (Wind)	Minimum Wind (investor-owned electric utilities): 75% of annual requirement. Minimum Wind (Alternative retail electric suppliers): 60% of annual requirement. Minimum PV (All): 6% of annual requirement in compliance year. 30 million in the Renewable Energy Resources Fund to the Illinois Power Agency for the purchase of Solar PV.
East North Central	Ohio	Alternative Energy Portfolio Standard	Renewables Portfolio Standard	Geothermal Electric, Solar Thermal Electric, Solar Photovoltaics, Wind (All), Biomass, Hydroelectric, Municipal Solid Waste, Combined Heat & Power, Fuel Cells using Non-Renewable Fuels, Landfill Gas, Anaerobic Digestion, Fuel Cells using Renewable Fuels, Microturbines.	Solar PV	Minimum Goal and varied ACP	Solar-Electric: 0.5% by 2026. The alternative compliance payment (ACP) for the renewable portion was initially set at $45/megawatt-hour (MWh) but is adjusted annually by PUCO according to the federal Consumer Price Index with a price floor of $45/MWh. Solar Alternative Compliance Payment (SACP) 250/MWh in 2017, reduced every 2 years by $50/MWh until a $50/MWh SACP at 2026.
East North Central	Ohio	Solar Renewable Energy Certificates Program (SRECs)	Solar Renewable Energy Credit Program	Solar Photovoltaics	Solar PV	Minimum Goal and varied ACP	Mandates the creation of SRECs and Solar Alternative Compliance Payments (SACPs) to meet the solar energy generation goal of 0.5% by 2026. SREC prices vary based on market conditions.
Middle Atlantic	New Jersey	Renewables Portfolio Standard	Renewables Portfolio Standard	Geothermal Electric, Solar Thermal Electric, Solar Photovoltaics, Wind (All), Biomass, Hydroelectric, Municipal Solid Waste, Landfill Gas, Tidal, Wave, Wind (Small), Anaerobic Digestion, Fuel Cells using Renewable Fuels. Minimum Technology:	Solar and Offshore Wind	Minimum Goal and varied ACP	Solar-Electric: 4.1% by energy year 2027-2028. Offshore Wind: 1,100 MW. Yearly ACP or Solar ACP (SACP) remitted for the amount of RECs and solar RECs that were required but not submitted. The initial ACP and SACP levels were set at $50 per MWh and $300 per MWh respectively in 2004. These levels are renewable.

Region	State	Policy Name	Policy Type	Targeted Renewables	Prioritized Renewable	Prioritization Method	Prioritization Goals, Mandates and ACPs
Middle Atlantic	Pennsylvania	Alternative Energy Portfolio Standard	Renewables Portfolio Standard	Solar Water Heat, Solar Space Heat, Geothermal Electric, Solar Thermal Electric, Solar Thermal Process Heat, Solar Photovoltaics, Wind (All), Biomass, Hydroelectric, Geothermal Heat Pumps, Municipal Solid Waste, Combined Heat & Power, Fuel Cells using Non-Renewable Fuels, Landfill Gas, Wind (Small), Anaerobic Digestion, Fuel Cells using Renewable Fuels, Other Distributed Generation Technologies	Solar PV	Minimum Goal and varied ACP	0.5% Solar PV by compliance year 2020-2021. Alternative compliance payment (ACP) of $45 per megawatt-hour. ACP for solar PV is calculated as 200% times the sum of (1) the market value of solar AECs for the reporting period and (2) the levelized value of up-front rebates received by sellers of solar AECs. For the compliance year 2012/2013 ACP for solar PV amounted to $218.47. Monies received through the ACP will be transferred into Pennsylvania's Sustainable Energy Funds and used solely to support alternative-energy projects.
Mountain	Nevada	Portfolio Energy Credits (PEC)	Performance -Based Incentive	Solar - Passive, Solar Water Heat, Solar Space Heat, Geothermal Electric, Solar Thermal Electric, Solar Thermal Process Heat, Solar Photovoltaics, Wind (All), Biomass, Hydroelectric, Municipal Solid Waste, Landfill Gas, Solar Pool Heating, Wind (Small), Anaerobic Digestion.	Solar PV	Performance-Based Incentive/varied REC compliance multipliers	Nevada's renewable energy producers can earn PECs, which can then be sold to utilities that are required to meet Nevada's portfolio standard. One PEC represents one kilowatt-hour (kWh) of electricity generated, with the exception solar PV. Solar PV system installed on the premises of a retail customer on or before December 31, 2015 has a REC compliance multiplier of 2.4 . Each kilowatt-hour of electricity generated by eligible waste tire facilities is credited at 0.7 (reduction factor for biogas).
Mountain	Nevada	Energy Portfolio Standard	Renewables Portfolio Standard	Solar Water Heat, Solar Space Heat, Geothermal Electric, Solar Thermal Electric, Solar Thermal Process Heat, Solar Photovoltaics, Wind (All), Biomass, Hydroelectric, Geothermal Heat Pumps, Municipal Solid Waste, Landfill Gas, Solar Pool Heating, Geothermal Direct-Use, Anaerobic Digestion	Solar	Minimum Goal and varied ACP	NV Energy (formerly Nevada Power and Sierra Pacific Power) must use eligible renewable energy resources to supply a minimum percentage of the total electricity it sells - 25% by 2025; Solar: 6% of annual requirement for 2016-2025 (1.5% of total sales in 2025). Compliance multiplier for solar PV is 2.4 for customer-sited PV installed by 2015. This multiplier ended in 2015 for new systems but will continue for existing solar PV systems.
Mountain	New Mexico	Renewable Portfolio Standard	Renewables Portfolio Standard	Geothermal Electric, Solar Thermal Electric, Solar Photovoltaics, Wind (All), Biomass, Hydroelectric, Landfill Gas, Wind (Small), Anaerobic Digestion, Fuel Cells using Renewable Fuels Zero Emission Technology	Solar and Wind	Minimum Goal and varied REC compliance multipliers	For IOUs by 2020: Solar - 20% of RPS requirement (4% of sales); Wind: 30% of RPS requirement (6% of sales). Other renewables including geothermal, biomass and certain hydro facilities: (5%) ACP of 3.0 for solar developed and operational before January 1, 2012, by a distribution cooperative or through the wholesale contract obligation of the wholesale supplier. Utilities are excused from the diversification targets should costs of achieving them raise the cost of electricity by more than 2% or if the targets cannot be accomplished without impairing system reliability.

Region	State	Policy Name	Policy Type	Targeted Renewables	Prioritized Renewable	Prioritization Method	Prioritization Goals, Mandates and ACPs
New England	Massachusetts	Alternative Energy Portfolio Standard	Other Policy	Biomass, Geothermal Heat Pumps, Combined Heat & Power	Biomass, Geothermal Heat Pumps, Combined Heat & Power	Minimum Goal	5% of the state's electric load with "alternative energy" by 2020. Alternative energy includes combined heat and power (CHP) projects, flywheel energy storage, energy efficient steam technology and renewable technologies that generate useful thermal energy.
New England	Massachusetts	Renewable Portfolio Standard	Renewables Portfolio Standard	Geothermal Electric, Solar Thermal Electric, Solar Photovoltaics, Wind (All), Biomass, Hydroelectric, Municipal Solid Waste, Landfill Gas, Tidal, Wave, Ocean Thermal, Wind (Small), Hydroelectric (Small), Anaerobic Digestion, Fuel Cells using Renewable Fuels.	Solar PV	Minimum Goal, and varied ACP	In-State Solar PV: Mandated target of 1600 MW by 2020. ACP New Resources: $67.70/MWh, Existing Resources: $27.79/MWh, Waste Energy: $11.12/MWh, Solar Carve-Out for New Resources: $448.00/MWh; Solar Carve-Out for existing : $350.00/MWh
New England	Connecticut	Renewables Portfolio Standard	Renewables Portfolio Standard	Geothermal Electric, Solar Thermal Electric, Solar Photovoltaics, Wind (All), Biomass, Hydroelectric, Municipal Solid Waste, Combined Heat & Power, Fuel Cells using Non-Renewable Fuels, Landfill Gas, Tidal, Wave, Ocean Thermal, Wind (Small), Anaerobic Digestion, Fuel Cells using Renewable Fuels	Combined heat and power (CHP) systems and Solar PV	Minimum Goals	Requires each electric supplier and wholesale supplier to obtain at least 4% of its retail; Goal of 300 MW of new solar PV by 2022. $55/MWh fixed compliance payment for unachieved goal.
New England	Maine	Renewable Portfolio Standard	Renewables Portfolio Standard	Geothermal Electric, Solar Thermal Electric, Solar Photovoltaics, Wind (All), Biomass, Hydroelectric, Municipal Solid Waste, Combined Heat & Power, Fuel Cells using Non-Renewable Fuels (up to 100 MW), Landfill Gas, Tidal, Fuel Cells using Renewable Fuels, Other Distributed Generation Technologies.	Wind	Minimum Goal	There are three goals for wind energy development in Maine: (1) at least 2,000 MW of installed capacity by 2015; (2) at least 3,000 MW of installed capacity by 2020, of which there is a potential to produce 300 MW from facilities located in coastal waters or offshore; and (3) At least 8,000 MW of installed capacity by 2030, of which 5,000 MW should be from facilities in coastal waters or offshore.
New England	New Hampshire	Renewable Portfolio Standard	Renewables Portfolio Standard	Solar Water Heat, Solar Space Heat, Solar Thermal Electric, Solar Thermal Process Heat, Solar Photovoltaics, Wind (All), Biomass, Hydroelectric, Hydrogen, Geothermal Heat Pumps, Combined Heat & Power, Landfill Gas, Tidal, Wave, Ocean Thermal, Wind (Small), Hydroelectric (Small), Anaerobic Digestion, Fuel Cells	Solar, Hydropower and Biomass	Minimum Goal and varied ACP	Solar Thermal Energy: 2.2% by 2023 (or $25.46/MWh not met in 2023). New Solar-Electric: 0.7% by 2020 (or $56.02/MWh not met in 2020). Existing Biomass: 8% by 2017 (or 55/MWh not met in 2017); . Existing Hydro: 1.5% by 2015 (or $27.49/MWh not met in 2015).

