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COMMUNITY RENEWABLE ENERGY: THE POTENTIAL FOR ENERGY GENERATION ON PUBLIC LAND IN CEDAR CITY, UTAH

by

Betsy C. Byrne

A project submitted in partial fulfillment
of the requirements for the degree

of

MASTER OF LANDSCAPE ARCHITECTURE

Approved:

Carlos V. Licon, Ph.D. Major Professor	Keith M Christensen, Ph.D. Committee Member
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UTAH STATE UNIVERSITY
Logan, Utah

2016

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ABSTRACT

Community Renewable Energy: The Potential for Energy Generation on Public Land In Cedar City, Utah

by

Betsy C. Byrne, Master of Landscape Architecture

Utah State University, 2016

Major Professor: Dr. Carlos V. Licon
Department: Landscape Architecture and Environmental Planning

As the world's population rises and becomes increasingly more urbanized, there is a greater demand on our resources. Current energy production practices are based on resources with finite supplies and are associated with environmental impacts such as greenhouse gas and particulate emissions, water resource use, and resource extraction. In contrast, renewable energy production is based on free, continually replenished sources with relatively few environmental impacts. Distributed renewable energy generation involves producing energy close to the point of consumption. The distributed generation model increases energy autonomy at the local level.

Distributed renewable energy generation is fairly common at point of use. However, it is not common at the community scale, at least here in the U.S. Communities that wish to pursue local energy generation as a strategy to increase energy autonomy may not be aware of what resources they have at hand either in the form of renewable energy sources or in terms of available land for energy production, nor an understanding of how much of their energy consumption could be met by locally produced energy.

This study explores the potential for local solar and wind energy generation on publicly owned land in Cedar City, Utah. The available public land was analyzed at two scales: within the municipal boundary and within 8 kilometers of the town boundary. Six scenarios were developed to represent different amounts of land given over to energy production in an attempt to meet the targets of 25%, 50%, or 100% of the city's annual energy consumption, and the amount of energy produced by each scenario was calculated. Within town, the opportunities for energy generation were fairly limited, though some strategies, such as installing solar panels at the point of use, would have value. In contrast, by expanding the scope to include an additional eight kilometers around the city, parcels of land were included for energy generation that would make a significant impact on the annual energy consumption of the city.

This study highlights the need for planners and landscape architects at the city level who can take an active role in energy planning by identifying resources, evaluating alternatives, and make strategic decisions on land and resource use.

(83 pages)

PUBLIC ABSTRACT

Community Renewable Energy: The Potential for Energy Generation on Public Land In Cedar City, Utah

Betsy C. Byrne

As the world's population rises and becomes increasingly more urbanized, there is a greater demand on our resources. Current energy production practices are based on resources with finite supplies and are associated with environmental impacts such as greenhouse gas and particulate emissions, water resource use, and resource extraction. In contrast, renewable energy production is based on free, continually replenished sources with relatively few environmental impacts. Distributed renewable energy generation involves producing energy close to the point of consumption. The distributed generation model decreases reliance on the traditional centralized grid, which limits the need for substantial and costly transmission infrastructure. Furthermore, distributed generation increases energy autonomy and self sufficiency at a local level.

Distributed renewable energy is fairly common at point of use. However, it is not common to develop renewable energy generation at the community scale, at least here in the U.S. Communities that wish to pursue local energy generation as a strategy to become more resilient by increasing energy autonomy may not be aware of what resources they have at hand either in the form of renewable energy sources or in terms of available land for energy production. There may also be little understanding of how much of their energy consumption could be met by locally produced energy.

This study explores the potential for local solar and wind energy generation on publicly owned land in Cedar City, Utah. The available public land was analyzed at two scales: within the municipal boundary and within 8 kilometers of the town boundary. Three zones for wind energy generation were identified based on height restrictions for turbines. Additionally, three types of locations for solar photovoltaics were identified: rooftops, parking lots, and land for free-standing arrays.

Six scenarios were developed to test whether the public land in Cedar City could generate enough energy to meet the targets of 25%, 50%, or 100% of the city's annual energy consumption. Within town, the opportunities for energy generation were fairly limited, though some strategies, such as installing solar panels at the point of use, would have value. In contrast, by expanding the scope to include an additional 8 kilometers around the city, parcels of land were included for energy generation that could significantly impact the annual energy consumption of the city.

Renewable energy generation can and should be integrated into a community's infrastructure. However, there are a number of factors that may affect the availability of land for energy generation as well as how much energy can be produced. This study highlights the need for planners and landscape architects at the city level who can take an active role in energy planning by identifying resources, evaluating alternatives, and making strategic decisions on land and resource use.

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Big thanks to my committee chair Dr. Carlos Licon for sticking with me through this and for always having a knack for describing my thesis in more creative terms than I ever could. I would also like to thank my committee members, Dr. Keith Christensen and Dr. Edwin Stafford, for their excellent insights and support. And finally, thank you to my partners in crime Eric Anderson, Kathryn Knight Sonntag, Ryan White, Ana Baez Sarita, Dayton Crites, and Joel Warren for being the best part of this whole going-back-to-school experience.

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CHAPTER I

INTRODUCTION

Our future is linked to how cities are shaped and how they function. The United Nations (UN) report on global urbanization projects an increase in population of 2.3 billion over the next four decades to a total of 9.3 billion by 2050. At the same time, the population living in urban areas is expected to grow 2.6 billion to a total of 6.3 billion, meaning that 67% of the world's population will be urban in 2050 (United Nations, 2012). In North America, that number will be even higher, as more than 88% of the population will be urban (United Nations, 2012).

This increase in population will have an effect on the ecological footprint of urban areas, not only in terms of the physical footprint upon the land but in terms of the resources needed to fuel the city's processes. With regards to energy for transport and energy use by buildings, cities consume 75% of the world's energy, and account for 80% of greenhouse gas emissions, according to the UN (as cited in Ash, Jasny, Roberts, Stone, & Sugden, 2008). The intensity of the impact of urban areas requires us to rethink the way we plan our cities and how we produce the resources necessary for economically, socially, and environmentally successful cities.

In response to this need, the mayors of 1,060 U.S. cities have signed an agreement recognizing that action must be taken at the local level to foster resilient cities that respond to global issues such as energy consumption, greenhouse gas emissions, and uncertain fossil fuel supply (United States Conference of Mayors, 2005). Part of this response involves changing the way cities access energy. Developing renewable energy projects within or near a community's boundaries has a number of benefits including reducing energy loss through transmission (Chiradeja & Ramakumar, 2004), reducing environmental impacts such as greenhouse gas emissions (Dincer, 2000), positive economic impacts (Lantz, Tegen, & National Renewable Energy Laboratory, 2009), and increased energy autonomy (Rae & Bradley, 2012).

Renewable energy projects that are locally sited and owned have the additional benefit of allowing a community to take an active role in energy planning. As Pahl (2007) points out, "local ownership and control allows the community to create a project that meets its particular needs while addressing its concerns about size, scale, and location" (p. 267). In order to do so, however, there is a need for carefully considered spatial planning to identify the areas where renewable energy generation can take place.

There are many examples of wind or solar projects on farm land or private land such as the Minwind projects near Luverne, Minnesota or the Poudre Valley Rural Electric Association solar farm near Ft. Collins, Colorado. But communities have another resource that may potentially be tapped: public land owned by the community itself. This land belongs to the community and therefore no land needs to be purchased or leased in pursuing an energy project for public benefit. However, in order to pursue such a project, city leaders and planners must understand what resources they have at hand locally or regionally, how much potential there is for energy generation, and what potential benefits and barriers there might be. There is little research on how a community might approach the use of publicly-held land as a potential source for generation, or how much energy might be generated by that land.

To address the need to better understand the potential for renewable energy generation within a community, this study explored the capacity of Cedar City, Utah, to generate enough energy on city- or county-owned land to meet 25%, 50%, or 100% of the community's annual energy consumption. The results of this study will help to highlight the potential, as well as the complexities, in community renewable energy.

CHAPTER II

LITERATURE REVIEW

The intent of this chapter is to give an overview of the importance of integrating renewable energy into sustainable, resilient cities, and to describe the possibilities provided by different forms of renewable energy.

Developing Resilient Cities

Newman, Beatley, and Boyer (2009) argue the importance of developing "resilient cities" that move towards reducing oil consumption in order to reduce impacts on the environment and human health; to reduce dependence on foreign oil and vulnerability to fluctuations in oil prices; and to increase economically competitive use of resources through new technology. A city that is resilient is less dependent on outside resources and therefore can better respond to changes in supply. In moving toward resilience, a city reduces its ecological footprint, while improving quality of life for its residents. To achieve these goals, "resilience needs to be applied to all the natural resources on which cities rely" (Newman et al., 2009, p. 7).

Newman et al. (2009) describe seven elements of resilience: the renewable energy city, the carbon neutral city, the distributed city, the photosynthetic city, the eco-efficient city, the place-based city, and the sustainable transport city. The goal of these elements is to create a city with carbon neutral homes and businesses; distributed power, water, and waste systems; closed-loop systems that reuse waste streams; and transportation based on walkability, public transit, and electric vehicles. In tandem with these

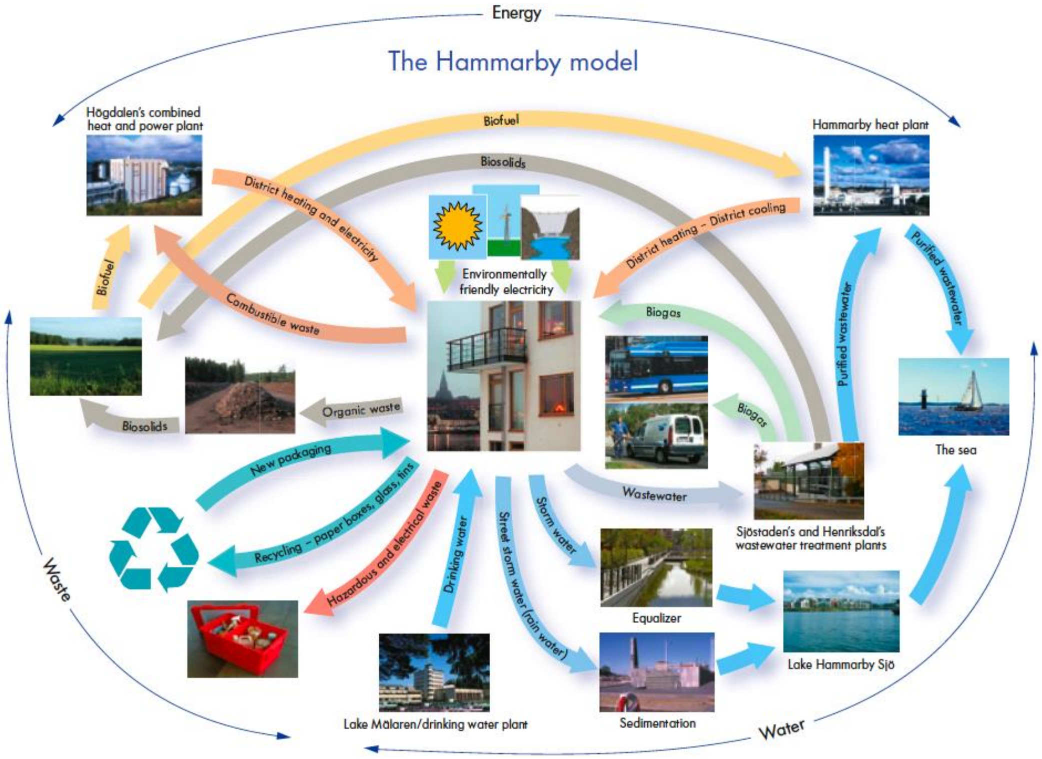


Figure 1. Hammarby Sjöstad is designed to have a closed-loop system that uses and reuses waste, water, and energy streams. From Hammarby Sjöstad, City of Stockholm, Sweden, by L.W. Bumling, 2009, retrieved from http://www.hammarbysjostad.se/

elements, renewable energy is a significant component of a resilient city and should be generated on multiple levels from the building to the region. In addition, cities should capitalize on local resources as a way to develop the local economy and encourage a sense of identity that is unique to the place. As the authors point out,

> In no small part, this is about a new way of understanding cities. Renewable energy production can and should occur within cities, integrated into their land use and built form, and comprising a significant and important element of the urban economy. Cities are not simply consumers of energy, but catalysts for more sustainable energy paths (Newman et al., 2009, p. 59).

