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### Introduction

Geographic Information Systems (GISs) are useful to support environmental analysis and consequent formulation of policy. Renewable energy is growing as a crucial component of world energy supply, growth stimulated by negative externalities of traditional forms of energy. Since renewable energy inherently relates to the earth, GIS and spatial analysis can be applied as a tool to gain greater insight into the varied stages of renewable development from policy setting and planning to exploration, permitting, installation, operations, transmission, consumption, and evaluation. GIS can be used to plan the steps, manage them, and evaluate them.

This study has the objective to analyze the uses of GIS as a crucial tool in establishing policies and planning for regional governments and regional planning by non-profit organizations. It will discuss the conceptual framework of stages of renewable development in a regional community. It induces a framework of the range of GIS applications and platforms that can inform renewables policy development. Next, it gives a case study of setting policy for renewable energy development in the Coachella Valley (CV) in southern California, including the present status of renewable energy and its spatial arrangement in CV as well as a sketch of its socioeconomic background, the uses of GIS to understand better the policy challenges and issues, and the insights provided by GIS. The discussion section explores how this approach is the same or differs from prior research, why the particular GIS platforms and software are appropriate for government policy setting, and how that fits into the GIS applications framework. The implications of the research are examined for regional renewables policymaking. The paper finishes by an examination of the study limitations, and conclusion.

The renewable energy sector is growing rapidly, due to government mandates and technology and cost advances. From 2000 to 2012, there was 97 percent growth worldwide in the installed electricity capacity for renewable energy, leading to its accounting for 23 percent of total global electricity production in 2012 (DOE, 2013). Renewable energy includes the common types of hydro, solar, wind, geothermal, and biomass. These energy forms are all tied to spatial aspects of the earth, and are more feasible in certain localities than others. For example, hydro power must be in a location with significant water flow, while solar energy is favored in areas of the planet with high solar intensity. In the U.S. locations in the south and southwestern states are favored. Wind energy is naturally favored by areas with high winds, in the U.S. particularly in the middle flank of the country from the Dakotas down to Texas. Geothermal energy occurs worldwide mostly in land areas along tectonic plate edges, for example in Sonoma and Imperial Counties, California, as well as in Japan, Philippines, and New Zealand, while biomass occurs in countries with substantial naturally-occurring or agriculturally produced plants that can be harvested and converted into use for fuel.

Since energy has these natural locations, GIS can be utilized to map existing localities, and points with projections to other places for exploration. However, in addition to natural supply factors, demand factors also influence locations of renewable energy consumption, including economic and social factors such as population, income, education, and energy proportion of household or business budgets. For this reason, populous nations lead in installed renewable electrical capacity. For instance the top three nations in five forms of renewable energy (see Table 1) are all from the world's top 10 populous nations, except for Italy in Solar Photovoltaic and the Philippines for Geothermal.

Table 1. Three Leading Nations in Installed Renewable Electrical Capacity, 2012

| Hydro Power | Solar Photovoltaic | Geothermal | Wind | Biomass |
|---|---|---|---|---|
| China | Germany | United States | China | United States |
| Brazil | Italy | Philippines | United States | Brazil |
| United States | United States | Indonesia | Germany | China |

(Source: DOE, 2013)

Lastly, energy transport somewhat expands the reach of renewable energy from its source. Electricity generated by renewable energy can be transported over an energy grid for hundreds of miles before diminishing, while geothermal heat can be transported several miles. Biomass can be transported hundreds of miles to refining plants and then transported long distances, similar to petroleum products, as fuel to consumers.

The setting for the paper is the Coachella Valley of California. The Coachella Valley extends southeast for about 45 miles from the southeastern extent of the San Bernardino mountains to the Salton Sea, which is a water basin filled by rainfall and irrigation runoff that flows northwards from the Imperial Valley draining into the Sea. The Valley has almost 490,000 residents, of which 347,000 resided in its 9 largest cities and largest unincorporated area in 2010, and additionally about 100,000 seasonal visitors who are resident in the winter.

The Valley is projected to have over 550,000 residents by year 2020, which implies a 2 percent growth rate, above the national estimate and equivalent to California. It has an economy that is based on agriculture, tourism, and retirement. Its farming is typified by fruits and vegetables; including national prominence in dates, palm trees, and citrus. As a well-known winter tourist location, its winter visitors are attracted by warm temperatures, dryness, and desert. It also has a major component of retired people, as seen by population that is about 20 percent of age 65 and older, which compares to California's 11 percent. There are high-end retirement communities and residential areas, as well as moderate priced retirement developments in the northeastern and southwestern parts of the Valley.

The Coachella Valley is endowed with some of the most plentiful natural resources for renewable energy in the U.S. The western part of the Valley has areas with large and exposed areas of high winds. The Valley's desert location is linked to high sunlight intensity, favoring solar energy production, both within the Valley and in the unpopulated areas of Riverside County to the West extending parallel to the Interstate 10 to the Arizona border. Finally, the Salton Sea which borders the south end of the Valley has one of the largest geothermal deposits in the U.S., which has lagged its potential so far in extracting the resource, due to high salinity and the varied composition of its brines (Garnish and Brown, 2010; Butler and Pick, 1982).

The Valley's resources are presently utilized for renewable energy, with potential for considerable growth, subject to natural barriers and community challenges and restrictions especially in the urban areas.

## Literature review

This section summarizes relevant prior research on GIS as a tool for analyzing renewable energy development; GIS particularly utilized for decision support for wind energy and for water rights; adoption-diffusion theory of technological innovations; in this case renewable energy constituting the innovation; the social acceptance of renewable energy innovations; and social, demographic, and economic influences on renewable energy development and policy.

### *GIS as a tool for analyzing renewable energy development.*

GIS and spatial analysis constitute excellent methods for enhancing the study of renewable energy for the reason given in the Introduction, i.e. that renewable energy relates to the earth.

There are diverse examples. In Imperial County, California, the site of a world-leading geothermal resource, GIS was utilized to show the location patterns in the county of population, labor force, dependency ratio, and human mobility, in the context of present and projected geothermal power plant capacities (Butler and Pick, 1982). This allowed determination of supply and demand of energy and its impact on the economy of the county and its cities and rural areas. A particular example was an estimate of the number of farm laborers displaced by the spatial arrangement of the land area for a geothermal power plant, its production wells, and reinjection wells. This could be extrapolated to determine, over a 40-year projection period, the entire county labor force displaced, based on assumptions of land reduction in geothermal fields, crop distribution, size of total energy production, and depth of geothermal wells (Pick and Butler, 1985).

GIS can assist in multiple dimensions of wind energy projects. For example, GIS allowed visualizing summary maps of hourly wind speed from 200 sampled locations throughout China in order to estimate the wind energy production capacities of its 31 provinces (Yue and Wang, 2006). In addition, changes daily or seasonally could be studied by location. This led to policy recommendations that China needs an improved and coordinated power grid system that can handle a huge resource of up to 3,500 terawatt (trillion watt) hours. Mapping indicates the highest wind potential is along the eastern and southeastern coasts.

GIS was utilized as a tool in assessing wind energy potential for the state of Iowa (Grassi et al., 2012). The estimates included a model of environmental characteristics, anthropological constraints, economic attributes, and regulation. This geospatial model provided projections of the state's annual energy production and installed capacity. The model was further tested with assumptions of a power purchase agreement. The spatial benefit was enabling annual production for specific localities based on the model, as impacted by local wind data, estimates that could be practically useful to wind project developers, government policymakers, and siting of transmission lines to windy areas (Grassi et al., 2012). In summary, GIS as an applied tool can provide more refined and accurate analysis and estimates of renewable energy production in states or regions than a non-spatial model.

*GIS utilized for decision support for wind energy and for water rights*

GIS contributes to decision support by enhancing the accuracy of decision information and adding spatial analysis capabilities to analytics tools (Pick, 2008, 2010). A recent example was a spatial decision support system (SDSS) that assessed the potential for siting wind farms in Northwest Ohio (Gorsevski et al., 2013). The decision support is based multi-criteria of economic, environmental, and locational information, which is processed through linear combination methods in which user-participants weight different factors. The SDSS is designed for group decision making based on Borda method weighting of each participant and was tested by 30 participants (Gorsevski et al., 2013). Another study cautions against prematurely defining the problem space of GIS decision-making, and gives suggestions of ways to more broaden the scope prior to applying SDSS (Ramsey, 2009). Methods from knowledge built up through the collaborative planning studies are applied to beforehand resolve tensions from politically competing interests when SDSS is applied that include incorporating an unbiased facilitator, not pre-defining the problem, and exploring the problem with flexible GIS applications (Ramsey, 2009). These studies inform the present study since its results will ultimately be used for decision-making by regional planners.

*Adoption-diffusion theory of technological innovations*

The Theory of Adoption and Diffusion of Innovations (ADI Theory) (Rogers, 2003), which is often utilized in the IS/IT discipline to justify innovation in information technologies, is designed for any type of innovation. In this research it is applied to renewable energy applications that have innovative components, such as geothermal energy for domestic space heating, solar energy to power light-weight electric vehicles, and giant wind farms. The Theory posits that an innovations follows an s-shaped cumulative adoption-diffusion process over time as measured by percent of market adopters (Rogers, 2003).