Region	State	Policy Name	Policy Type	Targeted Renewables	Prioritized Renewable	Prioritization Method	Prioritization Goals, Mandates and ACPs
				using Renewable Fuels, Microturbines Biodiesel			
South Atlantic	Delaware	Renewables Portfolio Standard	Renewables Portfolio Standard	Geothermal Electric, Solar Thermal Electric, Solar Photovoltaics, Wind (All), Biomass, Hydroelectric, Fuel Cells using Non-Renewable Fuels, Landfill Gas, Tidal, Wave, Ocean Thermal, Wind (Small), Anaerobic Digestion, Fuel Cells using Renewable Fuels.	Solar PV and Wind	Minimum Goals (Solar PV) Varied REC Compliance Multipliers (Solar PV, Wind) Varied ACP (Solar)	Minimum PV: 3.5% by compliance year 2025-2026. PV target is not in addition to the main target, it is included within it. REC Compliance Multipliers: 300% for in-state customer sited PV and fuel cells, 150% for wind turbines sited in DE, 350% for offshore wind, 110% for solar or wind installation in DE with 50% equipment manufactured in DE, 110% for solar or wind installation with a minimum of 75% local workforce Alternative Compliance Payment: ACP: $25/MWh (1st year), $50/MWh (2nd year), $80/MWh (3rd year onwards). Solar ACP (SACP): $400/MWh (1st year), $450/MWh (2nd year), $500/MWh (3rd year onwards)
South Atlantic	Maryland	Renewable Energy Portfolio Standard	Renewables Portfolio Standard	Divided into two tiers based on the electricity generation resource. Tier 1 includes solar, wind, biomass, anaerobic decomposition, geothermal, ocean, fuel cells powered through renewables, small hydro, poultry-litter incineration facilities, waste-to-energy facilities and Tier 2 includes hydroelectric power other than pump-storage generation.	Solar and Wind	Minimum Goal and varied ACP	Minimum Goals: Solar: 2.5% by 2020, Offshore Wind (limited to facilities located on the outer continental shelf between 10 and 30 miles off the coast of Maryland): 2.5% maximum beginning in 2017. Alternative Compliance Payment: Tier 1 (Non-Solar) - $37.5 per MWh, Tier 1 Solar -currently $195 per MWh, Tier 2 - hydroelectric power other than pump-storage generation -$15 per MWh, Tier 1 Industrial Process Load- IPL : $2.50/MWh.
South Atlantic	North Carolina	Renewable Energy and Energy Efficiency Portfolio Standard	Renewables Portfolio Standard	Solar Water Heat, Solar Space Heat, Geothermal Electric, Solar Thermal Electric, Solar Thermal Process Heat, Solar Photovoltaics, Wind (All) - up to 10 MW, Biomass, Hydrogen, Combined Heat & Power, Landfill Gas, Tidal, Wave, Wind (Small), Hydroelectric (Small), Anaerobic Digestion.	Solar and Swine Waste	Minimum Goal and varied REC compliance multipliers	Solar: 0.2% by 2018 independently by each utility. Biomass from Swine Waste: 0.2% by 2020. Poultry Waste: 900,000 MWh by 2016 total from all utilities. Triple credit for RECs generated by the first 20 MW of a biomass facility located at a "cleanfields renewable energy demonstration park". Goal/prioritization Driver: Potential driven based on high swine and poultry farms within the state.
South Atlantic	Virginia	Voluntary Renewable Energy Portfolio Goal	Renewables Portfolio Standard	Geothermal Electric, Solar Thermal Electric, Solar Photovoltaics, Wind (All), Biomass, Hydroelectric, Landfill Gas, Tidal, Wave, Anaerobic Digestion.	Wind, Solar and Animal Waste	Varied REC Compliance Multiplier	300% (triple) credit for energy derived from offshore wind. 200% (double) credit for energy derived from solar, onshore wind, animal waste

Region	State	Policy Name	Policy Type	Targeted Renewables	Prioritized Renewable	Prioritization Method	Prioritization Goals, Mandates and ACPs
South Atlantic	Washington DC	Renewable Portfolio Standard	Renewables Portfolio Standard	Solar Water Heat, Solar Space Heat, Geothermal Electric, Solar Thermal Electric, Solar Thermal Process Heat, Solar Photovoltaics, Wind (All), Biomass, Hydroelectric, Landfill Gas, Tidal, Wave, Ocean Thermal, Wind (Small), Fuel Cells using Renewable Fuels	Solar, including solar thermal.	Minimum Goal and Varied ACP	Minimum Solar (PV or Thermal): 5.0% by 2032. There is a non-compliance fee if the percentage is not met. $50 per MWh shortfall from Tier I resources; $10 per MWh shortfall from Tier II resources; $500 per MWh shortfall from Solar carveout (2016)
West North Central	Minnesota	Renewable Energy Standard	Renewables Portfolio Standard	Solar Thermal Electric, Solar Photovoltaics, , Biomass, Hydroelectric, Hydrogen, Municipal Solid Waste, Landfill Gas, Wind, Anaerobic Digestion Landfill Gas, Co-Firing, Anaerobic Digestion.	Solar and Wind	Minimum Goal	Statewide goal: 10% solar by 2030. Minimum goal for Minnesota's nuclear utility, Xcel Energy: Wind or Solar: 25% by 2020. Minimum goal for IOUs:1.5% from solar by 2020, 10% of which must be met with systems 20 kW or less.
West North Central	Missouri	Renewable Energy Standard	Renewables Portfolio Standard	Solar Thermal Electric, Solar Photovoltaics, Wind (All), Biomass, Hydroelectric, Municipal Solid Waste, Landfill Gas, Hydroelectric (Small), Anaerobic Digestion, Fuel Cells using Renewable Fuels.	Solar PV	Minimum Goal	Solar-Electric: 2% of annual requirement (0.3% of sales in 2021).
West South Central	Texas	Renewable Generation Requirement	Renewables Portfolio Standard	Solar Water Heat, Geothermal Electric, Solar Thermal Electric, Solar Photovoltaics, Wind (All), Biomass, Hydroelectric, Geothermal Heat Pumps, Landfill Gas, Tidal, Wave, Ocean Thermal, Wind (Small)	Non Wind	Voluntary minimum Goal and varied REC Compliance Multiplier	Non-Wind voluntary renewable energy goal of 500 MW by 2015. Non-wind renewable energy generated after Dec 31, 2007 has double the compliance value of electricity generated by wind.

Source: DSIRE Database, Last Accessed September 2017(N.C. Clean Energy Technology Center at the N.C. State University, 2017)

9.2 Similar AHP Studies

Author	Country Focus	Energy Alternatives	Criteria used in Evaluation	Benefits/Cost (B/C) Inclusion	Energy Potential Analysis	Scoring Method for Criteria Attributes	Study Conclusions
Okioga, 2017 (This Study)	United States	Solar PV, CSP, onshore wind, offshore wind, geothermal, and biomass.	**Technical Potential:** Thousand GWh of technical potential energy which accounts for resource potential constraints, such as capacity factors, land use constraints (wetlands, water bodies etc.) as detailed by Lopez et al. (2012) **Environmental:** Land Requirement - **S**quare kilometers of impacted land per terawatt-hour per year (km2/TW hr/yr) as projected for 2030; Emissions - grams of CO2 equivalent per kilowatt-hour of generation (g CO2eq/kWh); Water Demand - Max Water Consumed (Cooling and Generation. Gal/MWh) **Public Perception:** survey responses expressed as a % number of respondents that considered the alternative evaluated the most important.	B/C Analysis Conducted. Cost is not included as part of the criteria. 2012 Capital costs ($/kW)) are used for the analysis.	Energy Potential considered most important criteria. Variation in regions taken into consideration.	Quantitative data.	Study create benefits/costs-incentives/mandates (BCIM) model for selecting incentives and mandates based on a benefits/costs evaluation.

Author	Country Focus	Energy Alternatives	Criteria used in Evaluation	Benefits/Cost (B/C) Inclusion	Energy Potential Analysis	Scoring Method for Criteria Attributes	Study Conclusions
Stein E.W., 2013	United States	Wind, solar PV, hydropower, geothermal and biomass energy, together with nuclear, oil, natural gas and coal	**Financial**: Total overnightcost($/kW), Variable O&M($2009mills/kWh), Fixed O&M($2009/kW), Fuel costs($/MBtu). **Technical:** Average efficiency coefficient and Average capacity factor (%) **Environmental:** Average external costs ($), Loss of life expectancy(LLE) **Social/Economic/political:** Job creation, Net import % of energy, Fuel reserveyears.	No B/C Analysis	Did not consider resource potential.	Quantitative data.	AHP analysis was conducted using a software Super Decisions™ . A sensitivity analysis was done by changing the ranking order for the importance of criteria, using 4 different rank orders, and a balanced scenario, where all criteria had equal weights. Wind and solar were the top energies for all scenarios. Study recommended targetting incentives for wind, solar, hydro and geothermal but did not offer suggestions for the incentives criteria.

Author	Country Focus	Energy Alternatives	Criteria used in Evaluation	Benefits/Cost (B/C) Inclusion	Energy Potential Analysis	Scoring Method for Criteria Attributes	Study Conclusions
Ahmad S., and Tahar R.M., 2014	Malaysia	Solar PV, biomass (biogas and municipal solid waste), hydropower (mini and micro only large excluded) and wind energy	Investment Costs, CO_2 emissions, Efficiency, Land Requirements, Job Creation, Operational life and Construction Time	No B/C Analysis. Investment cost was the most important element for the alternatives ranking	The study indicated that investment costs also represented the resource potential.	Quantitative data.	Quantitative data was also used for investment costs, efficiency, land requirements, job creation potential, average operational life and construction time for renewable technologies. Solar power and biomass emerged as the preferred options over hydropower and wind. Study suggested that the "Malaysia's government should focus on the development and utilization of these renewable resources."