Williams (2007) relates the idea of community to ecology, describing a community as a living organism whose form is the result of interrelated elements and processes. According to him, the current focus on sustainable urban design is on the form of the community, on its walkability, the scale of the streets, the location of town centers and gathering places, and transportation. Williams includes local renewable energy generation as an important part of the community organism:

> However, long-term sustainability is not achievable in these communities, as they rely almost entirely on nonrenewable energy. No matter how charming the pattern, any biological community, including the human community, must tie its long-term development and use to the sustainable energies and resources that are resident to the *place.*" (Williams, 2007, p. 69)

Williams further points out the importance of understanding the ecological processes at a larger, regional scale in order to design communities that live within their means, leading to a greater impact on sustainability. He uses the term "biourbanism," which "involves designing the connections to make use of place-based energies and resources and integrating them into the urban and community scale" (Williams, 2007, p. 24). The way we design and lay out our infrastructure, including energy sources, transmission lines, roads, stormwater drainage, and other utilities, affects the sustainability of a community. Sprawl, pollution, and resource consumption can be reduced by generating locally what is needed by a community.

In an effort to provide guidelines for just how we might cultivate sustainable communities, the Congress for the New Urbanism issued the *Canons of Sustainable Architecture and Urbanism* (n.d.). The Canons clarify sustainable practices concerning the planning and design of communities and address renewable energy at three levels: the building, the neighborhood or town, and the region:

The Building and Infrastructure:

- Individual buildings and complexes shall both conserve and produce renewable energy wherever possible to promote economies of scale and to reduce reliance on costly fossil fuels and inefficient distribution systems.
- Renewable energy sources such as nonfood source biomass, solar, geothermal, wind, hydrogen fuel cells, and other nontoxic, nonharmful sources shall be used to reduce carbon and the production of greenhouse gases.

Neighborhood, Town and City:

- Renewable energy shall be produced at the scale of neighborhood and town as well as at the scale of the individual building in order to decentralize and reduce energy infrastructure.

Region:

- Regions shall strive to be self-sustaining for food, goods and services, employment, renewable energy and water supplies ("Canons," n.d., p. 3-6).

The call for rethinking the way we plan for and use energy is coming not only from planners and proponents of sustainable communities, but from the energy sector as well. Carlisle, Elling, and Penney (2008) discussed the need to reinvent the way we design and develop communities in order to reduce energy consumption and to increase the use of local resources. Carlisle et al. (2008) used the term "renewable energy community," which is defined as:

> a state-of-the-art community in which integrated, renewable energy technologies play the primary role in meeting the energy supply and demand needs of its residents, with the possibility of providing excess energy back to the grid or other communities. At a minimum, this community will have near-zero or zero-energy homes (ZEHs), integrated transportation modes with advanced vehicles, local renewable energy generation, and incorporate sustainable living practices. The community will provide economic benefits and a positive impact on quality of life (p.1).

Similar to Williams (2007) and Newman et al. (2009), this definition of a renewable energy community points out the necessity of thinking of energy as part of a larger system of human needs and practices, and the importance of considering the relationships within the whole system when integrating energy sources into the community. However, the report found that there was little information about *how* to design communities that incorporate renewable energy systems.

Understanding Distributed Generation

The majority of our power supply comes from large, centralized plants that are typically coal or natural gas fired. These plants are usually located far from population centers where the energy is consumed, requiring a vast network of transmission lines. In contrast, distributed generation refers to "small, modular, decentralized, grid-connected or off-grid energy systems located in or near the place where energy is used" (U.S. Environmental Protection Agency, 2014). This type of energy generation can occur at two levels, the local level and the end point or end user level (Akorede, Hizam, & Pouresmaeil, 2010). Though distributed generation can be fossil fuel powered, it is frequently associated with renewable energy sources, such as solar, wind, hydro, geothermal, and biomass.

There are several benefits associated with distributed energy generation. One of the primary benefits is the way in which decentralized, locally produced energy contributes to a community's energy autonomy. Energy autonomy can be defined as "the ability of an energy system to function (or have the ability to function) fully, without the need of external support in the form of energy imports through its own local energy generation, storage and distribution systems" (Rae & Bradley, 2012, p. 6499). While complete energy autonomy might not be possible for many American cities and communities at this time, diversification of energy supply through local generation can increase self-sufficiency and reduce the extent to which a community must rely on outside sources of energy.

The Northeast Blackout in 2003 is a dramatic example of the potential vulnerability of a complex interconnected power grid. The blackout caused 50 million people in eight U.S. states and two Canadian provinces to lose power after a cascading power surge affected over 400 transmission lines and 261 power plants (Andersson et al., 2005; Barron, 2003). Though this was an extreme case, it serves to illustrate that a community with its own power supply is potentially less vulnerable in the event of a major system failure, and in turn could lessen the demand on the greater network (Andersson et al., 2005).

Another potential benefit of distributed generation is the reduction in electrical system losses, or energy that is lost in the transmission, transformation and distribution between source and delivery points (U.S. Department of Energy, 2007). Electric system losses in the United States add up to an average of 7% of electricity transmitted annually, and in 2010, that meant a loss of 261,990 million kilowatt hours (U.S. Energy Information Administration, 2010). By producing energy closer to where it is used, such losses may be reduced (Chiradeja, 2005; Pepermans, Driesen, Haeseldonckx, Belmans, & D'haeseleer, 2005).

In addition to reducing transmission and distribution losses, distributed generation may contribute to local reductions in peak demand. Electricity demand fluctuates throughout the day and throughout the year, with the highest demand typically taking place on hot summer afternoons. The ability of local energy sources to trim the peak demand affects the larger grid system, reducing the load on transmission lines, substations, and equipment and allowing utilities to allocate electricity elsewhere. Wear and tear may also be reduced, leading to deferred infrastructure upgrade investments and maintenance costs (U.S. Department of Energy, 2007).

Understanding Renewable Energy

According to the U.S. Energy Information Administration (2013b), 4,054 billion kilowatt hours of electricity were generated in the United States in 2012. Fossil fuels accounted for 68% of that generated electricity, with coal accounting for the largest share (37%). In this conventional practice of generating electricity, fossil fuels such as coal, natural gas, and petroleum are burned to create high pressure steam used to rotate a turbine which in turn drives a generator to create an electric current. Fossil fuels are derived from carbon from decayed organic matter formed over millions of years and are considered to be finite in supply.

In contrast, renewable energy sources accounted for 12% of generated electricity in the U.S., with the majority coming from conventional hydropower (56% of total renewable energy) (U.S. Energy Information Administration, 2013a). Renewable energy resources are considered continuously replenished "but limited in the amount of energy that is available per unit of time" (U.S. Energy Information Administration, 2014). Such resources include solar, wind, hydro, geothermal, biomass, ocean thermal, wave action, and tidal action.

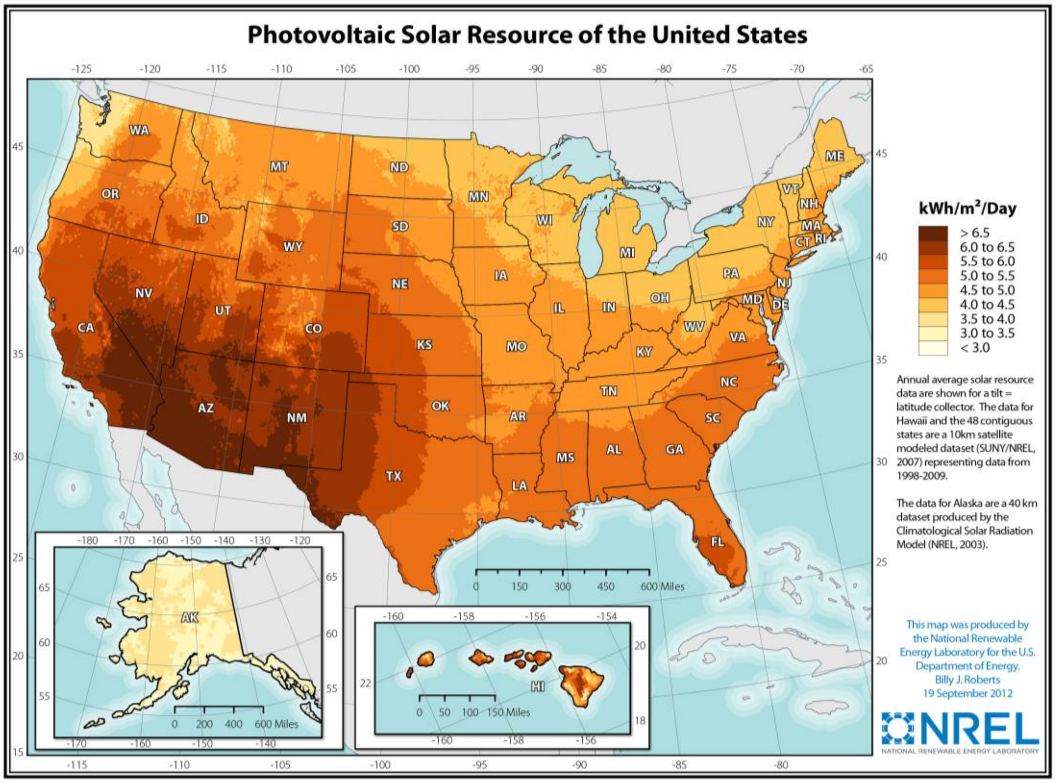
The production of electricity can have significant environmental impacts. For example, the electric power sector in the U.S. generated 2,039 million metric tons of carbon dioxide (CO_2) emissions in 2011. Coal fired power plants were the worst offenders, generating 1,514 million metric tons, or 74% of the total. (U.S. Energy Information Administration, 2013c). Fossil fuel fired power plants are also the largest sources of sulfur dioxide (SO_2) emissions (U.S. Environmental Protection Agency, 2012), and produce other greenhouse gas emissions such as nitrogen oxides, mercury compounds, and particulate matter (Gaffney & Marley, 2009).

By contrast, emissions from electricity produced by renewable energy sources such as solar, wind, and hydro are negligible, since no fuels are combusted. However, power produced from burning biomass or biogas does produce emissions such as nitrogen oxides, sulfur dioxide, and methane. The type and amount of emissions depend on what is burned and how (U.S. Environmental Protection Agency, 2013).

As mentioned above, potential sources of renewable energy are solar, wind, hydro, geothermal, biomass, ocean thermal, wave action, and tidal action. Any of these sources may have potential depending on the community. As will be seen in Chapter III, wind and solar were found to have the most potential in the study's focal city. The following is a brief description of these two most common sources of renewable energy.

Solar Energy

Though the incidence of solar radiation on the Earth's atmosphere varies, its average value is approximately 1,354 W/m^2. However, due to reflection, scattering, or absorption in the atmosphere, only about half of this energy on average reaches the earth's surface and can be used to generate power (Tester, Drake, Driscoll, Golay, & Peters, 2005; Quaschning, 2005). And of course, this solar irradiance varies throughout the world depending on latitude and throughout the year depending on the Earth's tilt.



Annual average solar resource data are shown for a tilt = latitude collector. The data for Hawaii and the 48 contiguous states are a 10km satellite modeled dataset (SUNY/NREL, 2007) representing data from 1998-2009.

The data for Alaska are a 40 km dataset produced by the Climatological Solar Radiation Model (NREL, 2003).

This map was produced by the National Renewable Energy Laboratory for the U.S. Department of Energy.
Billy J. Roberts
19 September 2012

Figure 2. Photovoltaic solar resource map. From National Renewable Energy Laboratory, 2012b.