ADI Theory covers not only adoption of innovations over time, but also over space, depending on the innovation characteristics. Space is posited in ADI Theory to influence the adoption and diffusion of innovations. For instance, "Cluster studies" examine how rapidly adoptions occur within neighborhoods and then spread to surrounding ones (Rogers, 2003). In the present study, a renewables technology can grow within a small city area and then spread by diffusion to neighboring parts of the city, forming clusters.

Another spatial implication of ADI Theory is that factors influencing the rate of adoption of an innovation can be *internal* to the geographic unit or *external* to it. Rogers proposed five factors of innovations that influence rates of adoption (Rogers, 2003, page 262). They are *relative advantage* (advantage of an innovative technology over an earlier one), *compatibility* (consistency of a technology with current values and needs and with prior experiences), *complexity* (perception of how challenging an innovative technology is to understand), *trialability* (extent to which the innovative technology can be pilot tested), and *observability* (how easy it is to observe the adoption-diffusion process for a technology). In the present study, these factors are useful in explaining the factors leading to more rapid diffusion of solar and wind technologies in the Coachella Valley.

*Social acceptance of renewable energy innovations*

A further step in analyzing the success of a renewable energy innovation is to study the social acceptance of an innovative renewable energy innovation. Inability to gain social acceptance may ultimately constrain the energy from reaching its market potential (Wustenhagen et al., 2007). Studies of such social acceptance for wind energy have examined the factors of socio-political acceptance, community acceptance, and market acceptance. Social/political acceptance can be gauged by opinion polls as well as be examining acceptance of innovations by key stakeholder and policymakers (Wustenhagen et al., 2007). Community acceptance is "specific acceptance of siting decisions and renewable energy projects by local stakeholders" and often involves greater or lesser resistance, while market acceptance refers to adoption of small-scale renewable technologies by consumer markets (Wustenhagen et al., 2007).

An empirical study of social acceptance of solar water heaters in Mexico City applied Roger's ADI Theory through a staged decision process of "knowledge, persuasion, implementation, and confirmation" involving Roger's five acceptance factors (Mallett, 2007). Extensive interviews and field testing confirmed that Roger's factors of observability, relative advantage, complexity, and trialability were all important in gaining social acceptance, but outside of Roger's model technology cooperation was also essential. These studies lend credence to considering social acceptance and to the usefulness of ADI Theory in understanding it. Although the present study did not measure social acceptance due to the early stages of adoption and diffusion, the studies support using ADI Theory for interpretation of renewables adoption including locational aspects.

*Social, economic, and political influences on renewable energy development and policy*

Finally, many studies have confirmed that social, economic, and political factors are related to the spatial distribution of renewable energy production and consumption at various scales and settings. For geothermal energy, energy production influenced the limited skilled workforce required for local production, while the locations of small cities influenced geothermal production environmental impacts. The total market demand for geothermal electricity was related to regional population that was slowly growing in the U.S. region surrounding the production sites, but rapidly growing in nearby Mexico (Butler and Pick 1982). These conclusions were supported by GIS analysis of socio-economic features of Imperial County and of its major small cities.

Another study examined the social, economic, and political correlates of solar photovoltaic residential installations throughout the United States (Kwan, 2012). A regression model revealed the importance correlates, and they in turn were utilized to predict and map the prevalence of solar photovoltaic residential arrays throughout the nation. The study method enabled estimation of locations with gaps between actual and potential solar-array prevalence that included the Southwest and state of Florida (Kwan, 2012). Based on locational gaps, policies were recommended such as rebates, credits, other financial incentives, and electricity pricing adjustments for particular locations. Another investigation examined solar, wind, and biomass renewable energy resources in rural Chigu in Taiwan that included analysis of economic, political, technical and environmental implications. The findings were implemented through a GIS that could be used to estimate the potential of local areas including assessment of socio-economic implications (Yue and Wan, 2006). These studies demonstrate the importance of social, economic, and political aspects in considering spatial patterns of renewable energy prevalence, and lend support to the present study's emphasis on these dimensions.

## Conceptual framework

The conceptual framework includes both a model of renewable energy development and the Adoption-Diffusion model of Rogers (2003), modified for renewable energy as a technological innovation. Geographic characteristics are part of this model and indicate the theoretical position of GIS in the larger integrated framework.

The model of integrated policy assessment for local/regional renewable energy development (Table 2) constitutes the basis for the larger study. Extra-local conditions constitute the exogenous influences on renewables development process. Federal, state, and local political structures and laws constrain as well as stimulate renewables development, for instance local zoning restrictions for siting wind energy farms, which can be noisy, or local incentives to attract a solar parts factory. Cost factors for renewable energy depends on national and global pricing for the renewable form, say solar, and on world markets for competing forms of energy. Environmental standards are set by different levels of government and constrain development. For instance, state air pollution laws that restrict geothermal development or federal credits for domestic solar installations which lower net costs and stimulate home use of solar.

Renewable site-specific characteristics are ones that were seen in the literature review to relate to renewable energy development, whether or not the cause-and-effect or underlying mechanisms are known. Regarding the geographic environment, renewables manufacturing, distribution, and operational sites are in particular places that have proximity to other locations, as well as a topographic setting. For example, a geothermal power plant would be located nearby its well sites and close to power lines. Renewables facilities have physical environmental considerations, most of which have a geographic aspect. For example, a single-wind turbine installation is located due to climatic and meteorological conditions that allow sufficient wind to have economic surplus. It is also located in close proximity to other turbines in a beneficial pattern, as well as near transmission lines that feed into the electrical grid.

Renewable facilities also relate to demographic, social, and economic attributes. The consumer or commercial markets are crucial to many forms of renewables, such as domestic solar, thermal home heating/cooling, and industrial markets for electricity. The model includes ten attributes that were carefully chosen to reflect consumer market size, socio-demographic profiles of consumer favoring renewables, spending strength, prevalence of manufacturing (i.e. a favorable factor for manufacturing of renewables), wealth (i.e. related to both spending and investment potential), internet use (which reflects access to knowledge of renewables), and crime (which is a general disincentive, but particularly for commercial facilities).

The model utilizes the knowledge from the renewable site-specific characteristics to inform regional policymaking. This includes at different levels of government (cities, counties), for non-governmental organizations that often influence government policies, the leaders in the region, and for modification of regulations. Policies also can directly influence decision-making, as seen in some of the prior studies, and some policies may be spatially informed, such as encouraging domestic renewables in rapidly growing areas or locating solar or wind farms away from population centers. GIS being used as a tool is seen to influence the impact of the step, Renewable Site-Specific Characteristics, on the Policies step. It does this by providing visual mapping information for characteristics that can provide geographic insights for a single map, be compared from map to map, and provide information on proximities of city characteristics, renewable energy locations, transportation, and other features.

The conceptual model is not fully examined in the case to follow, but could be fully analyzed if the case reached the stage of maturity of renewables development and if resources were available to evaluation with data each detailed part of the model. The model section receiving particular emphasis in the case are B1 (transportation access) and C1-10 (demographic, social, and economic attributes). In addition some local/regional policy recommendations stemming from those parts of the model are presented. It is evident that GIS is a useful tool for the middle model portion of Renewable Site-specific Characteristics, and that in turn the spatially-informed outputs from this middle portion influence the subsequent Policies model portion.

Table 2. Model for Integrated Policy Assessment of Local and Regional Renewable Energy Development

| Extra-Local Conditions → | Renewable Site-specific Characteristics **GIS as tool** → | Policies for Regional Political Systems |
|---|---|---|
| A. Federal, state, & local political structures | A. Geographical environment* | A. Level of government (local, regional) |
| | 1. Proximity to renewable sites | B. Non-governmental organizations |
| B. Federal, state, & local laws | 2. Topography | C. Leadership system |
| C. Cost of energy from renewables | B. Physical environment* | D. Decision-making processes |
| D. Cost of non-renewable energy | 1. Solar radiation | E. Spatial-based policies |
| E. Environmental standards | 2. Wind velocity | F. Regulations |
| | 3. Sub-surface geology | 1. Exploration |
| | 4. Transportation access | 2. Land acquisition |
| | C. Demographic, social, & econ. attributes* | 3. Installation of facilities |
| | 1. Population | 4. Production |
| | 2. Education | 5. Consumer use |
| | 3. Occupation | |
| | 4. Home value | |
| | 5. No. manuf. firms & employees | |
| | 6. Percent of sales in manufacturing | |
| | 7. Median net worth | |
| | 8. Prof./scientific/ tech. employees | |
| | 9. Internet use for bus. Purchase | |
| | 10. Total crime index | |

* GIS can applied for analysis (modified from Butler and Pick, 1982)

As mentioned in the prior discussion of ADI Theory, its usefulness in the present study is in interpreting mechanisms of adoption and diffusion of renewable energy uses, especially as reflected in the ADI Theory in Roger's adoption-diffusion factors of relative advantage, trialability, compatibility, complexity and observability. For example, relative advantage would be favorable to a form of renewable energy if its use was relatively advantageous versus the prior non-renewable energy use, i.e. a domestic solar energy set-up might be of lower long-term cost and more reliable than previous fossil- fuel one. The trialability would be lower for manufacturing using brines from a geothermal power plant, since a small scale pilot might not replicate the operation of a full-scale operational plant. Likewise, compatibility with values and lifestyle would depend on behavioral, attitudinal, and educational factors. Complexity might be justified if the energy form were simple to learn to use, as might be the outcome of a high quality solar installation that was well tested. Observability would be greater for domestic uses of solar energy and of heat pumps, which would be visible as structural features and might garner media coverage in environmentally-aware communities. More details on ADI Theory are available in the original source (Rogers, 2003) and subsequent more specialized research, (e.g. Mallett, 2007)

**Research questions**

Based on the central and right-hand portions of the conceptual model (Figure 2), the research questions are the following:

1. What is the size and spatial extent of the natural resource of renewables in the Coachella Valley?
2. What are the spatial aspects of social and economic factors that relate to renewable energy in the Coachella Valley?
3. What is the spatial arrangement of Coachella Valley's interstate ground transportation system and how does that relate to renewables' manufacturing and operations in the Valley?