Author	**Country Focus**	**Energy Alternatives**	**Criteria used in Evaluation**	**Benefits/Cost (B/C) Inclusion**	**Energy Potential Analysis**	**Scoring Method for Criteria Attributes**	**Study Conclusions**
Haddad B., Liazid A., and Ferreira P, 2017	Algeria	Solar, wind, biomass, geothermal and hydropower	**Technical**: Technology maturity, Energy systems safety, Reliability, Energy Production Capacity; **Economic:** Investment Cost, Operation and Maintenance (emphasis on investment costs), Life Service, Payback Period; **Environmental**: Impact on land use, water consumption, noise, visual impact, solid waste and ground contamination or effects on the biodiversity, Potential for reduction of greenhouse gases and **Sociopolitical criteria:** Social Benefits (job creation, social welfare and local income etc.); Social Acceptability, Political acceptance.	No B/C Analysis	Did not consider resource potential.	Qualitative data: Pairwise comparison scores computed based on expert judgement from 11 energy policy representatives.	Social and environment criteria found to be the most important criteria. Investment costs were the most important sub criteria under the economic cluster, as the technologies are capital intensive with low operation and maintenance costs. GHG emission was not found to be important since all renewable energy technologies reduce the impact of GHG emissions. Solar and wind ranked highest and, biomass ranked lowest but benefits related to waste management are acknowledged. Study recommended Solar and Wind for policy related to renewable energy development.

Author	Country Focus	Energy Alternatives	Criteria used in Evaluation	Benefits/Cost (B/C) Inclusion	Energy Potential Analysis	Scoring Method for Criteria Attributes	Study Conclusions
Demirtas O., 2013	Turkey	Geothermal, hydropower, wind, solar and biomass	**Technical:** Energy Production Capacity, Technological Maturity Reliability, Safety **Economical:** Investment Cost Operation and Maintenance Cost Service Life Payback Period **Environmental:** Impact on Ecosystem, CO_2 Emission **Social:** Social Benefits Social Acceptability	No B/C Analysis		Qualitative data: Pairwise comparison scores computed from expert feedback from 10 management personnel from the energy sector.	Based on the high potential of wind energy and lower cost, it ranked highest. Study noted that since wind energy is rapidly advancing in technology, it installation costs have reduced and encourages setting targets for wind energy generation.
Daniel J., Vishal N.V.R., Albert B., Selvarsan I., 2010	India	Wind, biomass, and Solar (both solar PV and solar Thermal)	Costs, %Estimated distribution, Installed Capacity, Estimated potential, Private sector participation, Reliability factor, Social Acceptance, Incentives and other benefits from government, Environmental impacts	No B/C Analysis. Cost was the most important criteria.	Expressed as part of the qualitative data.	Qualitative Data: Pairwise comparison scores established from brainstorming session with peers.	Cost was the top ranked criteria for evaluation. All criteria were expressed qualitatively. Wind energy ranked the highest, followed by biomass then solar. The study suggests to consider avenues for "bringing solar and biomass energy in equal competence with wind energy"

Author	Country Focus	Energy Alternatives	Criteria used in Evaluation	Benefits/Cost (B/C) Inclusion	Energy Potential Analysis	Scoring Method for Criteria Attributes	Study Conclusions
Kabir A B M Z and Shihan S M A, 2003	Bangladesh	Solar, wind and biogas	**Cost** (Per Unit of Power) **Social Impact**: People's Acceptability, Quality of Life; **Technical**: Equipment Design and Complexity, Plant Design, Equipment and Parts Availability, Plant Safety, Maintainability and Training Requirement **Location:** Flexibility and Plant Size **Environment:** Impact on Ecosystem and Noise	No B/C Analysis. Cost was the most important criteria.	Energy Potential not considered.	Qualitative Data used: Pairwise comparison scores computed based on expert judgement.	Solar ranked highest followed by biogas, and wind energy.
Amer M. and Daim T.U., 2011	Pakistan	Biomass, wind, solar thermal and solar PV energy	**Economical:** R&D cost, Capital cost, O&M cost, Economic value/viability, Electricity cost. **Technical:** Technology maturity, Efficiency/capacity factor, Reliability, Deployment time/duration, Expert human resource , Distribution grid availability, Resource availability. **Social:** Social benefits, Job creation, Social acceptance. Environmental: Land requirement, Emissions (greenhouse gasses etc.), Stress on eco-system. **Political:** National energy security, National economic benefits	No B/C Analysis. Cost was the most important criteria.	Considered as one of the criteria (resource availability) expressed qualitatively. No variability in resource potential by region considered.	Qualitative Data used: Pairwise comparison scores computed based on expert judgement.	Biomass ranked highest due to costs, potential and employment opportunities. Author suggests not to select a single technology option but develop a combination of multiple alternatives for diversity. AHP recommended for national renewable energy policy development.

9.3 Renewable Energy Social and Environmental Impacts

Criteria	Solar PV	Solar Concentrated	Onshore wind	Offshore	Biomass	Geothermal
General perception based on visual and noise disturbances	Large visual footprint worsened by open and flat landscape. Unnatural/regular geometry, glare from highly reflective surfaces (g). Generally quiet. No noise at night when system is unable to operate	Potentially significant visual impacts due to solar towers. Generally quiet. No noise at night when system is unable to operate	Significant visual pollution due to shadow flicker, tall wind turbines. Can cause significant amounts of noise pollution when located close to human populations	Potentially significant visual impacts on coastal lands. Generally located far from human populations for noise to be a big concern.	Little visual impacts resulting from biomass facility infrastructure, possibility of visual impacts from high growing energy crops etc. Some noise expected in biomass plant operation systems caused by steam generators, wood chippers etc. but this could be easily controlled to acceptable levels.	Little visual impacts from facilities pipe systems. The main visual impact is during the construction phase due to drilling operation. Normal operation produces less noise than the produced by "leaves rustling from breeze" (c).
Land-use changes and effects	Requires large areas of land except when installed on rooftops/buildings as this is already disturbed land.	Requires large tracks of land and may compete with other more profitable uses of land.	Competition with alternative/more profitable uses for land	May compete with other land uses such as fishing, recreational activities, navigation, and aquaculture.	Competition for land-use such as for food-based crops etc.	Causes damage to natural geothermal features, land subsidence, seismicity;
Pollution/Emissions	No pollution emitted in operation. However panels are often made from silicon and other metals that are potentially toxic.	No pollution emitted in operation. Some pollution from manufacturing process.	No pollution emitted in operation. Some pollution from manufacturing process.	No pollution emitted in operation. Some pollution from manufacturing process.	Increased need for pesticides and fertilizers for plant-based biomass. Biomass derived from waste products could contain contaminants. Pollution from biomass combustion. Not totally clean when burned (NOx, soot, ash, CO, CO2 etc.)	Release of harmful gases into the atmosphere, surface and subsurface waters (e)
Effects on Flora and Fauna	Little impact provided installation is not in an environmentally sensitive area (g).	Physical Injury/death - Species kill from concentrated rays, Habitat Loss	Localized impact on weather potentially affecting flora. Physical Injury/death to birds, bats and other flying animals from blades etc.;	Physical Injury/death - from blades etc.;. Noise effects on marine fauna including masking, disturbance and displacement etc. (a, b). 3. Electromagnetic fields induced in moving water (b)	Deforestation; Disruption to natural nutrient cycles. Can result in soil erosion.	Loss of rare thermophilic plants and algae (d).Discharge of hot water and/or toxic geothermal fluid from power generation cause impact fauna.
Water Demand	NA (No water used in generating)	Water required for cooling and turning steam turbines.	NA	NA	High water demand e.g. for cooling, growing energy crops etc.	NA (External surface water not required under normal conditions). (f)

Notes:

(a) S. Robinson, National Physical Laboratory, 2012. Noise issues for offshore windfarms Basic acoustics: what needs to be measured and why. Retrieved from http://www.ewea.org/events/workshops/wp-content/uploads/2012/12/EWEA-Noise-Workshop-Oxford-2012-5-1-Stephen-Robinson.pdf

(b) Bergström, L. et al., 2014. Effects of offshore wind farms on marine wildlife—a generalized impact assessment. Environmental Research Letters. Environ. Res. Lett. 9 (2014) 034012 (12pp). Retrieved from http://iopscience.iop.org/1748-9326/9/3/034012/pdf/1748-9326_9_3_034012.pdf

(c) Kagel A., Bates D., and Gawell K. Geothermal Energy Association (2007). A Guide to Geothermal Energy and the Environment . Retrieved from http://geo-energy.org/reports/environmental%20guide.pdf

(d) http://www.savingiceland.org/wp-content/uploads/2008/01/NEGATIVE%20ASPECTS%20OF%20GEOTHERMAL%20POWER%20GENERATION.pdf

(e) Rybach L. 2003. Geothermal energy: sustainability and the environment. Elsevier Ltd.

(f)) Goff SJ, 2004. Environmental Effects of Geothermal Power - Encyclopedia of Life Support Systems (EOLSS).