For example, in Utah, St. George averages about 7.6 kWh/m^2/day over the course of a year, while the Salt Lake Valley receives approximately 5.8 kWh/m^2/day (National Renewable Energy Laboratory, 2012a). Figure 2 shows the solar resource for the U.S.

Photovoltaics (PVs) generate electricity directly from solar radiation. Energy is produced when particles of light are absorbed by semi-conductors typically made from silicon. Solar panels are made from modules of about 40 or 50 cells and can be installed on rooftops, building walls, or as free standing arrays. Good exposure to the sun is key for effective energy generation, meaning panels must be oriented towards the sun as much as possible. Some panels have tracking systems in order to follow the sun and receive the optimum exposure at any time, but these systems are expensive. Fixed panels are less costly, and, if oriented correctly, can still be very effective. In the northern hemisphere, panels perform best when oriented perpendicular to the sun's rays and due south, though they can be positioned 30 to 45 degrees east or west of true south and still perform reasonably well. Because the angle of the sun changes throughout the year (at its highest angle in the summer, at its lowest in the winter), fixed panels should be tilted at an angle equal to the latitude to receive the maximum average. When siting solar panels, it is also critical to consider shading from nearby trees or buildings, as shade can significantly reduce the power output (Sewall, 2009; U.S. Department of Energy, 2012).

Even when properly sited, solar cells typically reach an efficiency of 14-17%, meaning only 14-17% of the input from the sun is being converted into energy (Ristinen & Kraushaar, 2005). Despite this, PVs are effective and are becoming increasingly more common, and the efficiency of the technology is improving. Small PVs are used quite frequently for small applications, such as road signs and outdoor lighting, and for more complex applications where power supply from the grid is not possible, such as remote water pumps and satellites. PVs are also becoming increasingly common for residential and commercial buildings, in part because of tax incentives that mitigate the cost of the system. Some communities are developing programs that allow participating residents to purchase solar panels in bulk, thus reducing costs and streamlining the process. Community Solar, an initiative of Utah Clean Energy, ran a pilot program in 2012 involving 64 households Salt Lake City, Utah ("Salt Lake Community Solar Program," n.d.). These types of community programs indicate one way in which renewable energy programs can happen: participants interested in instituting clean energy practices can pool their resources and work together to make renewable energy projects happen on a local scale.

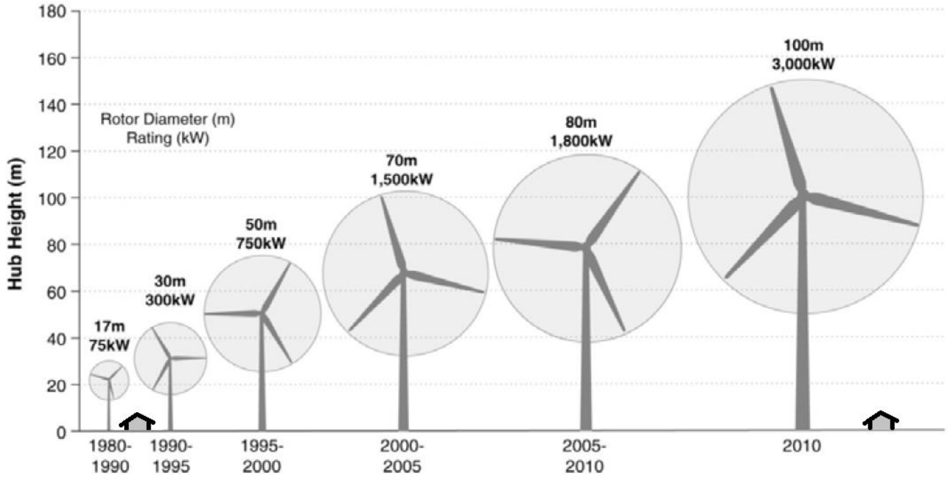
Concentrated solar power (CSP) involves using mirrors to focus the sun's rays in order to boil water to drive a conventional steam turbine electric generator. One type of CSP uses an array of reflectors to focus sunlight on a central tower; another system involves reflectors that focus light onto an individual receiver, and the heated fluid is circulated to a central steam engine (Ristinen & Kraushaar, 2005). These CSP facilities require a large land area and can have a significant footprint. CSP is also expensive, typically higher in cost than a coal-fired power plant even when considering the fuel is free; however, costs are expected to decrease as more facilities are built and technological advances are made. At present, CSP is being used for large, utility scale power production in remote locations, such as those in the Southern California desert, rather than in smaller, decentralized, community areas (Sheer & Stevens, 2012).

Wind Energy

The advantage of wind power over solar is that wind can blow day or night, with overcast skies, and during the winter when the sun is weak. However, wind can be highly intermittent with considerable variability in direction, speed, intensity, and duration. This intermittency may result in the wind blowing at times when the demand is low or being calm when demand is high. It is therefore important to understand the both the average wind speed and the distribution of wind speeds over time in order to determine the potential for wind energy at any site (Gipe, 1999; Ristinen & Kraushaar, 2005).

Power production is affected by factors such as air density, which varies with air temperature and elevation, and the height of the windmill, given that wind speed increases with height (Gipe, 1999). No wind turbine can harness the total energy from the wind however. A theoretical maximum power efficiency calculation known as the Betz limit suggests that 59% of the kinetic energy of wind can be converted into mechanical energy. This is a mathematical ideal that cannot be achieved in practice; in reality, wind turbines often attain an efficiency of 16-46% depending on the type of turbine, whether it has a vertical or horizontal axis, and the ratio of blade tip speed to wind speed (Anaya-Lara, 2009; MacKay, 2009; Ristinen & Kraushaar, 2005).

There are three general classes of wind turbines: small windmills of less than 10 kW used on farms or by individual households, medium sized turbines of 10-500 kW, and large wind turbines of 500 kW to 5 MW that generate utility scale power for



distribution on the grid (Anaya-Lara, 2009).   The height of wind turbines can vary from

Figure 3. Wind turbine size increase 1980-2010. From The Past and Future Cost of Wind Energy (p. 2) by E. Lantz, M. Hand, and R. Wiser, 2012, retrieved from http://www.nrel.gov/docs/fy12osti/54526.pdf

less than 50 m for small or medium-sized turbines to up to 120 m for the largest (see Figure 3). Since average wind speed increases with height and power increases as velocity cubed, the higher the hub height of the turbine the better the power output. In addition, air flow tends to fluctuate less at greater heights, with less turbulence from topography, buildings, or vegetation. However, increased size leads to increased cost as well as increased visual presence, so the cost/benefit tradeoff must be considered (Tester et al., 2005).

Location of Energy Production

When it comes to the location of distributed renewable energy generation, much of the focus is on building integrated sources. Solar PVs on roofs or wall mounted systems are frequently discussed as ways to integrate energy generation into homes or office buildings (Ritchie & Thomas, 2009; Smith, 2003) and are becoming more common. Wind energy in urban spaces is more problematic due to factors such as turbulence and variable wind speeds. Small building mounted wind turbines are available, but may not be viable except in the windiest of places, such as coastal regions (Bahaj, Myers, & James, 2007; Eriksson, Bernhoff, & Leijon, 2008). On a more dramatic scale, the Strata 1 Tower in London and the Bahrain World Trade Center are examples of efforts to integrate large wind turbines into the building as part of the structure itself. It has yet to be seen if this type of building integrated wind generation is viable, though early reports indicate that there are still many issues to be worked out, such as vibration, noise, and ability to actually capture enough wind (Stankovic, Campbell, & Harries, 2009; Wilson, 2009).

Though building integrated renewable energy consumes a significant part of the discussion, there are also efforts going on at the larger municipality or regional level. Some communities are developing community-owned renewable energy generation facilities from solar or wind farms to biomass plants (Walker, 2008). This practice is currently quite common in Europe, with numerous projects in Germany, Sweden, and Denmark, to name a few.

Denmark has set an ambitious goal of 100% renewable energy in its energy, heating, industrial, and transport sectors by 2050, and hopes to generate 50% of its electricity primarily from wind by 2020 (Danish Energy Agency, 2014; Fraende, 2011). Several communities are already 100% renewable such as those on Samsø, an island with six towns and 4000 residents. The island is powered by 10 offshore wind turbines and 11 onshore, and 16 of the turbines are owned by local farmers, local cooperatives, or by the municipality of Samsø (Danish Energy Agency, 2009). The island also has four district heating plants, primarily fueled by biomass, that provide heating for 65% of homes.

Forty-five percent of Sweden's energy for electricity, heating, and fuel comes from renewable energy. Hydropower and biofuels are the primary sources, with wind power on the rise (Swedish Institute, 2011). Sweden is particularly committed to sustainability, as exemplified in the Vastra Hamnen district in Malmö, a former shipyard that has been transformed into a model of sustainable urban development. The first phase of this development is known as Bo01, which was meant to be an innovative showcase of sustainable design principles such as high densities, architectural variety, rainwater treatment, access to green spaces, and an emphasis on cycling and public transport (Ritchie & Thomas, 2009). Renewable energy is a fundamental consideration in Bo01, with the goal of generating 100% of the district's energy from renewable sources. The district employs several strategies that work together to achieve renewable energy goals:

- Energy efficient buildings, lighting, and household appliances reduce heat and electricity consumption.
- Electricity is generated by a 2 MW wind turbine in the north harbor, supplemented by 120 m^2 of photovoltaics.
- Heating is supplied primarily from water stored in an underground aquifer as well as from 1,400 m^2 of solar thermal collectors.
- Organic waste and sewage are used to produce biogas which is pumped into the natural gas system.

The district is connected to existing city infrastructure, which acts as a backup when demand is high or as a repository for excess energy when supply is higher than demand (Malmö Stad, 2014; Ritchie & Thomas, 2009).

Projects like these are common in Europe, but a growing number of U.S. cities are making efforts as well. After a tornado obliterated Greensburg, Kansas, in 2007, the citizens decided to rebuild their town with a goal of 100% renewable energy. Their strategy included a 12.5 MW community owned wind farm to work in conjunction with energy efficient buildings (Pless, Billman, Wallach, & National Renewable Energy Laboratory, 2010). The wind farm consists of 10 1.25 MW turbines, enough to power the whole town as well as produce excess power that is sold to the grid. The total cost for the project was $23.3 million, paid for primarily through a U.S. Department of Agriculture Rural Development loan (U.S. Department of Energy & National Renewable Energy Laboratory, 2010).

In 1982, the city of Boulder, Colorado began installing turbine generators on pipelines in its municipal water system (International Energy Agency & CADDET Centre for Renewable Energy, 2000; Pahl, 2007). The city's water supply comes from the North Boulder Creek watershed and flows down the mountain under high pressure due to the drop in elevation. The turbines take advantage of this high pressure, reducing the need for pressure relieving valves. The environmental impacts from the project are minimal since it uses infrastructure that is already in place. In 2012, the municipal water system generated more than 35 million kWh, and the sale of some of that electricity generated more than $1.6 million for the community ("Hydroelectricity," 2013). Projects like these work well at the municipal level, providing not only local control but the potential for economic benefit.

As more communities pursue energy generation at the community or regional level with the goal of becoming more self reliant and sustainable, the need is growing for carefully considered spatial planning to identify the areas where renewable energy generation can take place. In the last few years, a new area of study has emerged that focuses on "sustainable energy landscapes" and the ways in which renewable energy generation can be integrated into the community or regional structure. Several articles have been published concerning spatial planning based on developing linkages between energy demand, land uses, and renewable or residual resources (Leduc & Van Kann, 2013; Stremke & Koh, 2011); the importance of considering the 'whole system' of the urban fabric and its energy supply and demand (Vandevyvere & Stremke, 2012); and the methods of landscape architecture or environmental planning that can be applied to the development of sustainable energy landscapes (Stremke, Koh, Neven, & Boekel, 2012; Stremke, Van Kann, & Koh, 2012).