4. What are the policies recommended, based on the Model, and what role does GIS play in developing the policies?

## Methodologies

Data to answer the research questions were gathered from a variety of secondary, mostly governmental, sources and analyzed through GIS methods, as well as by descriptive statistics and demographic estimation methods. The data sources included U.S. Census (2009, 2010-2014, 2014), State of California (2014), Solar Energy Industries Association (2014a, b), American Wind Energy Association (2014), and Esri Inc. (2014).

The data were analyzed by "spatial data analysis," i.e. descriptive and exploratory spatial analysis, as described by O'Sullivan and Unwin (2003). It does not represent the category of "spatial statistical analysis," in which the data are represented by a statistical model (O'Sullivan and Unwin (2003). The reason for not doing a spatial statistical analysis is that there are not accurate dependent variables for sub-county units such as zip codes and city boundaries available.

Descriptive data analysis was done using descriptive statistics from the software of SPSS Inc. and Excel, and mapping produced by Esri's ArcGIS 10.2 and its cloud-based GIS service, Business Analyst Online (BAO). The latter, although having fewer functions than the former, has the advantages of ease of use and much more extensive accompanying data sets. Later in the paper section on practical implications, BAO is recommended for ongoing use by NGOs and some government planning agencies.

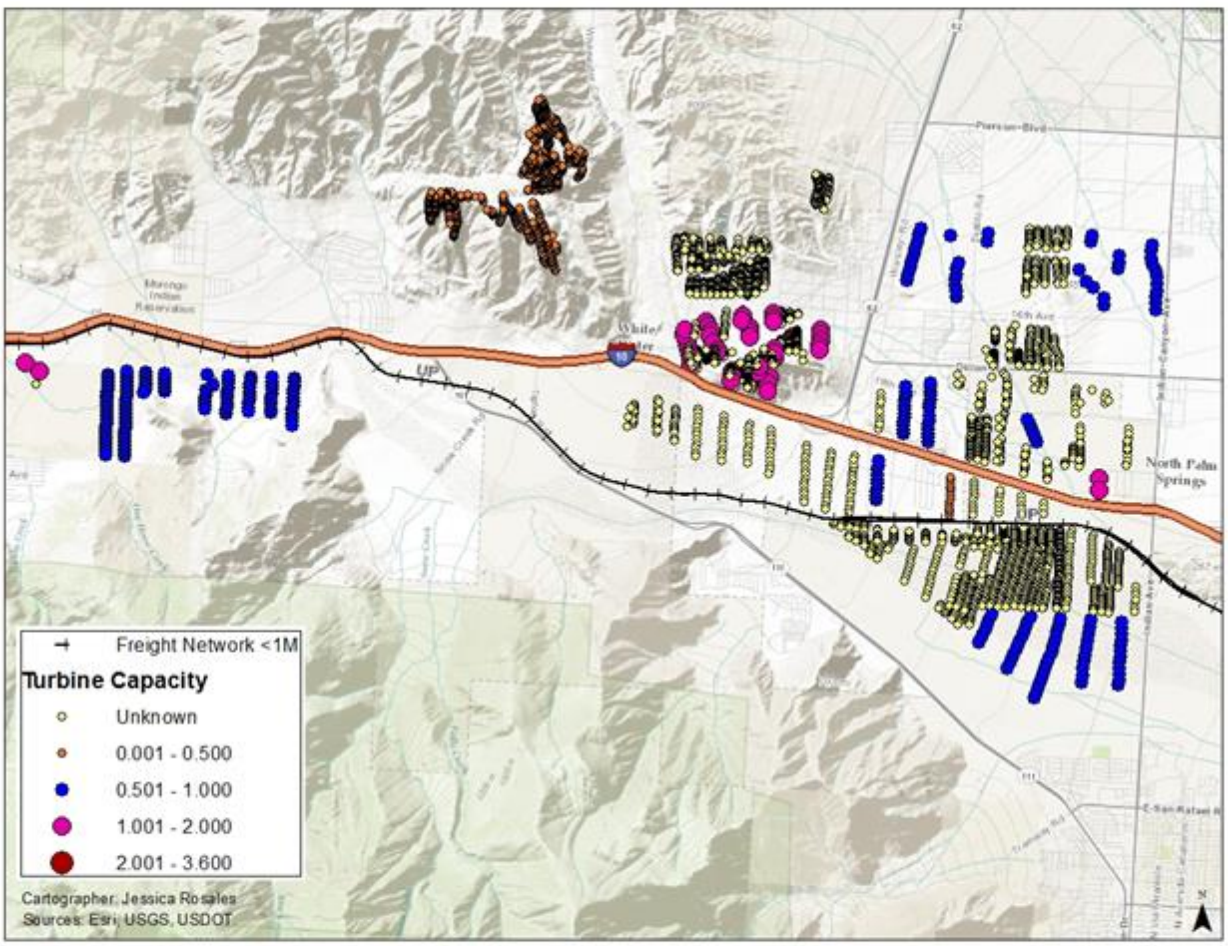
Although not covered in this research paper, interviews were conducted of seven leaders of renewable firms, two government officials, and three experts and those findings informed more detail about the policies and barriers to developing renewables manufacturing, distribution, and operations in Coachella Valley. The qualitative findings from the interviews are reported on in another paper (Perry, Pick, and Rosales, 2014).

**Findings**

Regarding renewables' size and extent, spatial analysis indicates the spatial arrangement of commercial wind and solar installations both within the Valley and to the East for solar. The locations of the resources address Research Question 1 and address policy considerations. Commercial installations, sometimes referred to as "wind farms" and "solar farms," are groupings of separate wind or solar facilities, the electrical output of which is pooled together into common output for the farm, before being input onto the electrical grid. This has advantages of economy of scale and it allows many solar panels or turbines to simultaneously take advantage of high wind or high solar areas.

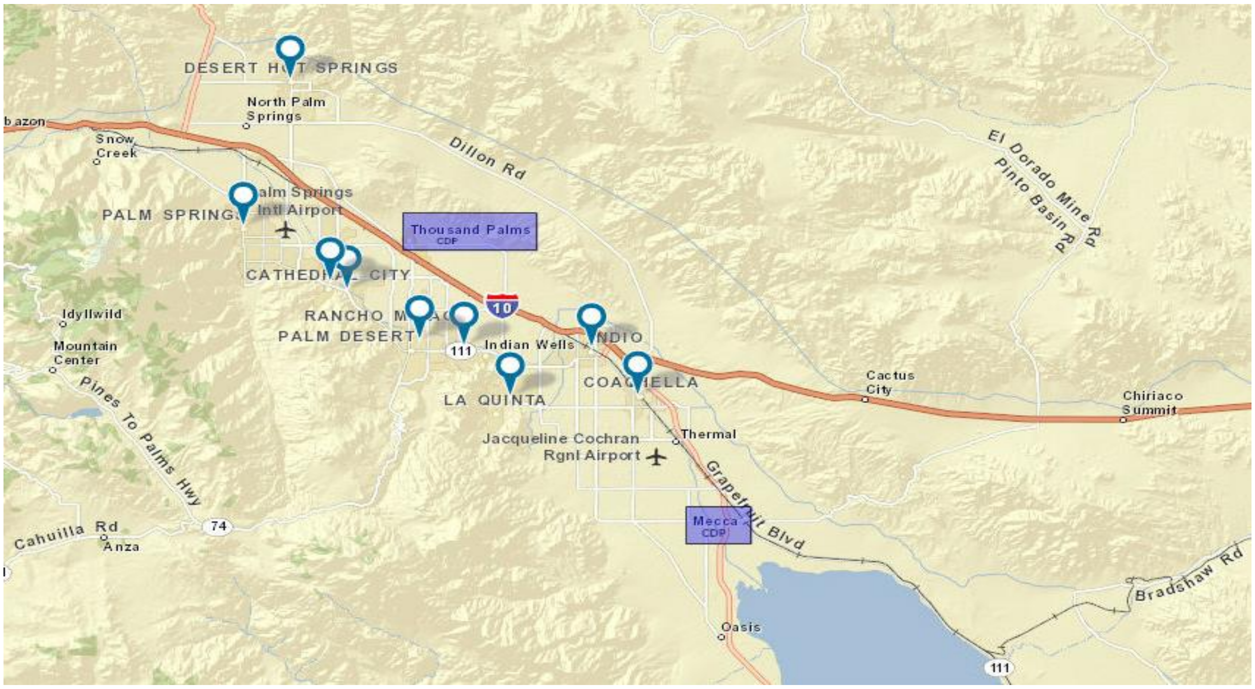
In the West, in the area of San Gorgonio Pass and mostly visible from Interstate 10 and along State Highway 62, hundreds of wind turbines output considerable electrical energy that is purchased by utilities for the electrical grid of southern California. For example, the San Gorgonio Pass Wind Farm, Figure 1, has a capacity of 615 MW, which is about one third the capacity of a nuclear plant. The map reveals how different size turbines are arranged in particular topographic locations, sized to take advantage of the corresponding amounts of wind flow. Furthermore, as is seen by a Valley's population map (Figure 2 and Table 2), these locations are away from populated areas and on the far West of the Coachella Valley towards the Los Angeles urban area. The location has the advantage of not causing noise disturbance or physical danger near CV populated areas, while also being close to large electrical demand of the metropolitan areas of San Bernardino and Riverside.  This instance of technological innovation illustrates the adoption-diffusion factor of compatibility, since the siting puts the wind farm away from urban population, so it is compatible with values and needs.