(g) Tsoutsosa T., Frantzeskakib N., and Gekas V. 2003. Environmental impacts from the solar energy technologies. 2003 Elsevier Ltd. Energy Policy 33 (2005) 289–296. Retrieved from http://www.circleofblue.org/waternews/wp-content/uploads/2010/08/Tsoutsos_Frantzeskaki_2006_EIA_ST.pdf

9.4 Renewable Energy Potentials by State

State	Total Utility Scale PV (GWh)	CSP (GWh)	Onshore Wind (GWh)	Offshore Wind (GWh)	Biopower Total (GWh)	Geothermal Total (GWh)
Alabama	3,758,165	0	283	0	12,727	535,490
Alaska	8,283,142	0	1,373,433	NA	575	15,437
Arizona	12,011,736	12,544,334	26,036	NA	1,925	1,247,477
Arkansas	5,023,834	0	22,892	NA	15,444	628,622
California	9,208,336	8,490,916	89,862	2,662,580	27,919	1,475,100
Colorado	10,297,717	9,154,524	1,096,036	NA	4,138	1,260,612
Connecticut	33,961	0	62	26,545	909	56,078
Delaware	289,375	0	22	60,654	898	22,813
District of Columbia	2,499	0	0	NA	66	698
Florida	5,274,121	359	1	34,684	13,358	374,161
Georgia	5,566,467	0	323	220,807	16,903	353,206
Hawaii	41,758	15,370	7,787	2,836,735	724	20,632
Idaho	3,964,094	3,502,877	44,320	NA	5,958	1,010,462
Illinois	8,224,624	0	649,468	66,070	31,960	676,056
Indiana	4,992,152	0	377,604	166	17,920	434,258
Iowa	7,029,897	0	1,723,588	NA	28,928	606,390
Kansas	14,540,817	7,974,256	3,101,576	NA	12,857	989,676
Kentucky	1,862,803	0	147	NA	8,322	484,659
Louisiana	4,184,643	0	935	1,200,699	14,873	484,271
Maine	1,105,986	0	28,743	631,960	4,398	377,075
Maryland	629,350	0	3,632	200,852	3,329	86,649
Massachusetts	111,397	0	2,827	799,344	2,149	92,227
Michigan	5,290,013	0	143,908	1,739,801	11,897	457,850

State	Total Utility Scale PV (GWh)	CSP (GWh)	Onshore Wind (GWh)	Offshore Wind (GWh)	Biopower Total (GWh)	Geothermal Total (GWh)
Minnesota	10,840,506	0	1,428,525	100,455	21,391	369,785
Mississippi	5,016,233	0	0	10,172	15,287	559,056
Missouri	5,381,978	0	689,519	NA	13,986	835,445
Montana	8,200,906	1,540,288	2,746,272	NA	5,072	1,653,852
Nebraska	9,285,048	4,846,929	3,011,253	NA	17,023	927,996
Nevada	8,650,115	8,295,753	17,709	NA	614	1,307,496
New Hampshire	63,453	0	5,706	14,478	1,343	104,314
New Jersey	499,848	0	317	429,808	3,523	35,230
New Mexico	16,396,412	16,812,349	1,399,157	NA	949	1,430,912
New York	1,574,149	0	63,566	614,280	8,509	375,401
North Carolina	4,329,556	0	2,037	1,269,627	16,650	420,741
North Dakota	9,741,236	36,050	2,537,825	NA	8,216	820,226
Ohio	3,742,742	0	129,143	170,561	14,372	495,922
Oklahoma	9,404,404	5,068,036	1,521,652	NA	5,094	779,667
Oregon	3,774,585	2,812,126	68,767	962,723	14,684	932,305
Pennsylvania	631,733	0	8,231	23,571	13,446	327,341
Rhode Island	17,135	0	130	89,115	618	11,492
South Carolina	2,803,221	0	428	542,218	8,415	364,105
South Dakota	10,015,529	1,629,660	2,901,858	NA	8,615	921,973
Tennessee	2,295,918	0	766	NA	8,080	428,380
Texas	39,366,982	22,786,750	5,552,400	1,101,063	21,976	3,030,251
Utah	5,222,884	5,067,547	31,552	NA	862	952,362
Vermont	57,475	0	7,796	NA	695	35,617
Virginia	1,932,186	0	4,589	361,054	10,365	290,737
Washington	1,785,440	161,713	47,250	488,025	13,826	565,571

State	Total Utility Scale PV (GWh)	CSP (GWh)	Onshore Wind (GWh)	Offshore Wind (GWh)	Biopower Total (GWh)	Geothermal Total (GWh)
West Virginia	59,938	0	4,952	NA	2,688	261,376
Wisconsin	5,111,137	0	255,266	317,755	13,295	647,173
Wyoming	5,736,007	5,406,407	1,653,857	NA	553	1,071,452
TOTAL	283,663,643	116,146,245	32,784,005	16,975,802	488,326	31,646,078

9.5 Onshore Wind Capital Costs

State	Region	City	Base Project Cost ($/kW)	Location Percent Variation	Delta Cost Difference ($/kW)	Total Location Project Cost ($/kW)
Alabama	East South Central	Huntsville	2,213	-4.50%	-100	2,113
Alaska	Pacific	Anchorage	2,213	28.00%	620	2,833
Alaska	Pacific	Fairbanks	2,213	49.90%	1,104	3,317
Arizona	Mountain	Phoenix	2,213	-3.10%	-68	2,145
Arkansas	West South Central	Little Rock	2,213	-3.60%	-81	2,132
California	Pacific	Bakersfield	2,213	11.60%	256	2,469
California	Pacific	Los Angeles	2,213	13.30%	294	2,507
California	Pacific	Redding	2,213	10.00%	221	2,434
California	Pacific	Sacramento	2,213	11.10%	245	2,458
California	Pacific	San Francisco	2,213	19.80%	439	2,652
Colorado	Mountain	Denver	2,213	2.00%	44	2,257
Connecticut	New England	Hartford	2,213	7.20%	159	2,372
Delaware	South Atlantic	Dover	2,213	5.00%	112	2,325
District of Columbia Washington	South Atlantic		2,213	8.40%	185	2,398
Florida	South Atlantic	Tallahassee	2,213	-5.30%	-116	2,097
Florida	South Atlantic	Tampa	2,213	-2.30%	-51	2,162
Georgia	South Atlantic	Atlanta	2,213	-5.20%	-114	2,099
Hawaii	Pacific	Honolulu	2,213	30.10%	667	2,880
Idaho	Mountain	Boise	2,213	3.20%	71	2,284
Illinois	East North Central	Chicago	2,213	15.20%	336	2,549
Indiana	East North Central	Indianapolis	2,213	-0.20%	-4	2,209

State	Region	City	Base Project Cost ($/kW)	Location Percent Variation	Delta Cost Difference ($/kW)	Total Location Project Cost ($/kW)
Iowa	West North Central	Davenport	2,213	4.70%	103	2,316
Iowa	West North Central	Waterloo	2,213	2.30%	51	2,264
Kansas	West North Central	Wichita	2,213	1.70%	37	2,250
Kentucky	East South Central	Louisville	2,213	-3.60%	-80	2,133
Louisiana	West South Central	New Orleans	2,213	-6.50%	-144	2,069
Maine	New England	Portland	2,213	6.20%	137	2,350
Maryland	South Atlantic	Baltimore	2,213	1.40%	30	2,243
Massachusetts	New England	Boston	2,213	11.60%	256	2,469
Michigan	East North Central	Detroit	2,213	2.70%	59	2,272
Michigan	East North Central	Grand Rapids	2,213	-1.30%	-29	2,184
Minnesota	West North Central	St. Paul	2,213	9.60%	213	2,426
Mississippi	East South Central	Jackson	2,213	-4.20%	-92	2,121
Missouri	West North Central	Kansas City	2,213	1.30%	28	2,241
Missouri	West North Central	St. Louis	2,213	3.20%	72	2,285
Montana	Mountain	Great Falls	2,213	4.50%	99	2,312
Nebraska	West North Central	Omaha	2,213	3.60%	81	2,294
Nevada	Mountain	Las Vega	2,213	9.40%	208	2,421
New Hampshire	New England	Concord	2,213	5.40%	119	2,332
New Jersey	Middle Atlantic	Newark	2,213	12.40%	274	2,487
New Mexico	Mountain	Albuquerque	2,213	3.80%	84	2,297
New York	Middle Atlantic	New York	2,213	27.10%	600	2,813
New York	Middle Atlantic	Syracuse	2,213	1.10%	25	2,238

State	Region	City	Base Project Cost ($/kW)	Location Percent Variation	Delta Cost Difference ($/kW)	Total Location Project Cost ($/kW)
North Carolina	South Atlantic	Charlotte	2,213	-4.90%	-109	2,104
North Dakota	West North Central	Bismarck	2,213	2.20%	48	2,261
Ohio	East North Central	Cincinnati	2,213	-2.80%	-61	2,152
Oregon	Pacific	Portland	2,213	8.90%	198	2,411
Pennsylvania	Middle Atlantic	Philadelphia	2,213	6.20%	136	2,349
Pennsylvania	Middle Atlantic	Wilkes-Barre	2,213	-1.70%	-38	2,175
Rhode Island	New England	Providence	2,213	2.40%	53	2,266
South Carolina	South Atlantic	Spartanburg	2,213	-6.80%	-149	2,064
South Dakota	West North Central	Rapid City	2,213	0.90%	19	2,232
Tennessee	East South Central	Knoxville	2,213	-5.60%	-124	2,089
Texas	West South Central	Houston	2,213	-5.90%	-131	2,082
Utah	Mountain	Salt Lake City	2,213	4.00%	89	2,302
Vermont	New England	Burlington	2,213	3.20%	70	2,283
Virginia	South Atlantic	Alexandria	2,213	2.20%	48	2,261
Virginia	South Atlantic	Lynchburg	2,213	-4.30%	-94	2,119
Washington	Pacific	Seattle	2,213	4.80%	105	2,318
Washington	Pacific	Spokane	2,213	5.40%	120	2,333
West Virginia	South Atlantic	Virginia Charleston	2,213	0.00%	0	2,213
Wisconsin	East North Central	Green Bay	2,213	1.20%	26	2,239
Wyoming	Mountain	Cheyenne	2,213	4.30%	95	2,308

(Data Source: EIA, 2013)