Sven Stremke of the Landscape Architecture Group at Wageningen University in the Netherlands is at the forefront of this new area of research and has recently edited a book that aims to gather these new ideas and methodologies to provide a resource for those interested in planning, designing and developing sustainable energy landscapes. The book provides this definition: "We define a *sustainable energy landscape* as a physical environment that can evolve on the basis of locally available renewable energy sources without compromising landscape quality, biodiversity, food production, and other life-supporting ecosystem services" (Stremke & Dobbelsteen, 2012. p. 4).

Stremke has developed a framework for the design process modeled after similar design approaches proposed by Steinitz, Albrechts, and Dammers. This framework consists of five steps: analysis of present conditions (step 1), mapping near-future developments (step 2), identifying possible far-futures (step 3), developing integrated visions (step 4), and identification of spatial interventions (step 5). The purpose of this process is to illustrate multiple possible interventions that are specific to the place. These scenarios can be used to guide the development of future sustainable energy landscapes that are integrated into the cultural and natural processes of the region (Stremke, 2012).

Stremke's work demonstrates the need for a landscape architect's skills in the planning and development of localized renewable energy systems that work as part of the community organism. In turn, landscape architects must understand the technical requirements for renewable energy generation within a community, and cultivate an understanding of how such systems can be integrated into a sustainable, resilient community.

In other countries, particularly in Europe, renewable energy-fueled cities are not just a topic of speculation, but a specific, defined goal that governments at both the local and national level are working towards. But here in the U.S., the idea of community-scale renewable energy is relatively unexplored, and we continue to rely on the old model of mass producing fossil fuel energy in distant locations and transporting it to population centers hundreds or thousands of miles away. Over the next 15 years, the electricity sector in the western United States will invest more than $200 billion in upgrading and replacing energy generation facilities and transmission systems (Linvill et al., 2011). As pointed out by Linvill et al. (2011), we have the choice to continue to rely on fossil fuels and the grid as it is now, or invest in a modernized, efficient, and clean alternative based on renewable energy. But this requires us to re-think energy - where it is generated, how it is generated, and how it is delivered. If our energy is to come from distributed renewable energy generation, as is argued for here, it requires us to think about our land use decisions and what priority we place on becoming self-sufficient and resilient.

Here in the U.S., many cities have not given serious consideration to integrating renewable energy generation into the fabric of the community, or know where to start in assessing the possibility. Furthermore, many communities are unaware of the resources they have at hand in terms of available land, or how much energy could be generated using local resources. One potential source for community-scale generation is land owned by the community itself. By using land that it already owns, a city can make use of its own assets without having to buy or lease land. Depending on what's available, energy production may be compatible with already established uses (the rooftops of schools may be used for solar PVs, for example) or may take place on vacant land that is not given over to any other use. However, it is important to understand just how much energy may be generated on such land, and what the benefits and drawbacks might be in order to determine whether it is in the community's best interest to use its public land in this way.

The following is an examination of the potential for energy generation on public land in one Utah city, how much energy might be generated on its public land, and what some of the effects of that use of the land might be.

CHAPTER III

METHODS

Cedar City Overview

With the variety of sources of renewable energy, every city has its own unique opportunities for becoming a renewable energy city, and there are many possible configurations depending on what's available in each place. Therefore the renewable energy picture will look different for each community. This requires an understanding both of what is available and of how that fits in to the infrastructure of the community. In order to explore the possibilities of locally owned, locally sited energy production, this study focuses on one Utah city and its potential.

The selection of a focus community started with an overview of the potential for renewable energy in Utah from the Utah Renewable Energy Zones Task Force Phase I Report (Berry, Hurlbut, Simon, Moore, & Blackett, 2009). Though the report was focused more on utility scale energy generation, it identified areas in the state with good wind, solar, and geothermal resources, and this information was used to pinpoint communities where renewables could meet at least some of the energy need. Logan, Tooele, Ogden, Salt Lake City, and Cedar City were among the cities considered. These candidates were narrowed down further by factors such as city size, population size, and topography as well as type, quality, and availability of renewable energy sources.

Cedar City was chosen due in part to the availability of data for the area, the positive wind and solar resources, and the size of the community. Cedar City is a small but growing community with a population of 28,857, an increase of 41% over its population in the year 2000, which makes it one of the fastest growing cities in the state and the largest city in Iron County (Utah Governor's Office of Planning and Budget, Demographic and Economic Analysis, 2011). Cedar City's growth is due in part to Southern Utah University and to the city's position as a gateway community to Cedar Breaks National Monument, Dixie National Forest, Brian Head Ski Resort, and the Kolob section of Zion National Park, which attract businesses, workers, and tourists to the city. Cedar City is small enough that there is the potential for a considerable amount of its energy needs to be met by renewable energy resources, and at a point in its growth where it can still make land use decisions that involve renewable energy generation (see Figure 4).

Once Cedar City was chosen as the focus community, geographic information system (GIS) data, specific to the city, was gathered that defined the geographic locations and characteristics of factors that affect where energy generation can take place (see Table 1). This GIS data was combined with aerial imagery to pinpoint publicly owned sites with a potential for energy generation. These included:

- City- or county-owned parcels of land
- Buildings located on city- or county-owned land
- Schools belonging to the Iron County School District
- Southern Utah University
- Parking lots on city- or county-owned land
- Parking lots adjacent to schools

The public land was included at two different scales: within the municipal boundary and within a buffer of eight kilometers around the municipal boundary. This

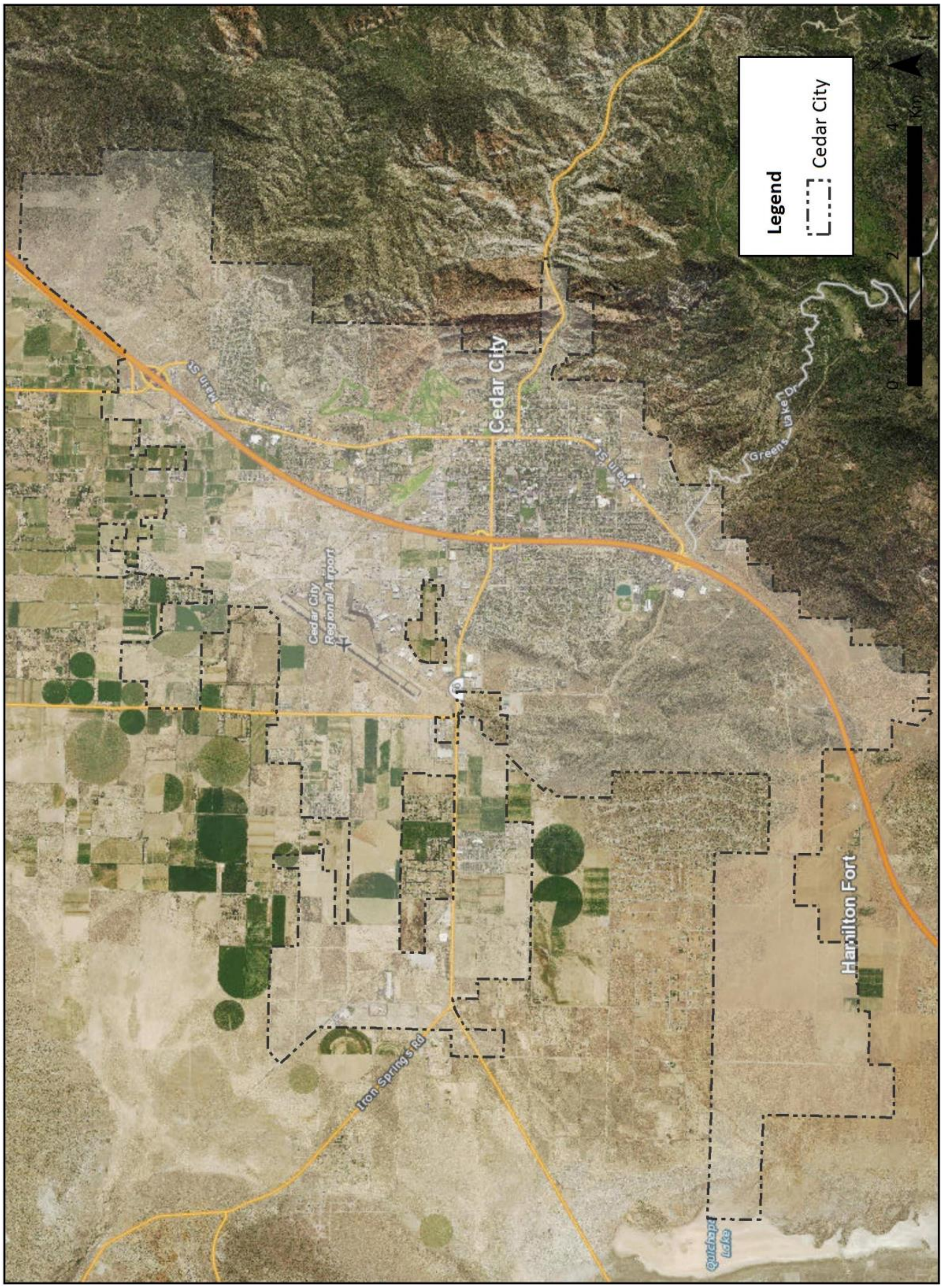


Figure 4. Cedar City, Utah.

Table 1.

Geospatial Data Gathered by Information Source

Utah Automated Geographic Reference Center (AGRC)
Land ownership (private, state, federal)
Wilderness or protected lands
Municipal boundaries
Parcel data
Schools
Parks and golf courses
Roads
Wildlife
National Renewable Energy Laboratory (NREL)
Wind: Utah 50 meter resolution wind
Solar: Annual average direct normal irradiance (kWh/m^2/day)
Geothermal: Deep enhanced geothermal systems
Biomass: Total biomass by square kilometer (tonnes/km^2/year)
Cedar City and Iron County
City-owned land
County-owned land
Building footprints

additional land within the eight-kilometer buffer was added as an acknowledgement that a municipal boundary line is somewhat arbitrary and subject to change as a city grows, and a community may reasonably look to the land adjacent to town for resources that may still be considered "local". This takes into account the fact that Cedar City will grow, and now is the time to look at what resources are available, decide how the city wants them to be used, and determine how that is affected by land use decisions

Other key information was gathered on the city's energy consumption and the source of that energy. While several communities in the state have their own municipal power systems such as Logan, Murray, and St. George, and therefore have more local control over planning, development, acquisition, and other power-related decisions, most of the state gets its power from Rocky Mountain Power. Rocky Mountain Power and its parent company PacifiCorp provide energy produced primarily from coal (60.37%), followed by gas (12.16%), hydro (8.42%) wind (7.92%), and other sources (11.12%) (PacifiCorp, 2013). Though a small percentage of its overall energy supply, the company supports renewable energy through its Blue Sky program, in which customers can buy 100 kilowatt-hour blocks of renewable energy that Rocky Mountain Power either produces or acquires through a power purchase agreement (Rocky Mountain Power, 2014). The Blue Sky program is also used to fund community-based renewable energy projects, usually involving solar panels, wind turbines, or low impact hydro for educational or public service facilities.

According to Mark Cox (personal communication, April 16, 2013), the Cedar City area Customer and Community Manager for Rocky Mountain Power, the annual electrical energy consumption in Cedar City is 261,365,000 kWh. Table 2 shows the current population of Cedar City, the total annual electricity consumption, and the future projections of population and consumption.

Table 2.
Current and Projected Population and Consumption

Cedar City, UT		
Current Population (2010)	28,857	Persons
Total Electricity Consumption	261,365,000	kWh/year
Coal	60.37%	
Natural Gas	12.16%	
Hydropower	8.42%	
Renewables	8.75%	
Other	10.29%	
Electricity Consumption Per Capita	9,057	kWh/person/year
Population Projection 2030	44,812[a]	Persons
Electricity Consumption 2030	405,862,284	kWh/person/year
Population Projection 2060	79,886[b]	Persons
Electricity Consumption 2060	723,527,502	kWh/person/year

[a,b] Utah Governor's Office of Management and Budget, 2013.