Figure 1.  San Gorgonio Wind Installations in Western Coachella Valley




(Data source: USGS Data Series DS-817, February, 2014)

Figure 2. Location of Major Cities of Coachella Valley




(Source: Esri Inc., 2014)

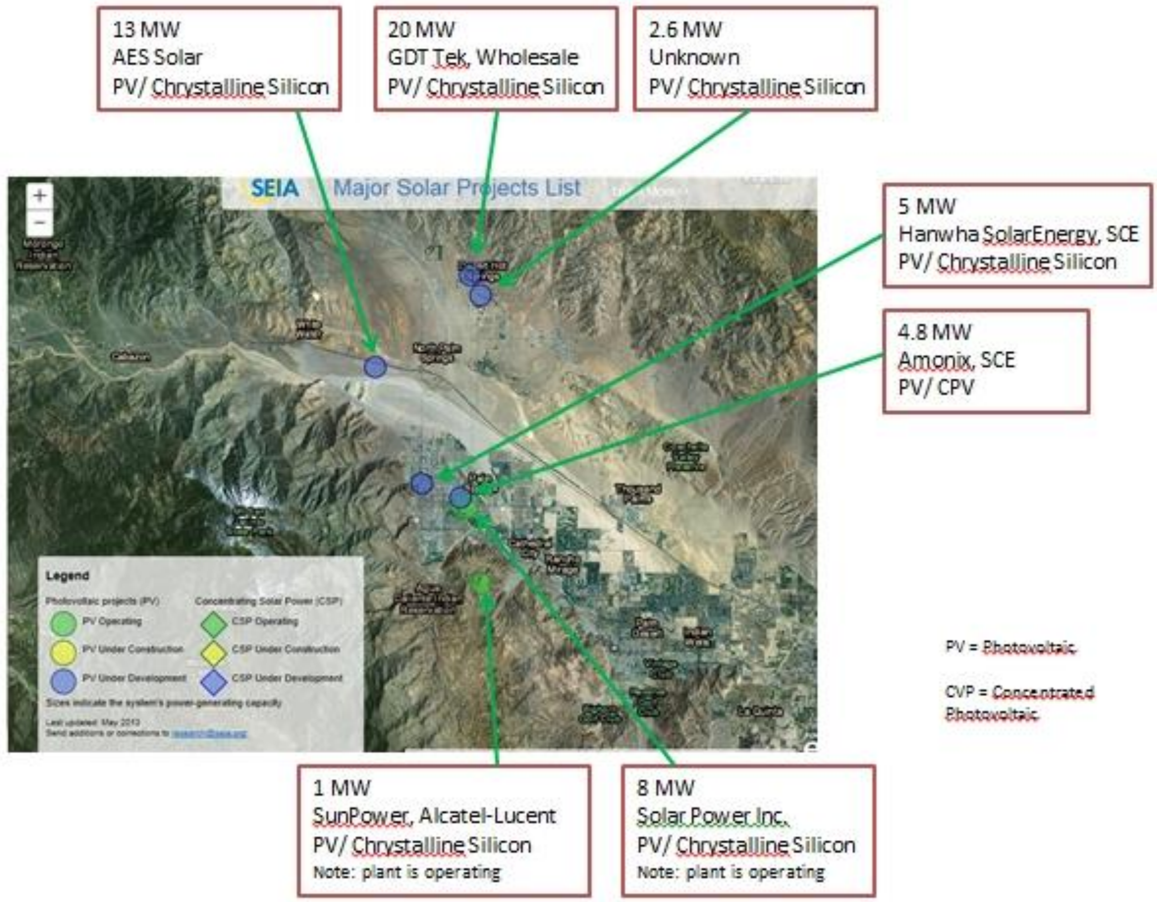
Table 2. Population of Coachella Valley and its Cities, 2000-2013, with projections

| COUNTY/CITY | 4/1/2000 | 1/1/2001 | 1/1/2008 | 1/1/2009 | 1/1/2010 | 4/1/2010 | 6/1/2013 | Annual growth rate 2003-2013 | Annual growth rate 2008-2013 | Annual growth rate 2008-2020 | Pop projected to 2020 (U. Redlands) | Pop projected to 2035 (SCAG) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Riverside County** | | | | | | | | | | | | |
| Cathedral City | 42,647 | 43,853 | 50,401 | 50,812 | 51,093 | 51,200 | 52,977 | 1.15 | 1.00 | | 56,786 | 64,600 |
| Coachella | 22,724 | 23,146 | 38,521 | 39,079 | 40,508 | 40,704 | 43,092 | 4.89 | 2.24 | | 50,329 | 128,700 |
| Desert Hot Springs | 16,582 | 16,664 | 25,115 | 25,690 | 25,886 | 25,938 | 27,902 | 4.91 | 2.10 | | 32,282 | 58,100 |
| Indian Wells | 3,816 | 4,123 | 4,826 | 4,910 | 4,947 | 4,958 | 5,000 | 1.78 | 0.71 | | 5,253 | 5,800 |
| Indio | 49,116 | 49,681 | 74,007 | 74,590 | 75,263 | 76,036 | 80,302 | 4.24 | 1.63 | | 89,942 | 111,800 |
| La Quinta | 23,694 | 25,459 | 36,744 | 37,116 | 37,044 | 37,467 | 39,331 | 3.17 | 1.36 | | 43,234 | 46,300 |
| Palm Desert | 41,155 | 41,685 | 47,453 | 47,993 | 48,215 | 48,445 | 50,508 | 1.56 | 1.25 | | 55,088 | 56,800 |
| Palm Springs | 42,805 | 43,025 | 44,026 | 44,346 | 44,480 | 44,552 | 46,584 | 0.72 | 1.13 | | 50,394 | 56,100 |
| Rancho Mirage | 13,249 | 13,798 | 16,815 | 17,037 | 17,165 | 17,218 | 17,799 | 1.68 | 1.14 | | 19,265 | 22,900 |
| Coachella Cities - Total | 255,788 | 261,434 | 337,908 | 341,573 | 344,601 | 346,518 | 363,495 | 2.69 | 1.46 | | 402,307 | 551,100 |
| Other Incorporated | | | | | | | | | | | | 24,300 |
| Coachella Valley (UofR) | | | 443,000 | | | | 489,626 | | 2.02 | | 563,261 | |
| | | | | | | | | | | | | |
| | | | | | | | | | | | | |
| Coachella Valley (SCAG) | | | 443,000 | | | | 503,256 | | | 2.58 | 604,000 | 884,000 |
| Coachella Valley, Unincorporated Areas (SCAG) | | | 87,500 | | | | 126,131 | | | | | 308,600 |
| Riverside County Total | 1,545,387 | 1,589,708 | 2,102,741 | 2,140,626 | 2,179,692 | 2,189,641 | 2,292,507 | 2.81 | 1.73 | | 2,584,620 | |

(Data Sources: U.S. Bureau of Census, 2014, SCAG, 2013)

Regarding commercial solar energy production within the Coachella Valley, there are small solar plants, Figure 3, within the Valley, currently totaling 55 MW (SEIA, 2014). These plants are small sized relative to the state, and their total generating capacity equates to about 3 percent of a nuclear plant. Nevertheless, since 2013 electrical demand in Coachella Valley is estimated at about 800 MW, based on California State total electric generation capacity is 78,133 MW (State of California, 2013), this solar energy provides energy equivalent about 7 percent of the Valley's electrical demand. Careful comparison with the population map indicates that 73 percent of the small solar plants are within close proximity to cities of Desert Hot Springs and Palm Springs. The contrast with wind energy farms reflects the lesser environmental issues with small solar plants. These small solar plants represent the ADI Theory factor of compatibility, since keeping the largely urban solar plants small increases their compatibility with citizens who favor renewable energy but don't wish huge installations in their backyards.