9.6 Location-Based Capital Costs for Onshore Wind

State	Region	City	Base Project Cost ($/kW)	Location Percent Variation (%)	Delta Cost Difference ($/kW)	Total Location Project Cost ($/kW)
Alabama	East South Central	Huntsville	2,213	-5%	-100	2,113
Alaska	Pacific	Anchorage	2,213	28%	620	2,833
Alaska	Pacific	Fairbanks	2,213	50%	1,104	3,317
Arizona	Mountain	Phoenix	2,213	-3%	-68	2,145
Arkansas	West South Central	Little Rock	2,213	-4%	-81	2,132
California	Pacific	Bakersfield	2,213	12%	256	2,469
California	Pacific	Los Angeles	2,213	13%	294	2,507
California	Pacific	Redding	2,213	10%	221	2,434
California	Pacific	Sacramento	2,213	11%	245	2,458
California	Pacific	San Francisco	2,213	20%	439	2,652
Colorado	Mountain	Denver	2,213	2%	44	2,257
Connecticut	New England	Hartford	2,213	7%	159	2,372
Delaware	South Atlantic	Dover	2,213	5%	112	2,325
District of Columbia Washington	South Atlantic		2,213	8%	185	2,398
Florida	South Atlantic	Tallahassee	2,213	-5%	-116	2,097
Florida	South Atlantic	Tampa	2,213	-2%	-51	2,162
Georgia	South Atlantic	Atlanta	2,213	-5%	-114	2,099
Hawaii	Pacific	Honolulu	2,213	30%	667	2,880
Idaho	Mountain	Boise	2,213	3%	71	2,284
Illinois	East North Central	Chicago	2,213	15%	336	2,549
Indiana	East North Central	Indianapolis	2,213	0%	-4	2,209

State	Region	City	Base Project Cost ($/kW)	Location Percent Variation (%)	Delta Cost Difference ($/kW)	Total Location Project Cost ($/kW)
Iowa	West North Central	Davenport	2,213	5%	103	2,316
Iowa	West North Central	Waterloo	2,213	2%	51	2,264
Kansas	West North Central	Wichita	2,213	2%	37	2,250
Kentucky	East South Central	Louisville	2,213	-4%	-80	2,133
Louisiana	West South Central	New Orleans	2,213	-7%	-144	2,069
Maine	New England	Portland	2,213	6%	137	2,350
Maryland	South Atlantic	Baltimore	2,213	1%	30	2,243
Massachusetts	New England	Boston	2,213	12%	256	2,469
Michigan	East North Central	Detroit	2,213	3%	59	2,272
Michigan	East North Central	Grand Rapids	2,213	-1%	-29	2,184
Minnesota	West North Central	St. Paul	2,213	10%	213	2,426
Mississippi	East South Central	Jackson	2,213	-4%	-92	2,121
Missouri	West North Central	Kansas City	2,213	1%	28	2,241
Missouri	West North Central	St. Louis	2,213	3%	72	2,285
Montana	Mountain	Great Falls	2,213	4%	99	2,312
Nebraska	West North Central	Omaha	2,213	4%	81	2,294
Nevada	Mountain	Las Vega	2,213	9%	208	2,421
New Hampshire	New England	Concord	2,213	5%	119	2,332
New Jersey	Middle Atlantic	Newark	2,213	12%	274	2,487
New Mexico	Mountain	Albuquerque	2,213	4%	84	2,297
New York	Middle Atlantic	New York	2,213	27%	600	2,813
New York	Middle Atlantic	Syracuse	2,213	1%	25	2,238

State	Region	City	Base Project Cost ($/kW)	Location Percent Variation (%)	Delta Cost Difference ($/kW)	Total Location Project Cost ($/kW)
North Carolina	South Atlantic	Charlotte	2,213	-5%	-109	2,104
North Dakota	West North Central	Bismarck	2,213	2%	48	2,261
Ohio	East North Central	Cincinnati	2,213	-3%	-61	2,152
Oregon	Pacific	Portland	2,213	9%	198	2,411
Pennsylvania	Middle Atlantic	Philadelphia	2,213	6%	136	2,349
Pennsylvania	Middle Atlantic	Wilkes-Barre	2,213	-2%	-38	2,175
Rhode Island	New England	Providence	2,213	2%	53	2,266
South Carolina	South Atlantic	Spartanburg	2,213	-7%	-149	2,064
South Dakota	West North Central	Rapid City	2,213	1%	19	2,232
Tennessee	East South Central	Knoxville	2,213	-6%	-124	2,089
Texas	West South Central	Houston	2,213	-6%	-131	2,082
Utah	Mountain	Salt Lake City	2,213	4%	89	2,302
Vermont	New England	Burlington	2,213	3%	70	2,283
Virginia	South Atlantic	Alexandria	2,213	2%	48	2,261
Virginia	South Atlantic	Lynchburg	2,213	-4%	-94	2,119
Washington	Pacific	Seattle	2,213	5%	105	2,318
Washington	Pacific	Spokane	2,213	5%	120	2,333
West Virginia	South Atlantic	Virginia Charleston	2,213	0%	0	2,213
Wisconsin	East North Central	Green Bay	2,213	1%	26	2,239
Wyoming	Mountain	Cheyenne	2,213	4%	95	2,308
Puerto Rico	Cayey	Middle Atlantic	2,213	8%	170	2,383

(Data Source: EIA, 2013)

9.7 Location-Based Capital Costs for Offshore Wind

State	City	Region	Base Project Cost ($/kW)	Location Percent Variation (%)	Delta Cost Difference ($/kW)	Total Location Project Cost ($/kW)
Alaska	Anchorage	Pacific	6,230	0	967	7,197
Alaska	Fairbanks	Pacific	-	0	-	-
Alabama	Huntsville	East South Central	-	0	-	-
Arizona	Phoenix	Mountain	-	0	-	-
Arkansas	Little Rock	West South Central	-	0.00%	-	-
California	Los Angeles	Pacific	6,230	6.70%	416	6,646
California	Redding	Pacific	-	0	-	-
California	Bakersfield	Pacific	-	0	-	-
California	Sacramento	Pacific	-	0	-	-
California	San Francisco	Pacific	6,230	15.00%	932	7,162
Colorado	Denver	Mountain	-	0	-	-
Connecticut	Hartford	New England	6,230	0	326	6,556
Delaware	Dover	South Atlantic	6,230	0	182	6,412
District of Columbia Washington	District of Columbia Washington	South Atlantic	6,230	1.90%	119	6,349
Florida	Tallahassee	South Atlantic	-	0	-	-
Florida	Tampa	South Atlantic	-	0	-	-
Georgia	Atlanta	South Atlantic	6,230	0	-505	5,725
Hawaii	Honolulu	Pacific	6,230	0	857	7,087
Idaho	Boise	Mountain	-	0	-	-
Illinois	Chicago	East North Central	6,230	0	914	7,144
Indiana	Indianapolis	East North Central	6,230	0	-113	6,117

State	City	Region	Base Project Cost ($/kW)	Location Percent Variation (%)	Delta Cost Difference ($/kW)	Total Location Project Cost ($/kW)
Iowa	Davenport	West North Central	-	0	-	-
Iowa	Waterloo	West North Central	-	0	-	-
Kansas	Wichita	West North Central	-	0	-	-
Kentucky	Louisville	East South Central	-	0	-	-
Louisiana	New Orleans	West South Central	-	0.00%	-	-
Maine	Portland	*New England*	6,230	0	-235	5,995
Maryland	Baltimore	South Atlantic	6,230	0	-174	6,056
Massachusetts	Boston	New England	6,230	0	725	6,955
Michigan	Detroit	East North Central	6,230	0	130	6,360
Michigan	Grand Rapids	East North Central	6,230	-3.20%	-202	6,028
Minnesota	St. Paul	West North Central	6,230	6.50%	405	6,635
Mississippi	Jackson	East South Central	-	0	-	-
Missouri	St. Louis	West North Central	-	0.00%	-	-
Missouri	Kansas City	West North Central	-	0.00%	-	-
Montana	Great Falls	Mountain	-	0.00%	-	-
Nebraska	Omaha	West North Central	-	0	-	-
New Hampshire	Concord	*New England*	-	0.00%	-	-
New Jersey	Newark	Middle Atlantic	6,230	13.30%	827	7,057
New Mexico	Albuquerque	Mountain	-	0.00%	-	-
New York	New York	Middle Atlantic	6,230	28.10%	1,754	7,984
New York	Syracuse	Middle Atlantic	6,230	-0.90%	-54	6,176
Nevada	Las Vega	Mountain	-	0.00%	-	-
North Carolina	Charlotte	South Atlantic	6,230	-8.30%	-514	5,716

State	City	Region	Base Project Cost ($/kW)	Location Percent Variation (%)	Delta Cost Difference ($/kW)	Total Location Project Cost ($/kW)
North Dakota	Bismarck	West North Central	-	0.00%	-	-
Ohio	Cincinnati	East North Central	-	0	-	-
Oregon	Portland	Pacific	6,230	0	304	6,534
Pennsylvania	Philadelphia	Middle Atlantic	-	0	-	-
Pennsylvania	Wilkes-Barre	Middle Atlantic	-	0	-	-
Rhode Island	Providence	*New England*	6,230	2.40%	152	6,382
South Carolina	Spartanburg	South Atlantic	6,230	-11.10%	-691	5,539
South Dakota	Rapid City	West North Central	-	0.00%	-	-
Tennessee	Knoxville	East South Central	-	0	-	-
Texas	Houston	West South Central	6,230	0	-544	5,686
Utah	Salt Lake City	Mountain	-	0.00%	-	-
Vermont	Burlington	*New England*	-	0	-	-
Virginia	Alexandria	South Atlantic	6,230	0	-157	6,073
Virginia	Lynchburg	South Atlantic	6,230	0	-423	5,807
Washington	Seattle	Pacific	6,230	0	277	6,507
Washington	Spokane	Pacific	-	0	-	-
West Virginia	Virginia Charleston	South Atlantic	-	0.00%	-	-
Wisconsin	Green Bay	*East North Central*	6,230	0.60%	40	6,270
Wyoming	Cheyenne	Mountain	-	0	-	-
Puerto Rico	Cayey	Middle Atlantic	6,230	-1.00%	-65	6,165

(Data Source: EIA, 2013)