Identification of Renewable Energy Potential

The potential for energy generation on public land in Cedar City is a function of how much energy is available from a source, the type of technology used to produce energy, and how much land is available for its production. After looking at the renewable energy resources in the Cedar City area, wind and solar were identified as having the most potential. While a true renewable energy community would take advantage of any and all resources including geothermal, micro-hydro, and biomass, the scope of this study was limited to wind and solar as the sources most likely to generate enough energy to serve a portion of the city's needs. Both sources were analyzed to determine the potential for energy generation on public land in Cedar City.

Wind Energy

To locate the public land parcels with the best potential for wind generation, the Utah 50 m wind resource data from the National Renewable Energy Laboratory (NREL) (2012c) was laid over Cedar City- and Iron County-owned property within an eight kilometer radius of the city limits. The NREL wind data provides an estimate of the annual average wind resource at a 50 m height split into seven classes, with one the lowest and seven the highest. The wind resource in the Cedar City area falls between Class 1 and Class 3 (see Figure 5). Since Class 1 represents a poor wind resource not suitable for energy generation, that class was eliminated leaving the parcels within Class 2 and Class 3. The wind speed in Class 2 falls between 5.6 meters per second (m/s) and 6.4 m/s, which is considered marginal for utility-scale energy generation. Class 3 has a

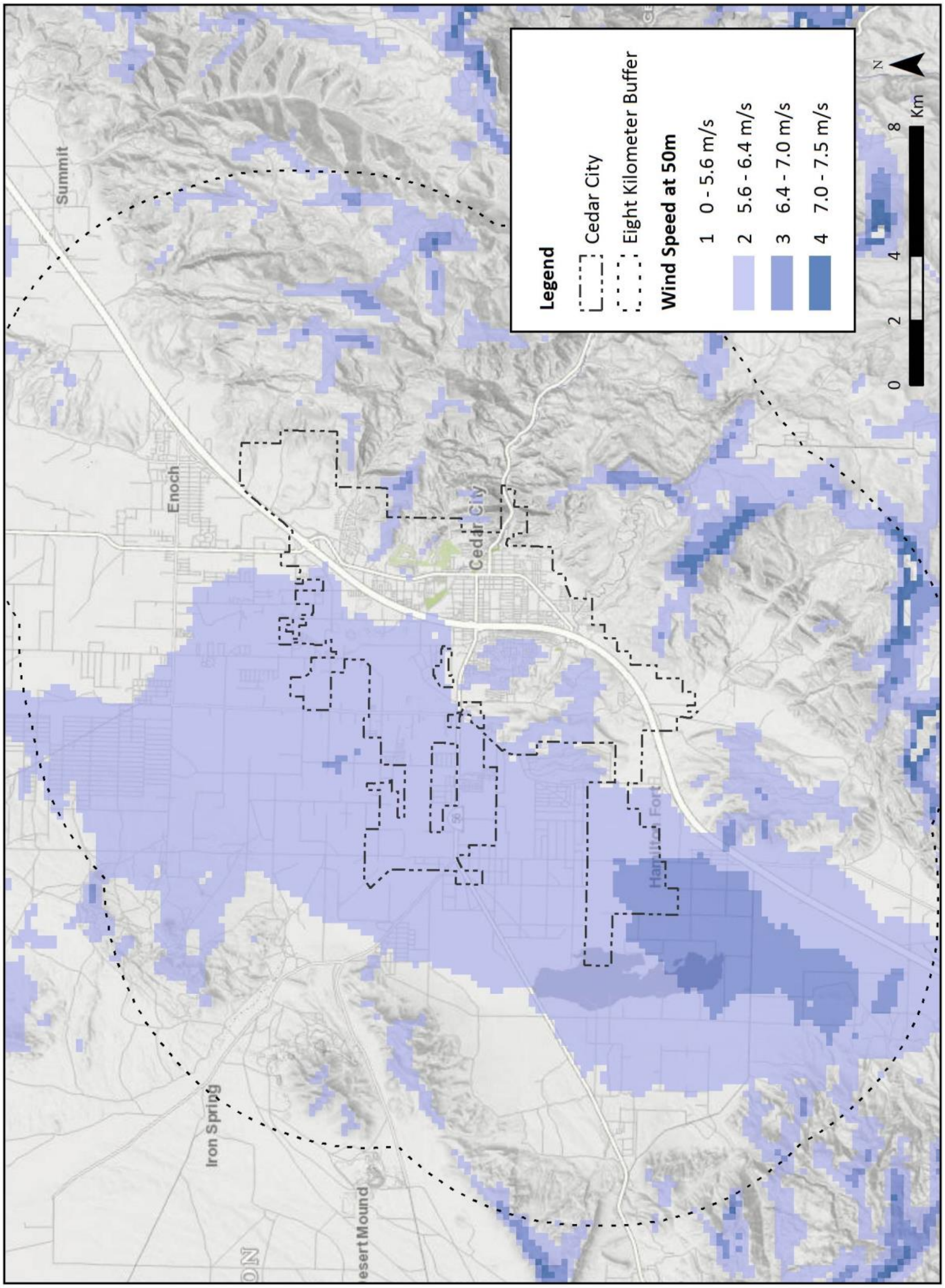


Figure 5. Utah 50 m wind resource data showing wind classes near Cedar City, UT.

wind speed range between 6.4 m/s and 7.0 m/s. With Class 1 eliminated, most of the public land parcels in Cedar City falls within Class 2.

Once the parcels within a suitable wind class had been identified, other factors were considered that might affect whether or not a parcel could be used to generate wind energy, and the Cedar City Regional Airport was found to have a major impact. The airport represents a significant portion of public land falling within Class 2, land that had to be removed from consideration due to aircraft landing and taking off. Furthermore, the land surrounding the airport is subject to height restrictions as determined by the Airport Overlay Zoning Ordinance (2001) (see Figure 6).

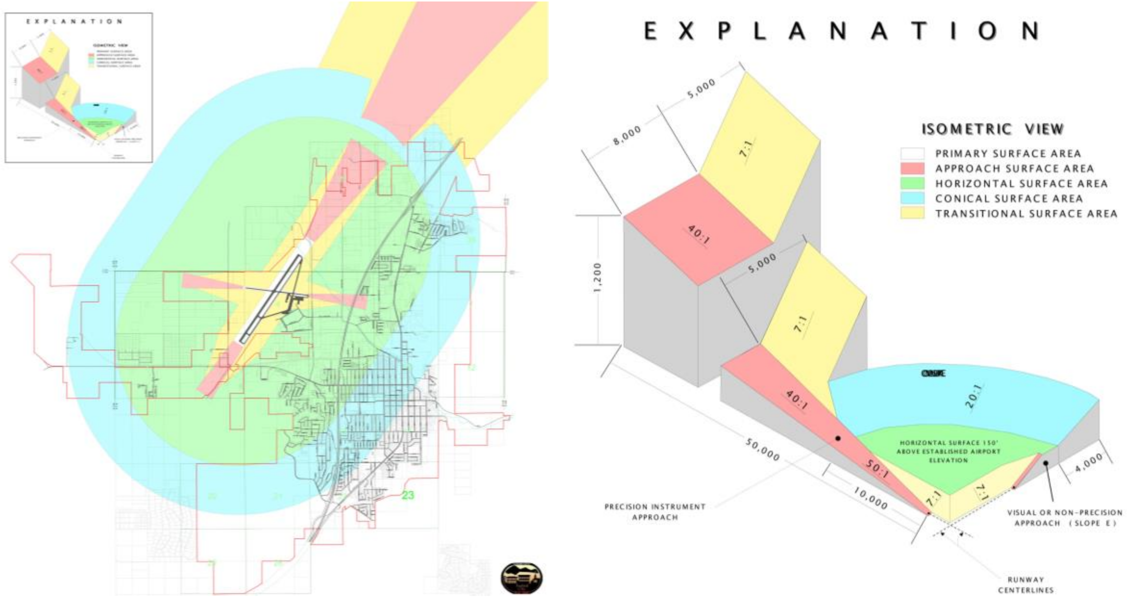


Figure 6. Cedar City airport height restriction map showing the areas of the city affected by height restrictions. Adapted from "Airport Height Restriction Land Use Map," City of Cedar City, 2001, retrieved from http://cedarcity.org/128/Maps

For the purposes of this study, the area the airport influences was split into four zones:

- Airport - the interior core area with the runways or primary surface area, the approach surface area, and the transitional area. This zone was eliminated from consideration due to conflict with air traffic.
- Zone 1 - the traffic pattern zone with a height restriction of 45.7 m (150') above the airport elevation. The total area of public land in this zone is 404,213 m^2 and falls entirely within the municipal boundary of Cedar City (see Figure 7).
- Zone 2 - the airport influence zone, a ring around the airport that slopes 6.1 m (20') outward for every 0.3 m (1') upward for 1219.2 m (4,000') beginning at 45.7 m above airport elevation and ending at 106.7 m (350') above airport elevation. This zone has 233,248 m^2 in public land within the municipal boundary, and another 55,238 m^2 within eight kilometers of the city boundary, for a total of 285,486 m^2 of public land (see Figure 7).
- Zone 3 - no restriction. This zone has 55,591 m^2 of public land within the municipal boundary. However, when the eight-kilometer buffer is included, that number jumps to 3,360,857 m^2, the largest amount of public land available in any zone (see Figure 7).

The height restrictions allow a range of different turbine sizes that work for the conditions of the area. Smaller wind turbines such as those used for schools, commercial properties, or farms fall below the 45.7 m height restriction in Zone 1, while larger utility scale turbines could be used in areas of Zone 3 where there is no height

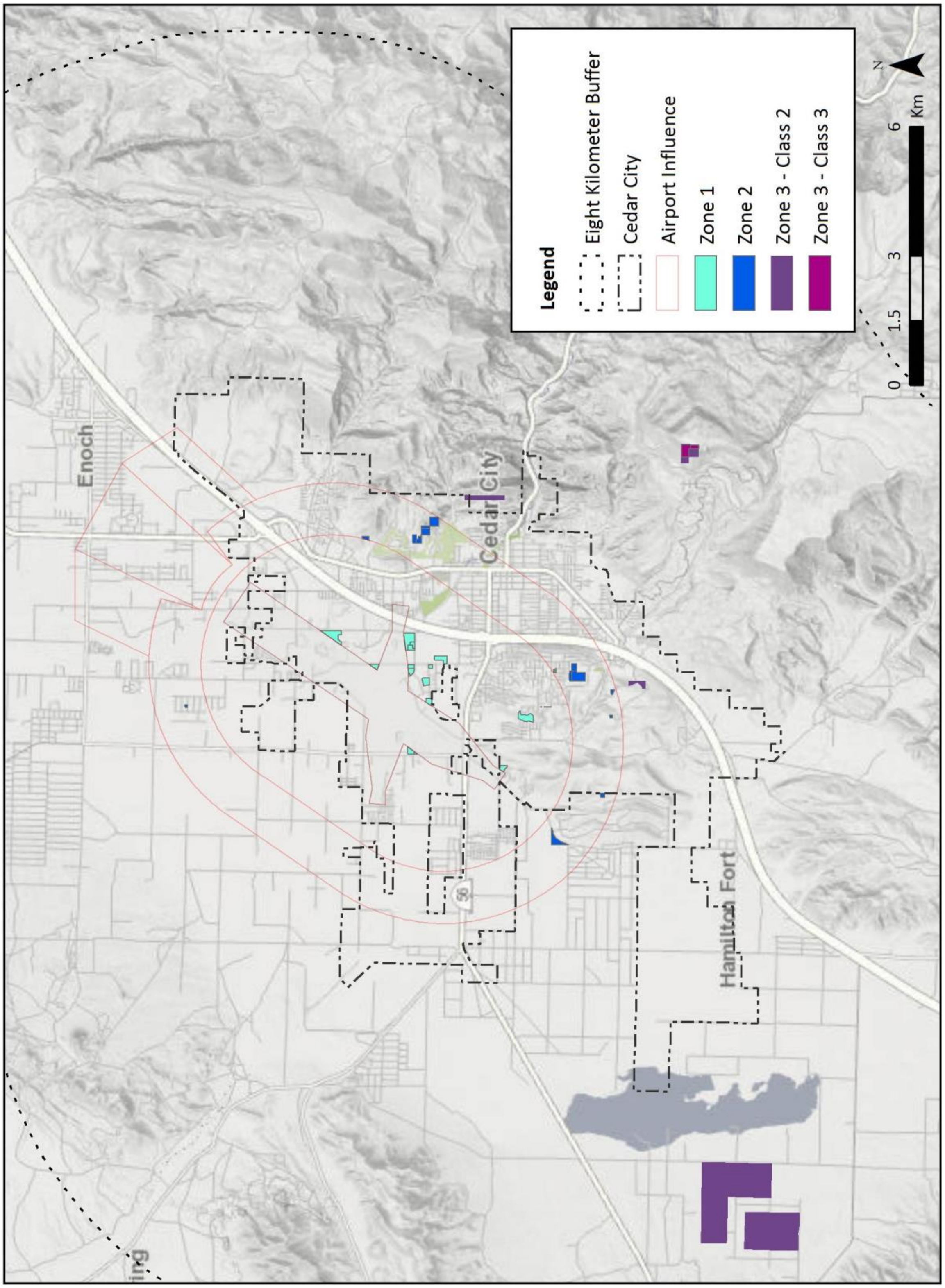


Figure 7. Wind energy parcels by wind zone.

restriction. This range of sizes represents a range of potential for wind energy generation. Turbines placed on parcels within Zones 1 and 2 may need to be approved by the Federal Aviation Administration (FAA).