Figure 3. Small Solar Plants in Western Riverside County

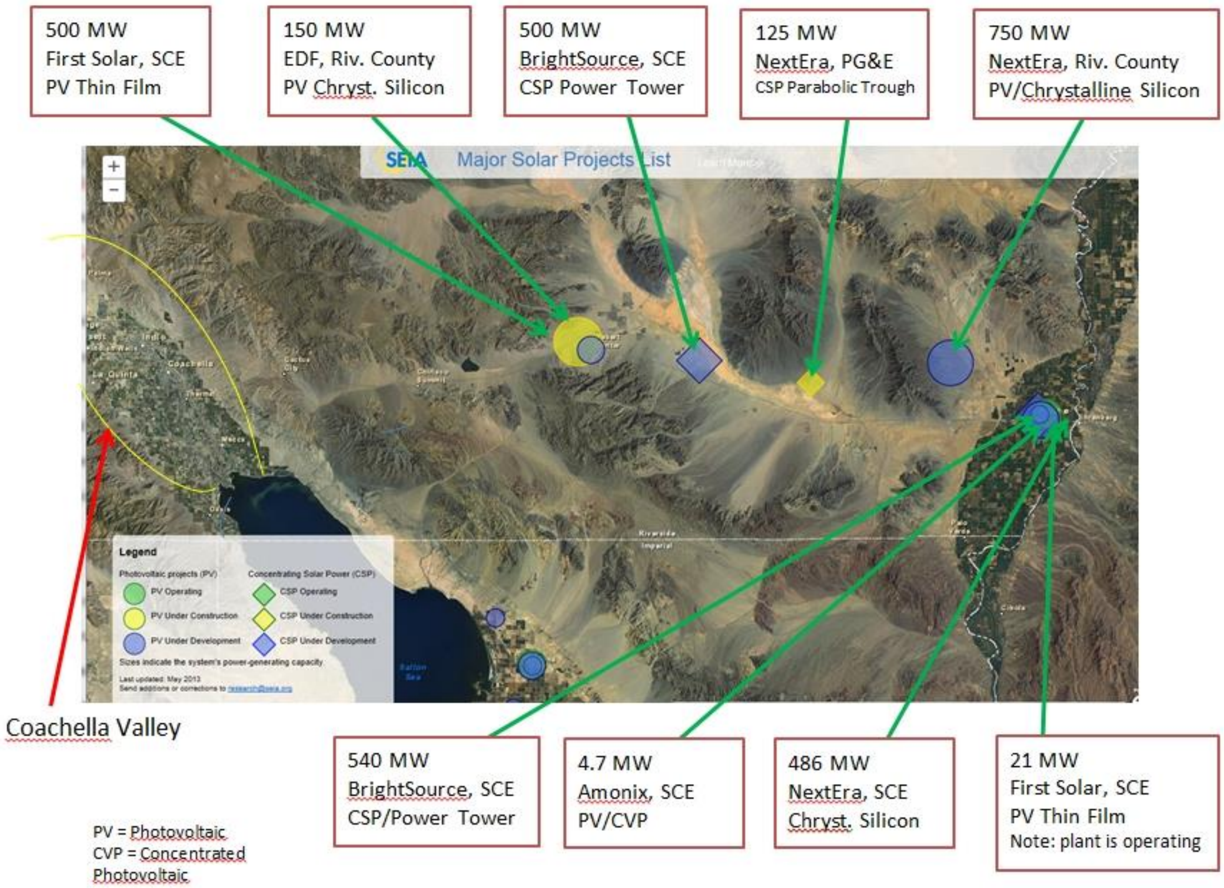



In residential solar energy, based on Coachella having 1.5x the California prevalence, we estimate the Valley had installed residential solar capacity in 2013 of 60.3 MW (U.S. Census, 2014; SEIA, 2013), which constitutes 5.3 percent of estimated total Valley capacity. . It is clear that the Valley's energy supply represents a high level of solar energy supply, about 10.3 percent (estimated) of the Valley's energy supply in 2013 and growing in proportion.

Because of rapid growth in residential solar projected for 2014, we estimate the Valley will have 99.1 MW of installed residential solar capacity at the end of 2014. This renewable energy source demonstrates the ADI Theory concepts of complexity, since once installed, solar energy use involves little or no intervention by the user, except in the infrequent needs for maintenance. It also provides relative advantage for the environmentally aware consumer, since its carbon and other pollutants are minimal versus significant pollution for fossil energy sources. Residential solar also provides moderate observability, because the solar panels are often visible in neighborhoods, depending on the side of the roof they occur on.

By contrast, along Interstate 10, between the western Coachella Valley and Arizona, there is a massive series of solar electrical generating plants in development/construction with several operating (see Figure 2). The total capacity in development/construction is 3,077 MW (SEIS, 2014), which equates to one and a half nuclear plants. This huge solar complex, probably when built out the largest in the U.S., illustrates the ADI Theory factor of relative advantage. Once built, the environmental externalities will be much less than for an equivalent fossil fuel plant, while a nuclear plant is not possible in this corridor due to lack of cooling water supply.

Figure 3. Solar Electrical Generating Plants in Operation or Planned between the Western Coachella Valley and Border with Arizona



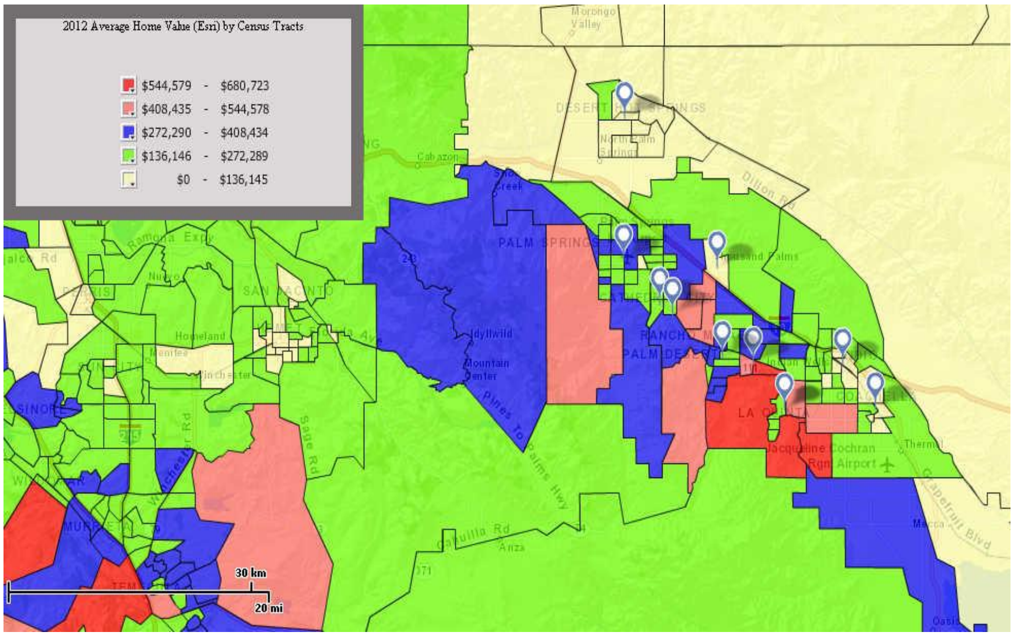

Regarding geothermal energy, there are presently no geothermal power plants located in the Coachella Valley, although there are several moderate sized geothermal plants located in Imperial County 60 miles to the south of the south extent of the Valley. At this distance, there are few energy, environmental, and economic impacts on the Valley, so commercial geothermal potential was not analyzed.

Regarding Research Question 2, concerning social and economic aspects that relate to the CV, the study spatially analyzed for the CV the ten demographic, social, and economic attributes in the conceptual model and considered them in terms of wind and solar commercial plant locations and also the impacts of already somewhat prevalent solar energy devices in homes, as well as geothermal heat pumps for homes, which are at the earliest adoption stage. Wind energy at the urban household level is not considered economically feasible unless the occupants have at least one acre of land with over 10 mile per hour wind speeds. However, the California Energy Commission and Federal Government provide credits to homeowners with small wind towers. Nevertheless, our interviews indicated that here are almost no residential wind towers in the CV.

Several of the spatial analyses of demographic, social, and economic attributes and presented here, and the full set of analyses are available (Pick, Perry, and Rosales 2014). Average home value by census tract in 2012 (see Figure 4) reflects a socioeconomic divide in the CV that shows a concentration of wealth several miles to the south of 10 freeway, which is represented in light orange-red and seen much more clearly in Table 2. Housing with pricing of over $408,000 to $681,000 is located in a grouping of census tracts from La Quinta to Palm Desert and also including western Palm Springs, while tracts with average values under $136,000 are located to the northeast of the 10 Freeway and in many tracts within 4 miles to the southwest of the 10 Freeway. The dramatic economic difference is similarly shown in the spatial pattern of the college educational divide (Pick, Perry, and Rosales, 2014).