9.8 Location-Based Capital Costs for CSP

State	City	Region	Base Project Cost ($/kW)	Location Percent Variation (%)	Delta Cost Difference ($/kW)	Total Location Project Cost ($/kW)
Alaska	Anchorage	Pacific	5067	23%	1139	6206
Alaska	Fairbanks	Pacific	5067	33%	1685	6752
Alabama	Huntsville	East South Central	5067	-12%	-619	4448
Arizona	Phoenix	Mountain	5067	-10%	-483	4584
Arkansas	Little Rock	West South Central	5067	-11%	-553	4514
California	Los Angeles	Pacific	5067	9%	477	5544
California	Redding	Pacific	5067	8%	414	5481
California	Bakersfield	Pacific	5067	8%	383	5450
California	Sacramento	Pacific	5067	11%	549	5616
California	San Francisco	Pacific	5067	23%	1177	6244
Colorado	Denver	Mountain	5067	-8%	-407	4660
Connecticut	Hartford	New England	5067	8%	410	5477
Delaware	Dover	South Atlantic	5067	4%	217	5284
District of Columbia Washington	District of Columbia Washington	South Atlantic	5067	2%	87	5154
Florida	Tallahassee	South Atlantic	5067	-13%	-666	4401
Florida	Tampa	South Atlantic	5067	-6%	-293	4774
Georgia	Atlanta	South Atlantic	5067	-14%	-697	4370
Hawaii	Honolulu	Pacific	5067	37%	1861	6928
Idaho	Boise	Mountain	5067	-6%	-302	4765
Illinois	Chicago	East North Central	5067	24%	1201	6268
Indiana	Indianapolis	East North Central	5067	-3%	-166	4901

State	City	Region	Base Project Cost ($/kW)	Location Percent Variation (%)	Delta Cost Difference ($/kW)	Total Location Project Cost ($/kW)
Iowa	Davenport	West North Central	5067	-1%	-27	5040
Iowa	Waterloo	West North Central	5067	-6%	-325	4742
Kansas	Wichita	West North Central	5067	-9%	-447	4620
Kentucky	Louisville	East South Central	5067	-10%	-502	4565
Louisiana	New Orleans	West South Central	5067	-16%	-824	4243
Maine	Portland	*New England*	5067	-8%	-386	4681
Maryland	Baltimore	South Atlantic	5067	-5%	-275	4792
Massachusetts	Boston	New England	5067	19%	958	6025
Michigan	Detroit	East North Central	5067	4%	175	5242
Michigan	Grand Rapids	East North Central	5067	-6%	-278	4789
Minnesota	St. Paul	West North Central	5067	10%	501	5568
Mississippi	Jackson	East South Central	5067	-11%	-573	4494
Missouri	St. Louis	West North Central	5067	3%	174	5241
Missouri	Kansas City	West North Central	5067	1%	64	5131
Montana	Great Falls	Mountain	5067	-5%	-235	4832
Nebraska	Omaha	West North Central	5067	-4%	-200	4867
New Hampshire	Concord	*New England*	5067	-3%	-138	4929
New Jersey	Newark	Middle Atlantic	5067	22%	1133	6200
New Mexico	Albuquerque	Mountain	5067	-5%	-273	4794
New York	New York	Middle Atlantic	5067	46%	2347	7414
New York	Syracuse	Middle Atlantic	5067	-2%	-92	4975
Nevada	Las Vega	Mountain	5067	9%	477	5544
North Carolina	Charlotte	South Atlantic	5067	-14%	-714	4353

State	City	Region	Base Project Cost ($/kW)	Location Percent Variation (%)	Delta Cost Difference ($/kW)	Total Location Project Cost ($/kW)
North Dakota	Bismarck	West North Central	5067	-9%	-433	4634
Ohio	Cincinnati	East North Central	5067	-8%	-397	4670
Oregon	Portland	Pacific	5067	6%	279	5346
Pennsylvania	Philadelphia	Middle Atlantic	5067	13%	676	5743
Pennsylvania	Wilkes-Barre	Middle Atlantic	5067	-6%	-312	4755
Rhode Island	Providence	*New England*	5067	4%	201	5268
South Carolina	Spartanburg	South Atlantic	5067	-19%	-943	4124
South Dakota	Rapid City	West North Central	5067	-12%	-593	4474
Tennessee	Knoxville	East South Central	5067	-15%	-756	4311
Texas	Houston	West South Central	5067	-15%	-748	4319
Utah	Salt Lake City	Mountain	5067	-7%	-338	4729
Vermont	Burlington	*New England*	5067	-8%	-416	4651
Virginia	Alexandria	South Atlantic	5067	-4%	-219	4848
Virginia	Lynchburg	South Atlantic	5067	-12%	-586	4481
Washington	Seattle	Pacific	5067	7%	362	5429
Washington	Spokane	Pacific	5067	-3%	-133	4934
West Virginia	Virginia Charleston	South Atlantic	5067	-3%	-142	4925
Wisconsin	Green Bay	*East North Central*	5067	1%	48	5115
Wyoming	Cheyenne	Mountain	5067	-8%	-394	4673
Puerto Rico	Cayey	Middle Atlantic	5067	-4%	-181	4886

(Data Source: EIA, 2013)

9.9 Location-Based Capital Costs for Solar PV

State	City	Region	Base Project Cost ($/kW)	Location Percent Variation (%)	Delta Cost Difference ($/kW)	Total Location Project Cost ($/kW)
Alaska	Anchorage	Pacific	3,873	21%	811	4,684
Alaska	Fairbanks	Pacific	3,873	34%	1,318	5,191
Alabama	Huntsville	East South Central	3,873	-8%	-292	3,581
Arizona	Phoenix	Mountain	3,873	-6%	-222	3,651
Arkansas	Little Rock	West South Central	3,873	-7%	-256	3,617
California	Los Angeles	Pacific	3,873	9%	361	4,234
California	Redding	Pacific	3,873	8%	292	4,165
California	Bakersfield	Pacific	3,873	8%	302	4,175
California	Sacramento	Pacific	3,873	9%	357	4,230
California	San Francisco	Pacific	3,873	18%	711	4,584
Colorado	Denver	Mountain	3,873	-3%	-123	3,750
Connecticut	Hartford	New England	3,873	7%	251	4,124
Delaware	Dover	South Atlantic	3,873	4%	150	4,023
District of Columbia Washington	District of Columbia Washington	South Atlantic	3,873	4%	148	4,021
Florida	Tallahassee	South Atlantic	3,873	-8%	-320	3,553
Florida	Tampa	South Atlantic	3,873	-4%	-141	3,732
Georgia	Atlanta	South Atlantic	3,873	-9%	-330	3,543
Hawaii	Honolulu	Pacific	3,873	43%	1,681	5,554
Idaho	Boise	Mountain	3,873	-2%	-67	3,806
Illinois	Chicago	East North Central	3,873	17%	655	4,528
Indiana	Indianapolis	East North Central	3,873	-2%	-65	3,808

State	City	Region	Base Project Cost ($/kW)	Location Percent Variation (%)	Delta Cost Difference ($/kW)	Total Location Project Cost ($/kW)
Iowa	Davenport	West North Central	3,873	1%	55	3,928
Iowa	Waterloo	West North Central	3,873	-2%	-89	3,784
Kansas	Wichita	West North Central	3,873	-4%	-142	3,731
Kentucky	Louisville	East South Central	3,873	-6%	-236	3,637
Louisiana	New Orleans	West South Central	3,873	-10%	-396	3,477
Maine	Portland	*New England*	3,873	-3%	-98	3,775
Maryland	Baltimore	South Atlantic	3,873	-2%	-83	3,790
Massachusetts	Boston	New England	3,873	13%	515	4,388
Michigan	Detroit	East North Central	3,873	2%	89	3,962
Michigan	Grand Rapids	East North Central	3,873	-4%	-134	3,739
Minnesota	St. Paul	West North Central	3,873	8%	319	4,192
Mississippi	Jackson	East South Central	3,873	-7%	-270	3,603
Missouri	St. Louis	West North Central	3,873	3%	109	3,982
Missouri	Kansas City	West North Central	3,873	1%	41	3,914
Montana	Great Falls	Mountain	3,873	-1%	-25	3,848
Nebraska	Omaha	West North Central	3,873	-1%	-24	3,849
New Hampshire	Concord	*New England*	3,873	0%	11	3,884
New Jersey	Newark	Middle Atlantic	3,873	14%	550	4,423
New Mexico	Albuquerque	Mountain	3,873	-1%	-48	3,825
New York	New York	Middle Atlantic	3,873	31%	1,216	5,089
New York	Syracuse	Middle Atlantic	3,873	-1%	-19	3,854
Nevada	Las Vega	Mountain	3,873	8%	307	4,180
North Carolina	Charlotte	South Atlantic	3,873	-9%	-333	3,540

State	City	Region	Base Project Cost ($/kW)	Location Percent Variation (%)	Delta Cost Difference ($/kW)	Total Location Project Cost ($/kW)
North Dakota	Bismarck	West North Central	3,873	-3%	-130	3,743
Ohio	Cincinnati	East North Central	3,873	-5%	-186	3,687
Oregon	Portland	Pacific	3,873	6%	227	4,100
Pennsylvania	Philadelphia	Middle Atlantic	3,873	9%	335	4,208
Pennsylvania	Wilkes-Barre	Middle Atlantic	3,873	-4%	-140	3,733
Rhode Island	Providence	*New England*	3,873	3%	107	3,980
South Carolina	Spartanburg	South Atlantic	3,873	-11%	-443	3,430
South Dakota	Rapid City	West North Central	3,873	-5%	-207	3,666
Tennessee	Knoxville	East South Central	3,873	-9%	-358	3,515
Texas	Houston	West South Central	3,873	-9%	-360	3,513
Utah	Salt Lake City	Mountain	3,873	-2%	-70	3,803
Vermont	Burlington	*New England*	3,873	-3%	-122	3,751
Virginia	Alexandria	South Atlantic	3,873	-3%	-100	3,773
Virginia	Lynchburg	South Atlantic	3,873	-7%	-276	3,597
Washington	Seattle	Pacific	3,873	5%	200	4,073
Washington	Spokane	Pacific	3,873	0%	14	3,887
West Virginia	Virginia Charleston	South Atlantic	3,873	-1%	-53	3,820
Wisconsin	Green Bay	*East North Central*	3,873	1%	33	3,906
Wyoming	Cheyenne	Mountain	3,873	-2%	-86	3,787
Puerto Rico	Cayey	Middle Atlantic	3,873	1%	40	3,913