Creating a general rule of thumb for how much land area in square meters each wind turbine requires depends on a number of factors such as tower height, rotor diameter, prevailing winds, and local ordinances. Iron County's Wind Energy Systems and Facilities Ordinance (2012) requires a setback of 125 percent of the turbine's total extended height from project boundaries or from a park, church, hospital, school, playground, or residentially zoned lot not owned or leased by the wind energy developer or owner. The ordinance further states that turbines in any commercial wind energy system should be spaced no closer together than 110 percent of a turbine's total extended height.

For projects with multiple turbines, however, spacing would need to be greater due to the disturbance in airflow from the turbines themselves. A wind turbine causes a wake in airflow that reduces velocity and increases turbulence, affecting the energy potential for a turbine placed behind. A balance needs to be struck between maximizing energy production through spacing of turbines and the amount of land that is available. Wider spacing typically means greater energy production, but also increases the footprint.

Windustry (2008) lays out the rule of thumb that some developers use, which is to space turbines 8 rotor diameters apart in the direction of the prevailing wind, and 4 rotor diameters apart in the direction perpendicular to the prevailing wind. The New York Energy Research & Development Authority (2009) gives similar recommendations: in locations where wind is generally coming from one direction, turbines may be placed in rows 3 to 4 rotor diameters apart with 8 rotor diameter spacing between rows. In sites with prevailing winds coming from multiple directions, greater spacing is recommended such as 5 to 7 rotor diameters between turbines in a row.

For this study, a minimum turbine footprint was determined based on a spacing of 4 rotor diameters by 8 rotor diameters. Three different turbines were selected to represent the size and energy generation potential each zone might accommodate.

Wind Zone 1

There are a number of smaller turbines under 500 kW by different manufacturers that are used in places where height, space, or visual impact are considerations. In Zone 1, a 250 kW turbine like the Wind Technik Nord WTN250 with a rotor diameter of 30 m and a hub height of 30 m, for a total height of 45 m, would work within the 45.7 m height restriction. The footprint of the turbine was determined by multiplying 4D x 8D, where D is the rotor diameter of 30 m. Therefore the footprint area for each wind turbine is 28,800 m^2**.**

For the purposes of this study and in order to understand the potential energy productivity of the land, the annual energy production was calculated as kilowatt-hours per square meter per year. The annual energy production for one 250 kW turbine at Class 2 wind speeds between 5.5-6.4 m/s equals approximately 387 to 571 MWh (RM Energy, 2013). Or, to break that down into energy per square meter, a range of 13.4 to 19.8 kilowatt-hours per square meter per year (kWh/m^2/year) (see Table 3).

Wind Zone 2

Zone 2 can accommodate a taller turbine, such as the 500 kW Vestas V39, with a rotor diameter of 39 m and a tower height of 40 m for a total height of 59.5 m. The

Table 3.

Wind Turbine Sizes and Energy Production

Zone	Rating	Rotor Diameter	Total Height	Total Footprint	Annual Energy Production-Wind Class 2	Energy in kWh/m^2/y
Wind Zone 1	250 kW	30 m	45 m	28,800 m^2	387-571 MWh	13.4
Wind Zone 2	500 kW	39 m	59.5 m	48,672 m^2	552-785 MWh	11.3
Wind Zone 3	1.5 MW	74 m	117 m	175,232 m^2	3,000-4,000 MWh	17.1

footprint of the turbine is 48,672 m^2, based on the 39 m rotor diameter and the 4 by 8 spacing rule of thumb.

The annual energy yield for this 500 kW turbine in Class 2 is in the range of 552-785 MWh (Wind Pioneer, 2011). In terms of annual energy production per square meter of land, this 500 kW turbine could potentially produce 11.3 to 16.1 kWh/m^2/year (see Table 3).

Wind Zone 3

Since the land in Zone 3 is on the outskirts of town and there are no height restrictions, this zone can accommodate larger, utility-scale wind turbines. A 1.5 MW turbine like the GE1.5-77 has a rotor diameter of 74 m and a tower height of 80 m for a total height of 117 m. The total footprint area based on 4 by 8 rotor diameter spacing is 175,232 m^2 (see Table 3).

A 1.5 MW turbine, while still on the small side compared to other utility-scale turbines, generates considerably more energy than its counterparts in the 250 to 500 kW range. The annual energy production at Class 2 wind speeds of 5.5-6.5 m/s is 3,000-4,000 MWh (Gipe, 2013), or 17.1 to 22.8 kWh/m^2/year.

Solar Energy

Cedar City, like much of southern Utah, has excellent solar resources. According to NREL (2012a), the annual average direct normal irradiance (DNI) or solar resource for the Cedar City area is above 7 kWh/m^2/day. Direct normal irradiance represents the amount of solar radiation received by a unit of surface area perpendicular to the sun's rays. This measure of solar resource is often used for concentrated solar projects that can track the path of the sun throughout the day. In terms of solar resource for photovoltaics that may be fixed and oriented south at an angle from horizontal equal to the latitude (37.7° for Cedar City), the resource is a little lower but still good at a little over 6 kWh/m^2/day (NREL, 2012b). Solar power has great potential in Cedar City, and can take several forms such as rooftop solar, canopies over parking lots, and free-standing photovoltaic arrays.

The potential energy that could be generated from solar PV was calculated using a 270 W solar panel such as the SolarWorld Sunmodule SW270. Solar panels come in a variety of sizes and power ratings, and the technology is improving all the time. While many panels like the Sunmodule SW270 have efficiencies in the 16-18% range (SolarWorld, 2013), some panels are being manufactured with efficiencies above 20%. Each panel is 1.68 m^2 and consists of 60 mono-crystalline cells.

The NREL PVWatts Calculator (National Renewable Energy Laboratory, 2014) was used to determine the potential kilowatt-hours per square meter per year. The PVWatts Calculator performs the calculation using the rating of the solar panel, the array type, the array tilt, and the array azimuth (see Table 4).

Table 4.

PVWatts Calculator Results

Location Specifications	
Latitude:	37.70° N
Longitude:	113.10° W
Elevation:	1712 m
PV System Specifications	
DC Rating:	270 W
DC to AC Derate Factor:	0.77
AC Rating:	210 W
Array Type:	Fixed Tilt
Array Tilt:	10.0°
Array Azimuth:	180.0°

Results		
Month	Solar Radiation (kWh/m^2/day)	AC Energy (kWh)
1	3.39	21.5
2	4.14	23.4
3	5.18	33.1
4	6.45	38.4
5	7.12	42.0
6	7.96	44.8
7	7.41	42.0
8	6.79	38.9
9	5.99	34.1
10	5.13	30.8
11	3.55	21.4
12	3.01	18.6
Year	5.52	389.1

The settings used for Cedar City were a solar panel rating of 270 W, a fixed-tilt array type, and an array azimuth of the default of south. However, rather than use an array tilt of 37.7°, which is the suggested default of Cedar City's latitude, a tilt of 10° was used instead. A tilt of 10° results in a lower average of solar radiation, about 5.5 kWh/ m^2/day compared to 6 kWh/ m^2/day at a tilt of 37.7°. But the solar radiation reaching a solar panel at a 10° angle is actually greater in the summer, when energy demand is usually highest, about 7.39 kWh/ m^2/day compared to 6.76 kWh/ m^2/day. The real benefit to the 10° tilt, though, is that more solar panels will fit into a given area because less space is needed between rows to avoid shading. By using a 10° tilt, it is possible to generate approximately 389 kWh/year per panel. Dividing that number by the panel's area of 1.68 m^2 provides the potential annual energy productivity per square meter, 231.5 kWh/ m^2/year.

Rooftop solar

Using the building footprints provided by the city, public buildings were identified such as administrative buildings, schools, recreation centers, libraries, and others (see Figure 8). All of the buildings considered for rooftop solar fall within the municipal boundary. The total roof area for all buildings so identified comes to 220,879 m^2. However, not all of that area would actually be available for solar panels. Several factors limit the useable space, such as the presence of air conditioning units, vents, and other infrastructure, and the pitch and orientation of the roofs. There are a number of large, flat roofs that would work well for solar panels, particularly on the schools, but some buildings have roofs that slope in a direction unsuitable for solar collection. The limitation due to these factors was taken into account in the scenario development (discussed in Chapter IV), and the available rooftop area was reduced by 50% when calculating the percentage of space available for energy generation.

Parking lot canopies

There are roughly 270,436 m^2 of parking lots on publicly-owned land within the municipal boundary of Cedar City (see Figure 8). These parking lots have great potential to produce energy by covering all that asphalt with carport canopies covered in solar panels. The framework of the canopies come in a variety of configurations and can support the same PV panels used on rooftops (see Figure 9). The slope of such canopies is usually between 7 and 15 degrees, so the array tilt of 10° works well with the framework.