Returning to the conceptual framework in Table 2, there are several implications for local and regional policies. Regarding attracting solar manufacturing to the CV, the many census tracts with relatively low housing prices would be attractive to low-skilled assembly or factory service workers, while the nearby very affluent housing areas might attract owners and highly qualified engineers. On the other hand, the dramatic divide might also lead to social or political tensions that would detract from the CV's appeal. For home owners and renters, solar home installations which cost approximately from $10,000 to $20,000 would constitute a financial challenge for the minimal-priced areas, but would be very affordable by the affluent. The spatial aspects of potential policies are discussed in the last section.

Figure 4. Average Home Value by Census Tract, for Coachella Valley, 2012



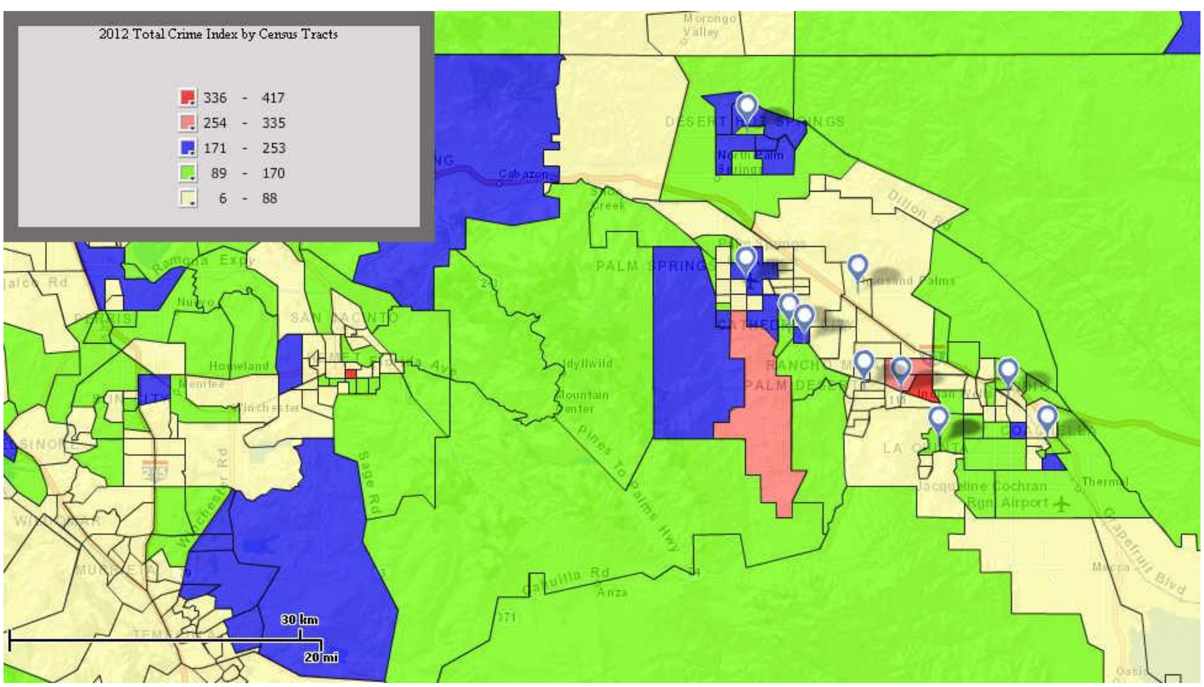

(Data Source: U.S. Bureau of the Census, 2014)

Another example of spatial analysis of a socio-economic attribute related to renewable energy manufacturing is percent of sales in manufacturing by census tract in 2012 (Figure 7). The map reveals over 5 percent in census tracts in the south portion of the City of Coachella and unincorporated tracts further south, and in the unincorporated area of Thousand Palms, both seen in Figure 3 to have very low housing values. In a separate, statistical analysis of U.S. Census data on size of manufacturing establishments in CV, Coachella was seen to have 3 out of the Valley's 5 largest manufacturing firms of size of 100 or more employees, while Thousand Palms had no firms over 49 employees. Areas with the lowest percents of manufacturing are predominantly in the affluent housing area from Figure 4. The most affluent areas had manufacturers with 19 or fewer employees, with a single exception of one large manufacturer located in Palm Springs.

Regarding the model framework, the spatial analysis of percent manufacturing sales, enhanced by a non-spatial manufacturing employee analysis, points clearly to relatively poor City of Coachella as the present manufacturing center of CV, albeit with a small number of employees, while the highly affluent areas have little manufacturing with one firm as an exception. Regional policy implications include that renewables manufacturing could be done on a small scale in the affluent areas, i.e. to hold down land costs, but that scale-up to larger manufacturing should target the City of Coachella if low costs were important. This attribute would not seem to influence residential solar market other than the persistence of much of the socio-economic divide mentioned earlier. Other implications of manufacturing locations are discussed in the section on policy recommendations.

The final example of an social characteristic is the total crime index by census tract for the Coachella Valley (see Figure 6).

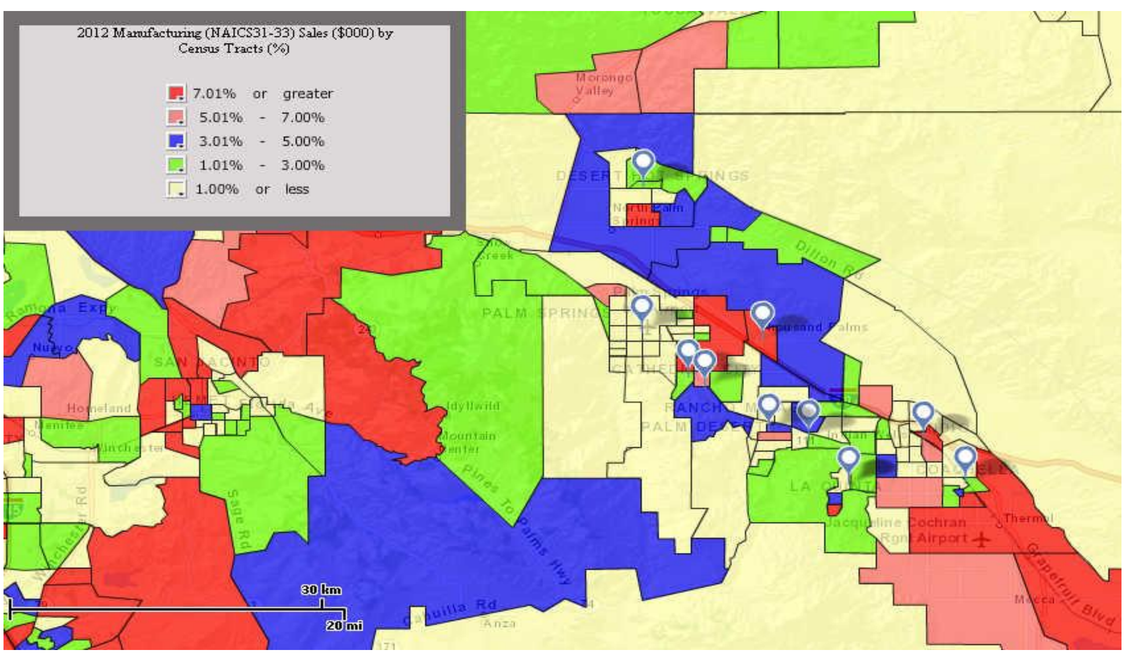
Figure 6. Total Crime Index by Census Tract, for the Coachella Valley, 2012




(Data Source: Esri Inc., 2014)

This social characteristic indicates low crime index in the poor census tracts of CV, but high crime index by over 3-fold in the several affluent tracts including parts of Palm Spring, Indian Wells, and La Quinta. This perhaps surprising finding is explained by these particular affluent areas providing targets for property crime, made easier by their neighboring on poor areas. This policy implications are less for residential solar, since theft is not likely to be solar equipment, but are potentially significant for the siting of solar distribution and manufacturing facilities that might be subject to higher crime, and it impacts the attractiveness of the CV to higher level renewable company executives, engineers, and scientists.

Figure 7. Percent of Sales in Manufacturing, for Coachella Valley, 2012




(Data Source: U.S. Bureau of the Census, 2014)

Transportation access is another key characteristic of renewable energy development that influences diverse aspects of renewables (Boyle, 2012). In exploration, transportation provides access to sometimes remote areas that might be rich in natural renewable energy potential, especially relevant if heavy exploration equipment is involved. In manufacturing of renewable energy equipment, access to major means of transportation becomes crucial. Many components of solar, wind, and geothermal facilities and installations are manufactured is other parts of the country or abroad. A well-known example is solar panels, which China now dominates for manufacturing, while some major wind turbine manufacturers are located in Europe. In the U.S., the most important center for manufacture of wind components is Texas. Likewise distributors and retailers of renewable equipment and parts need to have access to major expressways, air routes for higher valued components, and ocean shipping for large volumes or large-sized components such as the largest wind turbines.

GIS constitutes a very useful tool for optimizing locations based on transportation access. Results of such analysis can then inform policies.