(Data Source: EIA, 2013)

9.10 Location-Based Capital Costs for Biomass

State	City	Region	Base Project Cost ($/kW)	Location Percent Variation	Delta Cost Difference ($/kW)	Total Location Project Cost ($/kW)
Alaska	Anchorage	Pacific	4114	0.229	944	5058
Alaska	Fairbanks	Pacific	4114	0.248	1019	5133
Alabama	Huntsville	East South Central	4114	-0.09	-370	3744
Arizona	Phoenix	Mountain	0	-	-	
Arkansas	Little Rock	West South Central	4114	-0.081	-332	3782
California	Los Angeles	Pacific	4114	0.11	452	4566
California	Redding	Pacific	4114	0.072	296	4410
California	Bakersfield	Pacific	4114	0.061	251	4365
California	Sacramento	Pacific	4114	0.091	373	4487
California	San Francisco	Pacific	4114	0.298	1224	5338
Colorado	Denver	Mountain	4114	-0.074	-304	3810
Connecticut	Hartford	New England	4114	0.203	837	4951
Delaware	Dover	South Atlantic	4114	0.177	730	4844
District of Columbia Washington	District of Columbia Washington	South Atlantic	4114	0.301	1240	5354
Florida	Tallahassee	South Atlantic	4114	-0.097	-397	3717
Florida	Tampa	South Atlantic	4114	-0.045	-186	3928
Georgia	Atlanta	South Atlantic	4114	-0.101	-414	3700
Hawaii	Honolulu	Pacific	4114	0.536	2205	6319
Idaho	Boise	Mountain	4114	-0.059	-243	3871
Illinois	Chicago	East North Central	4114	0.177	727	4841
Indiana	Indianapolis	East North Central	4114	0.006	26	4140

State	City	Region	Base Project Cost ($/kW)	Location Percent Variation	Delta Cost Difference ($/kW)	Total Location Project Cost ($/kW)
Iowa	Davenport	West North Central	4114	-0.022	-89	4025
Iowa	Waterloo	West North Central	4114	-0.063	-258	3856
Kansas	Wichita	West North Central	4114	-0.079	-327	3787
Kentucky	Louisville	East South Central	4114	-0.069	-284	3830
Louisiana	New Orleans	West South Central	4114	-0.119	-488	3626
Maine	Portland	*New England*	4114	-0.042	-172	3942
Maryland	Baltimore	South Atlantic	4114	0.014	57	4171
Massachusetts	Boston	New England	4114	0.279	1148	5262
Michigan	Detroit	East North Central	4114	0.024	100	4214
Michigan	Grand Rapids	East North Central	4114	-0.038	-158	3956
Minnesota	St. Paul	West North Central	4114	0.058	239	4353
Mississippi	Jackson	East South Central	4114	-0.084	-344	3770
Missouri	St. Louis	West North Central	4114	0.025	104	4218
Missouri	Kansas City	West North Central	4114	0.009	38	4152
Montana	Great Falls	Mountain	0	-	-	
Nebraska	Omaha	West North Central	4114	-0.045	-187	3927
New Hampshire	Concord	*New England*	4114	-0.037	-150	3964
New Jersey	Newark	Middle Atlantic	4114	0.157	644	4758
New Mexico	Albuquerque	Mountain	0	-	-	
New York	New York	Middle Atlantic	4114	0.304	1250	5364
New York	Syracuse	Middle Atlantic	4114	0.077	316	4430
Nevada	Las Vega	Mountain	0	-	-	
North Carolina	Charlotte	South Atlantic	4114	-0.098	-404	3710

State	**City**	**Region**	**Base Project Cost ($/kW)**	**Location Percent Variation**	**Delta Cost Difference ($/kW)**	**Total Location Project Cost ($/kW)**
North Dakota	Bismarck	West North Central	4114	-0.08	-331	3783
Ohio	Cincinnati	East North Central	4114	-0.023	-94	4020
Oregon	Portland	Pacific	4114	0.053	220	4334
Pennsylvania	Philadelphia	Middle Atlantic	4114	0.094	386	4500
Pennsylvania	Wilkes-Barre	Middle Atlantic	4114	-0.043	-175	3939
Rhode Island	Providence	*New England*	4114	0.028	116	4230
South Carolina	Spartanburg	South Atlantic	4114	-0.134	-553	3561
South Dakota	Rapid City	West North Central	4114	-0.102	-422	3692
Tennessee	Knoxville	East South Central	4114	-0.104	-429	3685
Texas	Houston	West South Central	4114	-0.103	-425	3689
Utah	Salt Lake City	Mountain	0	-	-	
Vermont	Burlington	*New England*	4114	-0.075	-308	3806
Virginia	Alexandria	South Atlantic	4114	0.065	266	4380
Virginia	Lynchburg	South Atlantic	4114	-0.049	-202	3912
Washington	Seattle	Pacific	4114	0.083	341	4455
Washington	Spokane	Pacific	4114	-0.036	-148	3966
West Virginia	Virginia Charleston	South Atlantic	4114	-0.022	-91	4023
Wisconsin	Green Bay	*East North Central*	4114	0.036	146	4260
Wyoming	Cheyenne	Mountain	0	-	-	
Puerto Rico	Cayey	Middle Atlantic	4114	-0.04	-163	3951

(Data Source: EIA, 2013)

9.11 Net electricity generation by fuel with the Clean Power Plan, 2000–2040 (billion kilowatt-hours or Thousand GWh)

	Natural gas	Renewables	Coal	Nuclear	Liquids	Total	Renewables Percentage Generation	Renewable % increase Based on 2005	Renewable % increase Based on 2015
History 2000	601.04	356.48	1,966.26	753.89	111.22	3,788.90	9%		
2001	639.13	287.73	1,903.96	768.83	124.88	3,724.52	8%		
2002	691.01	343.44	1,933.13	780.06	94.57	3,842.21	9%		
2003	649.91	355.29	1,973.74	763.73	119.41	3,862.08	9%		
2004	710.10	351.48	1,978.30	788.53	121.15	3,949.56	9%		
2005	760.96	357.65	2,012.87	781.99	122.23	4,035.70	9%	0%	
2006	816.44	385.77	1,990.51	787.22	64.17	4,044.11	10%	8%	
2007	896.59	352.75	2,016.46	806.42	65.74	4,137.96	9%	-1%	
2008	882.98	380.93	1,985.80	806.21	46.24	4,102.17	9%	7%	
2009	920.98	417.72	1,755.90	798.85	38.94	3,932.40	11%	17%	
2010	987.70	427.38	1,847.29	806.97	37.06	4,106.39	10%	19%	
2011	1,013.69	513.34	1,733.43	790.20	30.18	4,080.84	13%	44%	
2012	1,225.89	494.57	1,514.04	769.33	23.19	4,027.03	12%	38%	
2013	1,124.84	522.07	1,581.11	789.02	27.16	4,044.20	13%	46%	
2014	1,126.61	538.58	1,581.71	797.17	30.23	4,074.30	13%	51%	
2015	1,348.27	546.36	1,354.90	797.69	25.84	4,073.05	13%	53%	0%
Projections 2016	1,330.27	597.59	1,356.84	781.33	24.28	4,090.32	15%	67%	9%
2017	1,322.62	652.07	1,365.22	786.22	21.90	4,148.03	16%	82%	19%
2018	1,288.80	694.04	1,386.10	771.43	21.24	4,161.61	17%	94%	27%
2019	1,265.56	766.96	1,387.02	770.35	15.10	4,204.98	18%	114%	40%
2020	1,201.19	835.99	1,388.03	777.49	14.88	4,217.58	20%	134%	53%

	Natural gas	Renewables	Coal	Nuclear	Liquids	Total	Renewables Percentage Generation	Renewable % increase Based on 2005	Renewable % increase Based on 2015
2021	1,163.62	926.79	1,346.80	787.11	14.56	4,238.87	22%	159%	70%
2022	1,196.45	975.53	1,296.13	789.09	14.22	4,271.42	23%	173%	79%
2023	1,244.24	996.55	1,272.75	789.09	13.97	4,316.59	23%	179%	82%
2024	1,326.68	1,006.57	1,222.29	789.09	13.63	4,358.27	23%	181%	84%
2025	1,396.41	1,015.46	1,179.27	789.09	13.19	4,393.42	23%	184%	86%
2026	1,463.67	1,023.65	1,143.13	789.09	12.66	4,432.21	23%	186%	87%
2027	1,536.87	1,036.99	1,093.10	789.09	12.27	4,468.32	23%	190%	90%
2028	1,597.87	1,054.83	1,049.64	789.09	11.93	4,503.37	23%	195%	93%
2029	1,661.86	1,069.91	1,004.68	789.09	11.64	4,537.18	24%	199%	96%
2030	1,702.09	1,088.37	972.49	789.09	11.36	4,563.39	24%	204%	99%
2031	1,704.00	1,114.28	973.92	789.09	11.02	4,592.31	24%	212%	104%
2032	1,704.79	1,148.77	978.40	789.09	10.90	4,631.95	25%	221%	110%
2033	1,726.82	1,175.83	971.56	789.09	10.73	4,674.03	25%	229%	115%
2034	1,753.18	1,201.31	965.12	789.09	10.57	4,719.28	25%	236%	120%
2035	1,768.43	1,238.06	962.43	789.09	10.44	4,768.45	26%	246%	127%
2036	1,812.69	1,254.13	951.59	789.09	10.24	4,817.75	26%	251%	130%
2037	1,823.96	1,297.08	949.22	789.09	10.07	4,869.42	27%	263%	137%
2038	1,868.34	1,318.65	937.92	789.09	9.70	4,923.70	27%	269%	141%
2039	1,909.73	1,340.01	927.57	789.09	9.51	4,975.91	27%	275%	145%
2040	1,942.26	1,374.11	918.79	789.09	9.35	5,033.59	27%	284%	152%