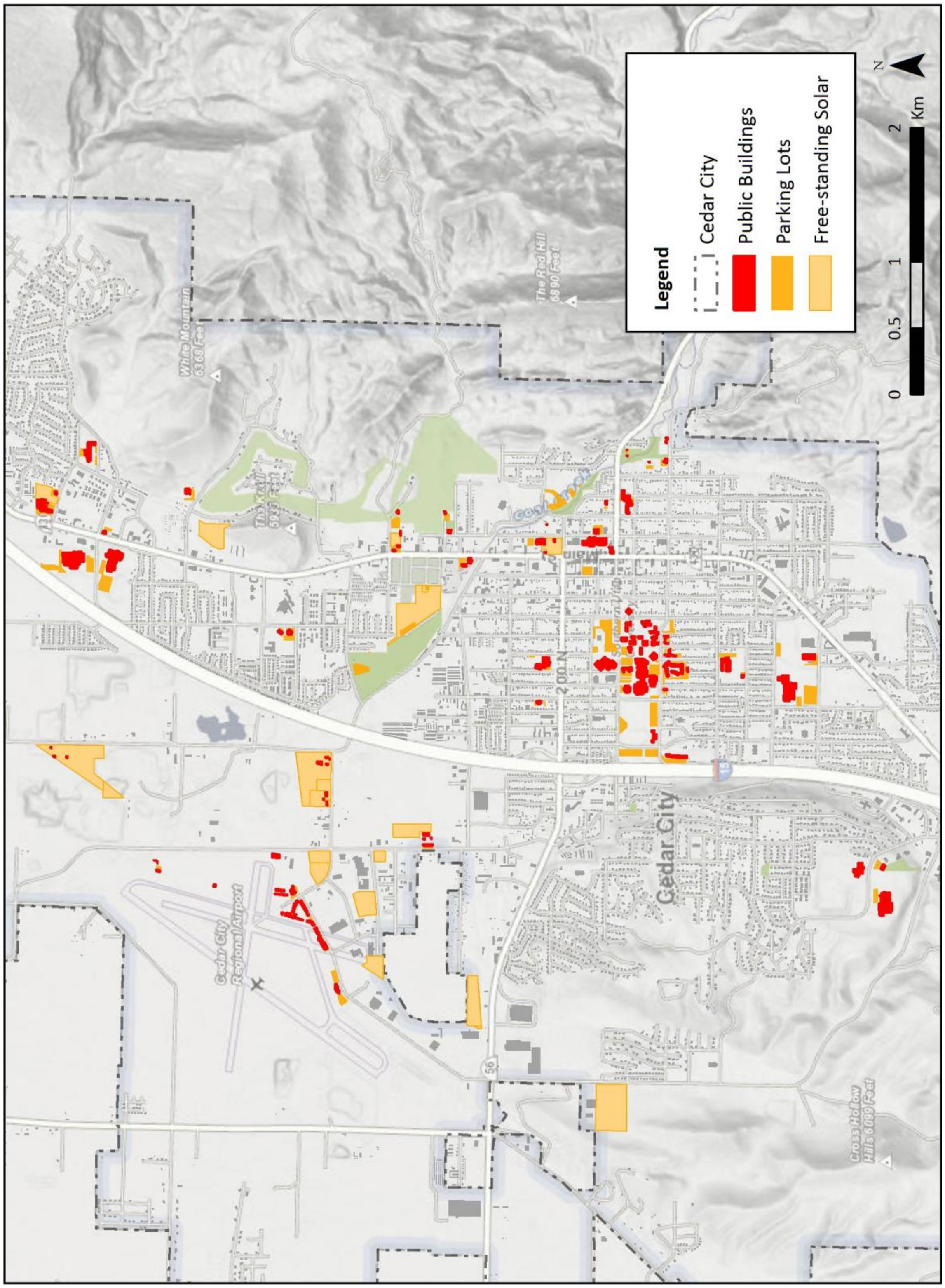


Figure 8. Map of public buildings, parking lots, and parcels for free-standing arrays for solar energy generation.

Figure 9. Solar parking lot canopies at the VA Medical Complex in Albuquerque, NM. By J.N. Stuart, 2011, retrieved from https://www.flickr.com/photos/stuartwildlife/with/ 8402076067 Reprinted with permission.

This framework could not be placed on the entirety of the parking lot; canopies are typically placed over the parking spaces, leaving travel lanes and entry areas open. Therefore, as with the rooftops, this limitation was taken into account and the area was reduced by 50% when calculating the percentage of space available for energy generation.

Free-standing solar

While there is considerable potential for energy generation on rooftops and parking lots, Cedar City also has a lot of open land where free-standing PV arrays could be placed. To determine suitable places for such arrays, public land was selected that was on less than a 3% slope, then parcels were eliminated such as the airport core area, parcels that were occupied by buildings or parking lots that were being counted in the two sections above, and parcels such as the golf course and ball fields (see Figure 8).

The remaining land adds up to 616,056 m^2 within the city boundary, and that number increases considerably to 4,195,234 m^2 once the eight-kilometer buffer is included.

The land considered suitable for free-standing arrays is largely vacant, and thus there are few limitations on placing the panels. However, the available area was reduced by 40% to account for space between rows, travel lanes for maintenance vehicles, electrical infrastructure, and sheds or other structures that might be on the land.

Analyzing Renewable Energy Potential

The preceding section describes the types of technology used to harness energy resources, the amount of public land available, and the energy productivity of that land in kilowatt-hours per square meter per year. Table 5 shows the amount of public land available for each of the six resource types within the city boundary and within eight kilometers of the boundary, and the amount of energy each square meter can produce depending on each resource type. The amount of energy each square meter can produce

Table 5.
Available Land in Square Meters and Energy in Kilowatt-Hours per Square Meter per Year

Resource Type	Available Land in City Boundary (m^2)	Available Land Within 8 km (m^2)	Energy in kWh/m^2/y
Wind Zone 1:	404,213	404,213	13.4
Wind Zone 2:	233,248	285,486	11.3
Wind Zone 3:	55,591	3,360,857	17.1
Solar 1 - Rooftops:	220,879	220,879	231.5
Solar 2 - Parking lots:	270,436	270,436	231.5
Solar 3 - Free-standing:	565,891	4,195,234	231.5

varies for wind turbines depending on the rotor diameter, but the amount of energy produced by solar panels remains the same because the same type of panel at the same angle was used for each of the three types of solar energy production.

There are many factors that affect whether or not a given parcel of land can be used to produce energy. This is public land, and there may be plans for other uses on that land, for instance buildings, public facilities, maintenance facilities, water or sewage treatment facilities, or parks. The use of that land for energy generation may be incompatible with land uses on adjacent parcels, the airport being a major example. There may be buildings or trees on the land that shade rooftops or that block wind flow or cause turbulence that reduces the efficacy of the turbine. Some portion of roofs may be facing a direction that reduces that amount of sun energy that reaches the panel. The placement of wind turbines or solar panels on a particular parcel may impact the viewshed in a way that is undesirable, or there may be opposition from the public against placing turbines or panels in certain areas. There may be public safety reasons why a parcel may not be suitable. In short, there are many factors that must be considered when determining where renewable energy generation can take place.

These various factors are important and affect whether or not a piece of land can be used for energy generation, but each parcel in the study area was not analyzed for each of these specific prohibitive factors. Rather, the land was considered and analyzed as a whole to investigate the kilowatt-hours per square meter per year that could be generated on the land area available for each of the six types of energy generation (for wind: Zone 1, Zone 2, and Zone 3, and for solar: rooftops, parking canopies, and free-standing arrays).

Once the renewable energy potential of Cedar City's public land was identified, several scenarios were constructed to determine whether the energy generated on the land could reach the targets of 25%, 50%, or 100% of the city's energy needs, depending on how aggressive the community might want to be about energy production. The conservative scenarios were constructed to see if a target of 25% of the city’s annual energy consumption could be met given a desire to minimize the impact of energy generation technology, because the land was slated for other uses or was unavailable for use, or because of lack of support in the community. A moderate scenario was constructed to reach 50% of the annual energy consumption in order to meet a substantial proportion of the community's energy needs with less of an emphasis on preserving the status quo. Finally, an aggressive scenario was developed to achieve 100% of the community's annual energy consumption to represent a community that wanted to maximize the use of the land to meet as much of its energy needs as possible locally, prioritizing energy generation over other land uses, viewsheds, or other issues.

The scenarios will be discussed in the next section.

CHAPTER IV

SCENARIO ANALYSIS

Rather than determining a prescription or master plan for exactly where renewable energy generation should be located in Cedar City, the purpose of this study was to explore possibilities and potential through the formulation of several scenarios. Alternative patterns of growth for the city depend in part on the value that is placed on its resources, and as Carrington pointed out (as cited in Weller, 2008), "…the power of evidence based scenarios lies only partially in their accuracy: more significant is their capacity to stimulate ideas" (p. 20). By testing the energy generation potential produced by several scenarios, this study is meant to stimulate ideas and help identify both the benefits and the challenges that arise.

As described in the previous section, several scenarios were developed based on how aggressive the community wanted to be about meeting its energy needs by pursuing renewable energy generation on public land. Low, moderate, and high scenarios were created for the city within its municipal boundary, then the scope was expanded to include the 8-kilometer buffer to explore how the addition of that land affected the results. The scenarios were based on kilowatt-hours per square meter per year that could be generated by certain percentages of the available public land with the goal of hitting 25%, 50%, or 100% of the community's annual energy consumption.

Town Scenarios

Town Scenario 1: Low

The conservative scenario for land within the town boundary was based on the concept that the community might wish to develop some renewable energy capacity to meet 25% of its energy needs while limiting the impact and keeping costs down. Table 6 provides a summary of the six resource types and the amount of energy generated by each in this scenario. There were several key factors that shaped this scenario. First, all parcels of land in Wind Zone 1, which are all in close proximity to the airport, were removed from consideration to eliminate the possibility of conflict with airport operations. All parcels in Wind Zone 2 were also eliminated because the majority of these parcels are located on the hills to the east of town where a wind turbine would significantly impact the viewshed. The remainder of the parcels in this zone recently

Table 6.
Total Energy Generated by Town Scenario 1

Resource Type	Total Land %	Land Area (m^2)	Total Energy (kWh)	Comments
Town Scenario 1				
Wind Zone 1:	0%	0	0	Eliminated due to proximity to airport.
Wind Zone 2:	0%	0	0	Priority placed on preserving viewshed.
Wind Zone 3:	75%	41,693	558,690	Limited to two adjacent small parcels; 250 kW turbine used to limit visual impact.
Solar 1 - Rooftops:	15%	33,132	7,670,023	Limited to the largest, flattest roofs (primarily school buildings). Further reduced by 50% to account for rooftop restrictions.
Solar 2 - Parking lots:	12%	32,452	7,512,712	Limited to the largest parking lots (primarily school lots). Reduced by 50% to allow for driving lanes , entry points, etc.
Solar 3 - Free-standing:	15%	84,884	19,650,565	Limited to industrial areas near airport. Reduced by 40% to allow for service access etc.
Total:		192,161	35,391,990	
Percentage of total electricity consumption:			14%	

became the home of the Cedar City Aquatic Center, with several baseball fields and a fishing pond which just opened at the time of this writing. There is the possibility that a small wind turbine could still be placed within the complex, but the land was removed from consideration for safety reasons.

The only parcel that was considered suitable for a wind turbine is located in Wind Zone 3, and though this parcel represents roughly 75% of the total available land in that zone within the municipality, there is only space for one wind turbine. The parcel lies just southwest of the shopping complex on the south end of town, near I-15, and is in a visually prominent location. Though Wind Zone 3 has no height restrictions, a smaller, 250 kW turbine was chosen for this parcel due to limitations of space and to reduce the visual impact of the turbine.

In terms of the three solar resource types, the available area was limited to the places where it would be easiest to install and come into the least conflict with other uses. Only the largest roofs with ample space for solar panels were chosen, mostly school buildings. Similarly, the parking lots suitable for solar panel canopies were limited to the largest lots where it would be easiest to install, mostly school parking lots. Lastly, several parcels of land in the industrial area close to the airport were chosen as suitable for a limited amount of free-standing solar arrays.

The total energy generated by the six resource types in this conservative scenario equaled 35,391,990 kWh, or approximately 14% of the total electricity consumption of Cedar City, which failed to meet the goal of 25%.

Town Scenario 2: Moderate

The middle scenario was explored as a mid-point between the conservative and aggressive scenarios, representing a desire to increase the energy generation to meet 50% of the city's needs and placing increased importance on energy generation over other considerations. Table 7 provides a summary of the six resource types and the amount of energy generated by each in this scenario. The middle scenario shares some elements with the conservative scenario. For instance, Wind Zones 2 and 3 were left the same, Wind Zone 2 because of the importance placed on preserving the view of the mountains, and Wind Zone 3 because there simply wasn't a reasonable way to add more turbines. However, unlike the conservative scenario, the land around the airport was brought into consideration, and the possibility was explored of placing one or two turbines in that area.

Criteria similar to the conservative scenario was used for the three solar resource types, the percentages for each were merely increased. The number of buildings and

Table 7.
Total Energy Generated by Town Scenario 2

Resource Type	Total Land %	Land Area (m^2)	Total Energy (kWh)	Comments
Town Scenario 2				
Wind Zone 1:	20%	80,843	1,083,291	Limited to one or two parcels near airport.
Wind Zone 2:	0%	0	0	Preserve viewshed of mountains.
Wind Zone 3:	75%	41,693	558,690	Limited to two adjacent small parcels; 250 kW turbine used to limit visual impact.
Solar 1 - Rooftops:	30%	66,264	15,340,047	Increased the number of available roofs. Reduced by 50% to account for rooftop restrictions.
Solar 2 - Parking lots:	25%	67,609	15,651,484	Increased the number of available parking lots. Reduced by 50% to allow for driving lanes, etc.
Solar 3 - Free-standing:	20%	113,178	26,200,753	Increased to include more parcels in the industrial areas near airport. Reduced by 40% to allow for service access etc.
Total:		369,587	58,834,264	
Percentage of total electricity consumption:			23%	

parking lots considered suitable was increased. The number of parcels available for free-standing solar was also increased, though still limited to the area near the airport. By expanding the parcels for free-standing solar, the town would be placing priority for energy generation over other uses that the land could be used for in that industrial area.