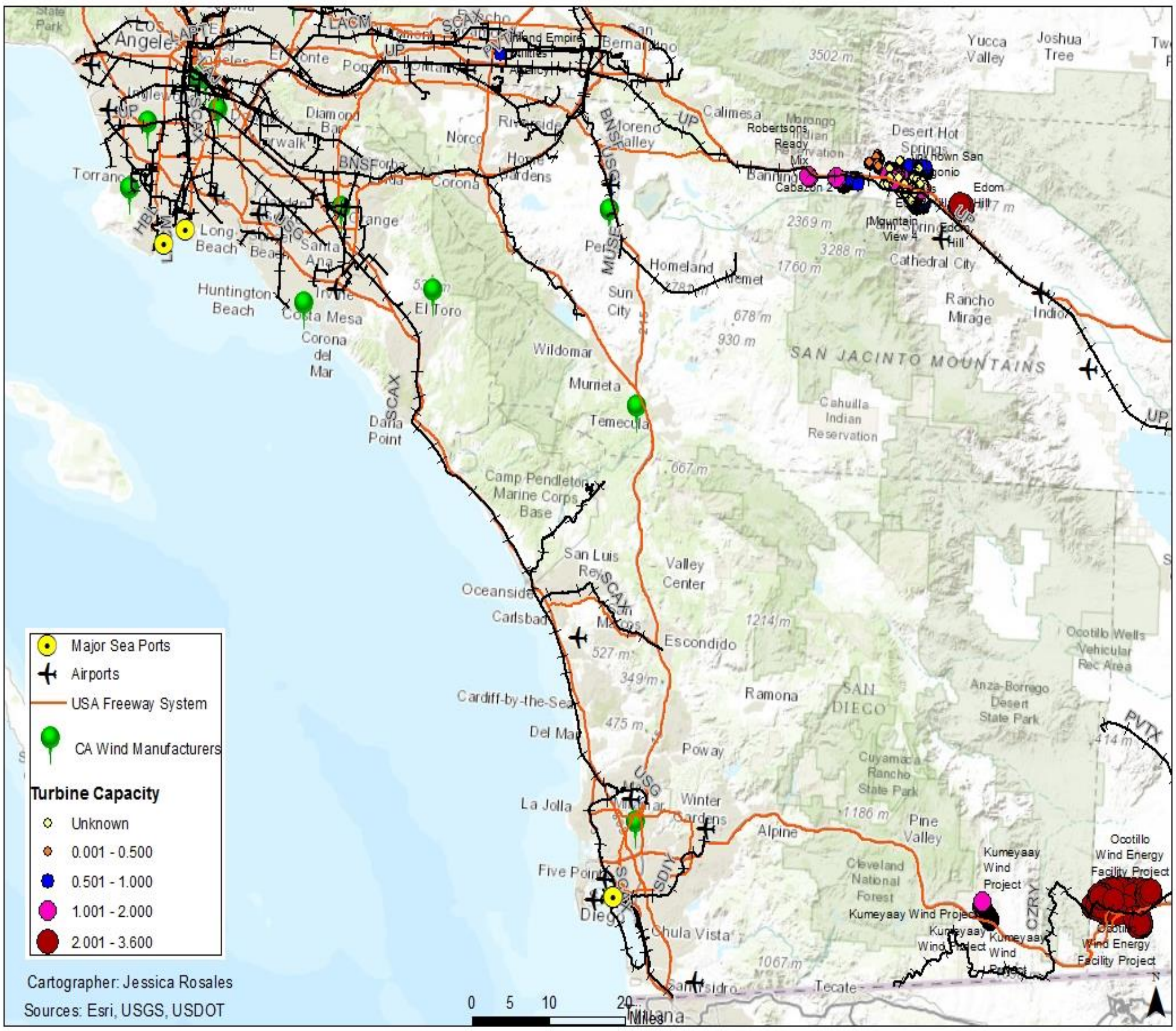
In the Coachella Valley case study, a variety of transportation linkages and sitings were analyzed, both by interviews of solar manufacturing executives and by spatial analysis. An example for the case study is spatial analysis of the transport routing and distances between wind energy manufacturing in Los Angeles and San Diego and locations of important wind energy installations in the Coachella Valley, San Diego, and Imperial Counties (see Figure 8).

This map indicates the important transport options available for the complex of wind operations shown in larger scale in the upper right of Figure 1. There is clearly a dependence for the first 75 miles of major high on Interstate Freeway 10. Then at the juncture point in Riverside with many other highways routes transport becomes more flexible. Nevertheless, the distance to major sea ports of Los Angeles and Long Beach is approximately 120 miles, which is disadvantageous for transport of huge turbines arriving by oceanic shipping. The transport of large turbines is challenged at the destination end, since the wind farms need feeder roads from the 10 Freeway to the sites. This is one reason that the operational facilities are fairly close to the major freeway. Also a factor for some wind equipment is transport from a variety of wind manufacturers shown by green pin icons on the map. Although not the focus of this paper, similar wind equipment transport issues are present for the Wind Farms in Ocotillo in Imperial County and Kumaysaay in San Diego County on the lower right of the map.

This example demonstrates many spatial transportation policy implications such as new routes and heavy transport costs that are examined in the policy section.

Figure 8. Wind Energy Operations and Manufacturers, Compared to Highway Transportation Network accessing the Coachella Valley

(Sources: U.S. Geological Survey, U.S. Department of Transportation, Esri, 2014)



## Discussion

The case study illustrates concepts from ADI Theory and from the paper's Model of Integrated Policy Assessment of Local/Regional Renewable Energy. All the ADI Theory factors, except trialability, were present in some of the wind and solar installations in the Coachella Valley and the area along the Interstate 10 stretching to the Arizona border. Different locations, energy types, and urban proximities implied certain adoption-diffusion factors would be important. The absence of trialability as a factor implies that the technologies have previously been tested, which is consistent with an industry sector under fairly strict federal and state usage regulations.

For the paper's Model (Table 2), nearly all the factors shown were analyzed using spatial methods, sometimes supplemented by non-spatial methods. However, for the physical environment, only transportation access was illustrated in the case. Spatial analysis of each factor lead to policy implications, that are examined in more detail in the next section. The left-hand portion of the Model, concerning Extra-Local Conditions, is beyond the scope of this paper and is examined in the full research study report (Pick, Perry, and Rosales, 2014).

GIS is seen to be a beneficial tool for integrated policy assessment. As was true in renewable studies of geothermal in California, wind projects in China and wind potential in Iowa (Butler and Pick,1982; Yue and Wang, 2006; Grassi et al., 2012), GIS allowed more careful evaluation of locational differences in input and output factors and processes for renewables, so that the whole effect could be more accurately determined. Once a spatially-referenced data-base of model parameters is established, GIS can be utilized to project provide estimates of potential renewable energy production in new locations (Grassi et al., 2012). The latter advantage is not realized in the present research, but could be if there were more extensive data gathering, model building and testing.

Using the present Model, GIS does inform understanding of the renewable site-specific characteristics, which in turn influence policies for regional governmental and nonprofit systems. The Model is flexibly organized, so new site-specific characteristics and data can be added and GIS re-applied, leading to policy modifications.

**Practical Policy Implications**

The case study revealed many policy implications. For the geographical environment, proximity is seen to be important for wind and solar energy development.  This includes consideration of nearness to urban population, workforce, and the electrical grid.  Topography is particularly influential for gaining the best windy locations, and also for mitigating environmental impacts.  Transportation routing is essential for estimating time and cost of transport of commercial renewable installation components and maintenance materials. Since some commercial installation components are bulky such as large wind turbines, the size and strength of highways is important.  Policymakers should consider carefully multi-dimensional aspects place before recommending locations of commercial renewables installations.

The Coachella Valley is seen to have a large socioeconomic geographic divide, with contrasting poor areas to the northeast and south in Interstate 10, versus wealthy areas in a portion of the southeast of the freeway.  For local/regional government policy, this factor informs recommendations on residential locations of renewable's workers, markets, and investors. Policymakers in CV cities need to consider tax implications.

The present spatial arrangement of manufacturers indicates the major concentration is in Coachella City and adjoining unincorporated areas to the south, while the affluent zone has only small manufacturing with one exception of a single large firm in Palm Springs. This informs governments on policies for attracting renewables manufacturing; for instance affluent areas seeking such manufacturers might need to extend subsidies and credits, while Coachella City could emphasize lower land and labor costs. Spatial analysis of crime patterns demonstrated higher risk in certain affluent areas, so those city governments might consider anti-crime policies if they wish to attract renewables sector commercial business. These examples only constitute a part of a thorough demographic, social and economic spatial analysis could strongly support government policies.

Nonprofit organizations have been prominent in promoting and supporting development of renewable energy in CV (Pick, Perry, and Rosales, 2014), so similar benefits of spatial analysis of site-specific characteristics would apply to them, although their technology budgets and equipment restrict the scope and intensity of spatial analysis. For them or for unincorporated areas, the use of public domain free software services, or relatively inexpensive commercial services, such as the minimal subscription to Business Analyst Online or Google services might be necessary, and as demonstrated in this paper, can provide substantial locational information.