9.12 Technical Resource Potential Values in Thousands GWh (Lopez et al., 2012)

REGION	STATE	STATE ABBR.	PV	CSP	ONSHORE WIND	OFFSHORE WIND	BIOMASS	GEOTHERMAL
East North Central	Wisconsin	WI	5111	0	255	318	13	647
East North Central	Indiana	IN	4992	0	378	0	18	434
East North Central	Ohio	OH	3743	0	129	171	14	496
East North Central	Illinois	IL	8225	0	649	66	32	676
East North Central	Michigan	MI	5290	0	144	1740	12	458
			27361	0	1555	2295	89	2711
East South Central	Kentucky	KY	1863	0	0	0	8	485
East South Central	Tennessee	TN	2296	0	1	0	8	428
East South Central	Alabama	AL	3758	0	0	0	13	535
East South Central	Mississippi	MS	5016	0	0	10	15	559
			12933	0	1	10	44	2007
Middle Atlantic	New York	NY	1574	0	64	614	9	375
Middle Atlantic	Pennsylvania	PA	632	0	8	24	13	327
Middle Atlantic	New Jersey	NJ	500	0	0	430	4	35
			2706	0	72	1068	26	737
Mountain	Montana	MT	8201	1540	2746	0	5	1654
Mountain	Wyoming	WY	5736	5406	1654	0	1	1071
Mountain	Idaho	ID	3964	3503	44	0	6	1010
Mountain	Nevada	NV	8650	8296	18	0	1	1307
Mountain	Utah	UT	5223	5068	32	0	1	952
Mountain	Colorado	CO	10298	9155	1096	0	4	1261
Mountain	Arizona	AZ	12012	12544	26	0	2	1247
Mountain	New Mexico	NM	16396	16812	1399	0	1	1431
			70480	62324	7015	0	21	9933

REGION	STATE	STATE ABBR.	PV	CSP	ONSHORE WIND	OFFSHORE WIND	BIOMASS	GEOTHERMAL
New England	Maine	ME	1106	0	29	632	4	377
New England	Vermont	VT	57	0	8	0	1	36
New England	New Hampshire	NH	63	0	6	14	1	104
New England	Massachusetts	MA	111	0	3	799	2	92
New England	Connecticut	CT	34	0	0	27	1	56
New England	Rhode Island	RI	17	0	0	89	1	11
			1388	0	46	1561	10	676
Pacific	Hawaii	HI	42	15	8	2837	1	0
Pacific	Washington	WA	1785	162	47	488	14	566
Pacific	Oregon	OR	3775	2812	69	963	15	932
Pacific	California	CA	9208	8491	90	2663	28	1475
Pacific	Alaska	AK	8283	0	1373	0	1	0
			23093	11480	1587	6951	59	2973
South Atlantic	District of Columbia	DC	2	0	0	0	0	1
South Atlantic	Delaware	DE	289	0	0	61	1	23
South Atlantic	West Virginia	WV	60	0	5	0	3	261
South Atlantic	Maryland	MD	629	0	4	201	3	87
South Atlantic	Virginia	VA	1932	0	5	361	10	291
South Atlantic	North Carolina	NC	4330	0	2	1270	17	421
South Atlantic	Georgia	GA	5566	0	0	221	17	353
South Atlantic	South Carolina	SC	2803	0	0	542	8	364
South Atlantic	Florida	FL	5274	0	0	35	13	374
			20885	0	16	2691	72	2175
West North Central	North Dakota	ND	9741	36	2538	0	8	820
West North Central	South Dakota	SD	10016	1630	2902	0	9	922
West North Central	Minnesota	MN	10841	0	1429	100	21	370

REGION	STATE	STATE ABBR.	PV	CSP	ONSHORE WIND	OFFSHORE WIND	BIOMASS	GEOTHERMAL
West North Central	Iowa	IA	7030	0	1724	0	29	606
West North Central	Nebraska	NE	9285	4847	3011	0	17	928
West North Central	Kansas	KS	14541	7974	3102	0	13	990
West North Central	Missouri	MO	5382	0	690	0	14	835
			66836	14487	15396	100	111	5471
West South Central	Oklahoma	OK	9404	5068	1522	0	5	780
West South Central	Texas	TX	39367	22787	5552	1101	22	3030
West South Central	Arkansas	AR	5024	0	23	0	15	629
West South Central	Louisiana	LA	4185	0	1	1201	15	484
			57980	27855	7098	2302	57	4923

9.13 Summary of Assumptions in Technical Resource Potential (Lopez et al., 2012)

General Formula (Solar and Wind)

$$State\ Potetial\ MWh = State \sum |Available\ Area\ (km2) \times Power\ Density\ \left(\frac{MW}{km2}\right) \times State\ Capacity\ Factor\ (\%) \times 8760(hours\ per\ year)\ |$$

Technology	Capacity Factor (CF)	Power Density (MW/km2)
Rural and Urban Solar PV	0.105 (Alaska) to 0.263 (Arizona, Nevada, New Mexico)	48
Rooftop PV (Flat roofs)	Availability CF (0.22 to 0.65), Efficiency (0.13)	110
Rooftop PV (Flat roofs)	Availability CF (0.22 to 0.65), Efficiency (0.13)	135
Concentrated Solar	0.315 to 0.448	32.8
Onshore Wind	0.30	5
Offshore Wind	0.36 to 0.5	5

Assumptions for Solar Photovoltaics (PV)

1. Power Density of 48 MW per square kilometer (MW/km2)
2. Single-axis tracking collector
3. Axis of rotation aligned north-south
4. 0 degrees tilt from the horizontal
5. Urban Utility-Scale Photovoltaics
    a. Large-scale PV restricted to large urban open spaces
    b. Excludes unsuitable areas: slopes > 3% ; Areas < 18,000 m^2 (large enough to support ~1 MW of PV; Parking lots, roads, and urbanized areas (areas with imperviousness >=1%); Areas deemed unlikely for development (landmarks, parks, wetlands, water bodies, forests)
6. Rural Utility-Scale Photovoltaics
    a. Large-scale PV installed outside urban boundaries
    b. Excludes unsuitable areas: slopes > 3% ; Areas <1 km2; Parking lots, roads, federally protected lands; Areas deemed unlikely for development (landmarks, parks, wetlands, water bodies, forests)
7. Rooftop Photovoltaics
    a. Building footprints based on floor space estimates for commercial and residential buildings considering the average number of floors.
    b. Availability factor to account for shade and obstructions.
        i. Residential buildings in cool climates – 22%
        ii. Residential buildings in warm/arid climates– 27%
        iii. Commercial building in cool climates – 65%
        iv. Commercial building in warm/arid climates– 60%
        v. Efficiency - 13.5%
    c. Power density :
        i. Flat roofs - 110 W/m2
        ii. Pitched roofs - 135 W/m2
        iii. Assumed 8% of residential rooftops and 63% of commercial rooftops5 were flat and pitched roofs were symmetrical.
    d. Capacity Factors for closest TYM

8. **Assumptions for Concentrating Solar Power (CSP)**

    a. Utility-scale solar power facility in which the solar heat energy is collected in a central receiver. If the receiver contains oil or molten salt as the heat-transfer medium, then the thermal energy can be stored for later use.
    b. Land filters similar to rural utility-scale PV were applied.
    c. Direct normal solar insolation values restricted to areas with an average annual value >=5 kWh/m2/day .

   d. Solar multiple was used to normalize the size of the solar field in terms of a power block size: "The solar multiple is the ratio of the actual size of the solar field to the solar field size needed to feed a turbine at nominal design capacity with maximum solar irradiance (about 1 kW/m)."1
   e. Power density = 32.8 MW/km2 for a dry cooled trough system with six hours of storage and a solar multiple of 2.

9. **Assumptions for Onshore Wind Power**
   a. Considered onshore wind potential at 80 m above surface
   b. Gross capacity factor of 0.3 using wind turbine power curves
   c. 10 and 15% energy losses to calculate net capacity factor (including downtime, parasitic power etc.)
   d. Areas unlikely to be developed excluded: i.e. urban areas, protected lands, and onshore water features
   e. Power density 5 MW/km2

10. **Assumptions for Offshore Wind Power**
    a. Wind speed >= 6.4 m/s at 90 m above surface
    b. Eliminate areas deemed unlikely to be developed e.g. shipping lanes, marine sanctuaries etc.
    c. Power density of 5 MW/km2

11. **Assumptions for Bio-power**
    a. Solid
       i. Based on crop, forest, primary/secondary mill residues, and urban wood waste
       ii. Potential energy generation assuming 1.1 MWh/ bone-dry tons (BDT)
       iii. Based on 20% conversion efficiency and a higher heating value (HHV) of 8,500 BTU/lb
    b. Solid
       i. Potential energy generation assuming 4.7 MWh/ton of CH4 from animal manure, domestic wastewater treatment plants, and landfills
       ii. Based on 30% conversion efficiency

12. **Geothermal Energy Technologies - Hydrothermal Power Systems**
    a. Based on estimated developed for eastern United States, Alaska, and Hawaii
    b. Exclusions included public lands, such as national parks, that are not available for resource development

13. **Enhanced Geothermal Systems (EGS)**
    a. Based on temperature at depth data with depth ranging from 3 km to 10km
    b. Viable regions - depth interval with temperatures ≥150°C.
    c. Known potential electric capacity (MWe/km3) applied to each temperature-depth interval to estimate total potential at each depth interval.
    d. 90% capacity factor.