**Limitations**

A limitations of this exploratory research study is the absence of statistical testing. However, the research was intended as exploratory and involves only a single case study, such testing was not possible, but in the future could offer confirmatory testing of findings. Another weakness is that the General Model for Integrated Policy Assessment is not fully examined. However, the scope of the model is large, so it is only feasible to test all portions of it in a single exploratory paper. Finally, renewable energy and utility companies, although willing to be interviewed, are reluctant for competitive reasons to provide detailed information, including spatial referencing, about their planning, installations, environmental impacts, supply chains, and customers. This limits the scope of understanding the commercial and business aspect and particularly the spatial patterns and processes of renewables development.

**Conclusion**

Renewable energy is growing rapidly in the United States and worldwide, due to concern about pollution and other unwanted externalities of non-renewable energy. Renewable energy development can be analyzed at different scales of the world, nation, states, and regions/local areas. This research studied the development of renewable energy in the Coachella Valley region of southern California, based on a Model of Integrated Policy Assessment. The exploratory study utilized GIS and descriptive statistics to provide a single case example of portions of the Model.

The findings provided answers to the study's research questions (RQs), as follows.

*RQ1. What is the size and spatial extent of the natural resource of renewables in the Coachella Valley?*
The wind energy resource is shown to be very large in the northwest part of CV, which has commercial wind farms proximate to a major expressway but away from urban population. Solar energy commercial development is seen to be relatively modest proximate to the cities of CV, but very large in the corridor to the East of CV up to the Arizona border. Geothermal energy is minimal in the CV, with no commercial plants, and a bare start on domestic heat pumps.

*What are the spatial aspects of social and economic factors that relate to renewable energy in the Coachella Valley?*
Of the sixteen site-specific characteristics that appear in the Model, six were examined spatially in the exploratory case study. All six, in particular topography, transportation, population home value, percent of sales in manufacturing, and crime had spatial aspects related to renewable energy development.

*What is the spatial arrangement of Coachella Valley's interstate ground transportation system and how does that relate to renewables' manufacturing and operations in the Valley?*
The ground transportation system was analyzed with GSI and shown to have limited expressway access i.e. only Interstate 10, for the first 70 miles of routing from the CV, and then opening up to a large and complex highway network giving access to two major oceanic ports and dozens of

renewables manufacturing sites in greater Los Angeles. Overall distances are significant for cost of transport, and time-consuming especially for very large equipment items.  Roads to some operational commercial sites would need to be large and durable.

*What are the policies recommended based on the Model, and what role does GIS play in developing the policies?*

Examples of policies include recognition of a sharp socio-economic divide in the CV for attracting renewables workforce and facilities.  This divide is unfortunate and could lead to future tensions and conflict. GIS mapping can delineate detailed patterns of this divide as well as progress that can be made on narrowing it.  Recommendations on policies to attract manufacturers can be based on the dominant current location of CV manufacturing in the City of Coachella and southern adjacent unincorporated areas. Additionally, the CV crime patterns are shown by spatial mapping to be in selected affluent census tracts, which can inform policymaking in those cities.

This study has explored the use of GIS for analyzing policy-related conditions and characteristics and proven useful in formulation of government policies.  Future enlargement of the study can strive to populate the entire Model with spatially informed findings yielding powerful support to regional policymaking.

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**References**

AWEA.  (2014).  Manufacturing Facilities.  Washington, DC: American Wind Energy Association.

Berry, B.J.L., and Garrison, W.L. (1958).  The functional bases of the central-place hierarchy. *Economic Geography* 34(2):145-154.

Berry, B.J.L., and Parr, J.B. (1988). *Market Centers and Retail Location*. Englewood Cliffs, NJ_ Pearson Prentice Hall.

Boyle, G. (2012). *Renewable energy: Power for a sustainable future*. Oxford: Oxford University Press in association with the Open University.

Butler, E.W. and Pick, J.B. (1982). *Geothermal Energy Development: Problems and Prospects in the Imperial Valley of California*. New York: Plenum Publishing Company.

Caltrans. (2013). Coachella Valley Intercity Rail Corridor Planning Study. May. Sacramento, CA: California Department of Transportation.

DOE (2013) *2012 Renewable Energy Data Book: Energy Efficiency and Renewable Energy*. Washington, D.C.: Department of Energy.

Esri Inc. (2014) Business Analyst Online. Data sources from various government and private agencies. Redlands, CA: Esri Inc.
Gorsevski, P.V., Cathcart, S.C., Mirzaei, G.L., Jamali, M.M., Ye, X., and Gomezdelcampo, E. (2013) A group-based spatial decision support system for wind farm site selection in Northwest Ohio. *Energy Policy* 55:374-385.

Grassi, S., Chokani, N., and Abhari, R.S. (2012) Large scale technical and economical assessment of wind energy potential with a GIS tool: case study Iowa. *Energy Policy* 45:73-85.

Greene, R.P. and Pick, J.B. (2012). *Exploring the Urban Community: A GIS Approach*. 2nd ed. Englewood Cliffs, NJ, Prentice Hall.

He, G., and Kammen, D.M. 2014. Where, when, and how much wind is available? A provincial-scale wind resource assessment for China. *Energy Policy*, in press.

Kwan, C.L. 2012. Influence of local environmental, social, economic, and political variables on the spatial distribution of residential solar PV arrays across the United States. *Energy Policy* 47:332-344.

Longley, P.A., Goodchild, M.F., Maguire, D.J.., and Rhind, D.W. (2011). *Geographic Information Systems and Science*. New York: John Wiley and Sons.

Mallett, A. (2007) Social acceptance of renewable energy innovations: the role of technology cooperation in urban Mexico. *Energy Policy* 35:2790-2798.

Matek, B. and K. Gawell (2014) Report on the State of Geothermal Energy in California. February. Washington, DC: Geothermal Energy Association.

O'Sullivan, D., and Unwin, D.J. 2003. *Geographic Information Analysis*. New York: John Wiley and Sons.

Perry, M., Pick, J.B., and Rosales, J. (2014) Renewable energy challenges and opportunities: geospatial and qualitative analysis of southern California, in Xie, Y. (Ed.), *Proceedings of 2nd Annual Conference on Geo-Informatics in Resource Management and Sustainable Ecosystem, Springer's Communications in Computer and Information Science Series*, Heidelberg, Germany, Springer Verlag, in press.

Pick, J.B. (2008) *Geo-Business: GIS in the Digital Organization*. New York: John Wiley and Sons.

Pick, J.B., Jung, T.H., and Butler, E.W. (1985). "Projection of Direct Farm Laborer Displacement from Geothermal Development, Imperial County, California." International Journal of Environmental Studies 24:255-265.

Pick, J.B. (2010). Web and Mobile Spatial Decision Support as Innovations: Comparison of United States and Hong Kong, China. *Annals of Information Systems*, Vol 14, D. Schuff, D. Paradice, F. Burstein, D.J. Power, and R. Sharda (Eds.), *Decision Support: An Examination of the DSS Discipline*, pp. 83-112.

Pick, J.B., Perry, M., and Rosales, J. (2014) Renewable energy development and manufacturing potential in the Coachella Valley, California. Final Report submitted to Coachella Valley Economic Partnership. U.S. Department of Commerce Award No. 07-69-06995. Redlands, California: Center for Business GIS and Spatial Analysis, University of Redlands.

Ramsey, K. (2009) GIS, modeling, and politics: on the tensions of collaborative decision support. *Journal of Environmental Management* 90:1972-1980.

Rogers, E.M. (2003) *Diffusion of Innovations*. New York: Free Press.

SEIA (2014a) Various Data Reports. Washington, DC: Solar Energy Industries Association.

SEIA (2014b). Major Solar Projects Map. Washington, DC, Solar Energy Industries Association. Retrieved on May 20, 2014 at www.seia.org.

SCAG (2013) Special Population Projections prepared for Coachella Valley. Los Angeles: Southern California Association of Governments.

State of California (2013) *California State Energy Handbook*. Sacramento: State of California.

Stebbins, R.A. (2001). *Exploratory Research in the Social Sciences*. Thousand Oaks, CA: Sage Publications.

Union of Concerned Scientists (2014) California's Renewables Portfolio Standard (RPS) Program. Report, January. Washington, DC: Union of Concerned Scientists

U.S. Bureau of the Census (2009) Civilian labor force status by selected metropolitan areas, 2009. Washington, D.C.: U.S. Bureau of the Census.

U.S. Bureau of the Census (2010-2014) various publications on States, Counties, Cities, and Unincorporated Places. Washington, D.C., U.S. Bureau of the Census.

U.S. Bureau of the Census (2014) American Factfinder. Washington, DC: U.S. Bureau of the Census.

Wustenhagen, R., Wolsink, M., and Burer, M.J. (2007)  Social acceptance of renewable energy innovation: an introduction to the concept. *Energy Policy* 35:2683-2691.

Yue, C.-D., and Wang, S.-S. (2006) GIS-based evaluation of multifarious local renewable energy sources: a case study of the Chigu area of southwestern Taiwan. *Energy Policy* 34:730-742.