The total energy generated by the six resource types in the moderate scenario due to the increase in land put aside for energy generation would be 58,834,264 kWh, or approximately 23% of the total electricity consumption. This percentage almost met the 25% target for the conservative scenario, but failed to meet the 50% target for this scenario.

Town Scenario 3: High

The aggressive scenario represents an increase across almost all resource types to incorporate the majority of the land where it is feasible to include renewable energy generation in an attempt to meet 100% of the city's energy needs. The percentage of land available was raised in Wind Zone 1 and for the three solar types, which meant an increase in turbines and solar panels scattered through town (see Table 8). The most notable change was in Wind Zone 2, where in the previous scenarios the land was eliminated in order to preserve the viewshed. In this scenario, several of the parcels were included which could accommodate two or three turbines. This change would be indicative of a community that placed great importance on renewable energy generation, and with a different concept of the impact of wind turbines on the visual quality of the area.

Table 8.
Total Energy Generated by Town Scenario 3

Resource Type	Total Land %	Land Area (m^2)	Total Energy (kWh)	Comments
Town Scenario 3				
Wind Zone 1:	40%	161,685	2,166,582	Increased the number of parcels near the airport.
Wind Zone 2:	55%	128,286	1,449,636	Included several parcels on ridges on the northeast side of town.
Wind Zone 3:	75%	41,693	558,690	Limited to two adjacent small parcels; 250 kW turbine used to limit visual impact.
Solar 1 - Rooftops:	40%	88,352	20,453,395	Increased the number of available roofs. Reduced by 50% to account for rooftop restrictions.
Solar 2 - Parking lots:	35%	94,653	21,912,077	Increased the number of available parking lots. Reduced by 50% to allow for driving lanes, etc.
Solar 3 - Free-standing:	35%	198,062	45,851,318	Increased number of parcels to include land in town away from the airport. Reduced by 40% to allow for service access etc.
Total:		712,731	92,391,698	
Percentage of total electricity consumption:			35%	

Still, even with this increase, the energy generated by the land in this scenario would be 92,391,698 kWh, 35% of Cedar City's annual consumption of 261,365,000 kWh, which is not a significant increase over the moderate scenario and nowhere near the target of 100%. This scenario would involve a greater number of turbines and solar panels widely dispersed around the town, but without much gain in generated energy.

Figure 10 shows a comparison of the amount of energy generated by the six resource types in the three Town Scenarios, and the total percentage of energy generated in each scenario. The next step was to expand the area of interest to include the 8-kilometer buffer around the municipal boundary in order to investigate the change that would make.

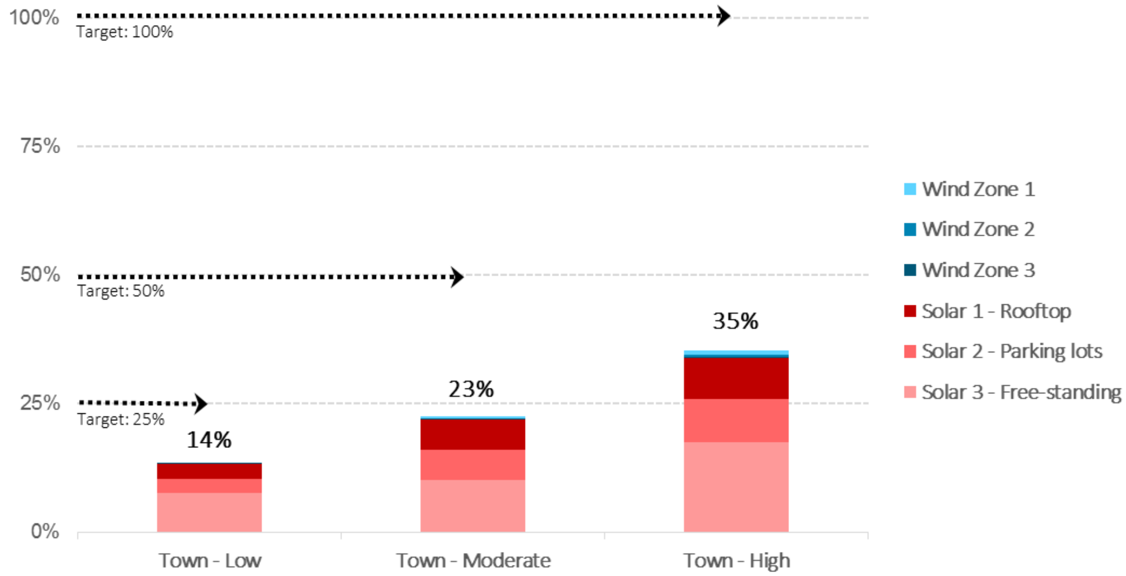


Figure 10. Summary of the total energy generated by the six resource types in each Town Scenario.

Eight-Kilometer Scenarios

Eight-Kilometer Scenario 1: Low

As it turns out, adding that eight kilometer ring resulted in a significant increase in the amount of land available and the amount of energy that could be generated. This is due primarily to the presence of to several large parcels in close proximity to each other in an agricultural area west of town that together add up to 3,072,033 m^2. Such a large amount of land could accommodate utility-scale levels of energy generation. Table 9 provides a summary of the six resource types and the amount of energy generated by each in this scenario.

There are also several parcels to the east of town, one on a ridge just below what's known as The Red Hill north of State Route 14 which goes up Cedar Canyon, and

Table 9.

Total Energy Generated by Eight-Kilometer Scenario 1

Resource Type	Total Land %	Land Area (m^2)	Total Energy (kWh)	Comments
Eight-kilometer Scenario 1				
Wind Zone 1:	0%	0	0	Eliminated due to proximity to airport.
Wind Zone 2:	0%	0	0	Priority placed on preserving viewshed.
Wind Zone 3:	10%	336,086	5,747,065	Limited to two turbines in the parcels west of town.
Solar 1 - Rooftops:	15%	33,132	7,670,023	Limited to the largest, flattest roofs (primarily school buildings). Further reduced by 50% to account for rooftop restrictions.
Solar 2 - Parking lots:	12%	32,452	7,512,712	Limited to the largest parking lots (primarily school lots). Reduced by 50% to allow for driving lanes , entry points, etc.
Solar 3 - Free-standing:	5%	209,762	48,559,834	Limited to a small portion of the land west of town. Reduced by 40% to allow for service access etc
Total:		611,432	69,489,634	
Percentage of total electricity consumption:			27%	

another cluster on the peak of Cedar Mountain just to the south of Cedar Canyon. These ridges have a significant impact on the viewshed and are a major part of the backdrop of Cedar City. Any turbines placed there would be highly prominent visually. The parcels on Cedar Mountain are the only ones that fall within Wind Class 3 with wind speeds between 6.4 m/s and 7.0 m/s, and could have good energy generation potential.

With these new areas in mind, the conservative scenario to supply 25% of the energy needed started out very similar to Town Scenario 1. Parcels in Wind Zone 1 and Wind Zone 2 were eliminated due to proximity to the airport and because of the impact to the viewshed. The percentages for the rooftop and parking lot solar also remained the same as Town Scenario 1, since the resource types completely within the town boundary remained the same and did not change.

Where Eight-Kilometer Scenario 1 diverged from the town scenario was in Wind Zone 3 and in the free-standing solar due to the availability of the land parcels out west, where there is so much land available with few constraints. For this scenario, 10% of the land was set aside for wind generation, which would accommodate two turbines. Five percent of the land was set aside for free-standing solar.

Eight-Kilometer Scenario 1 would generate enough energy to cover 27% of Cedar City's annual consumption, or 69,489,634 kWh, which slightly exceeded the target for this scenario.

Eight-Kilometer Scenario 2: Moderate

Eight-Kilometer Scenario 2 featured the same increase in the amount of rooftops and parking lots developed for solar as Town Scenario 2, and included some land near the airport for wind. The major change came from increasing the amount of wind and solar on the large parcels to the west, as with Eight-Kilometer Scenario 1. In this scenario, the land set aside for wind increased to 30%, which would allow for five or six turbines, and the land for solar increased to 20%. Table 10 provides a summary of the six resource types and the amount of energy generated by each.

The target for this moderate scenario was 50%; however, this scenario would result in a significant increase in the amount of energy generated, and would nearly meet the annual electricity consumption of Cedar City. The energy generated would be approximately 243,555,352 kWh, or 93% of the total, and this is not surprisingly due to the impact of the large parcels.

Table 10.

Total Energy Generated by Eight-Kilometer Scenario 2

Resource Type	Total Land %	Land Area (m^2)	Total Energy (kWh)	Comments
Eight-kilometer Scenario 2				
Wind Zone 1:	20%	80,843	1,083,291	Limited to one or two parcels near airport.
Wind Zone 2:	0%	0	0	Priority placed on preserving viewshed.
Wind Zone 3:	30%	1,008,257	17,241,196	Increased number of turbines in the parcels west of town to 5.
Solar 1 - Rooftops:	30%	66,264	15,340,047	Increased the number of available roofs. Reduced by 50% to account for rooftop restrictions.
Solar 2 - Parking lots:	25%	67,609	15,651,484	Increased the number of available parking lots. Reduced by 50% to allow for driving lanes, etc.
Solar 3 - Free-standing:	20%	839,047	194,239,334	Increased percentage of land used west of town. Reduced by 40% to allow for service access etc
Total:		2,062,019	243,555,352	
Percentage of total electricity consumption:			93%	

Eight-Kilometer Scenario 3: Aggressive

Eight-Kilometer Scenario 3 was developed to be very aggressive and to use a significant portion of the land to reach 100% of the city's annual energy consumption. Percentages were increased in every sector (see Table 11). The most notable changes were the addition of all the parcels on the hills and ridges on the east side of town, which would result in multiple wind turbines ranged along the skyline and would represent a serious alteration to the viewshed. The land in Wind Zone 3 was increased to include nearly all of the land where it was potentially feasible to install turbines, which ended up being around 94% of the total land in that zone. Free-standing solar was increased in the large western parcels as well.

Table 11.

Total Energy Generated by Eight-Kilometer Scenario 3

Resource Type	Total Land %	Land Area (m^2)	Total Energy (kWh)	Comments
Eight-kilometer Scenario 3				
Wind Zone 1:	40%	161,685	2,166,582	Scattered in several parcels near airport.
Wind Zone 2:	60%	171,292	1,935,595	Included several parcels on ridges on the northeast side of town.
Wind Zone 3:	94%	3,192,814	54,597,122	Expanded to almost all of the available land, including the parcels out west and parcels on the ridges east of town.
Solar 1 - Rooftops:	40%	88,352	20,453,395	Increased the number of available roofs, large and small, scattered all over town. Reduced by 50% to account for rooftop restrictions.
Solar 2 - Parking lots:	35%	94,653	21,912,077	Increased the number of available parking lots. Reduced by 50% to allow for driving lanes, etc.
Solar 3 - Free-standing:	40%	1,678,094	388,478,668	Increased percentage of land to encompass most of the large parcels west of town. Reduced by 40% to allow for service access etc.
Total:		5,386,889	489,543,439	
Percentage of total electricity consumption:			187%	

The energy generated by this aggressive scenario would be approximately 489,543,439 kWh, or 187% of the present annual consumption, far exceeding the target of 100% of the city's needs. Figure 11 shows a comparison of the amount of energy generated by the six resource types in the three Eight-Kilometer Scenarios, and the total percentage of energy generated in each scenario.

When looking at these results, it is important to keep in mind that these numbers are estimates based on idealized numbers. Solar panel ratings are based on standard test conditions, and may not achieve the output that the manufacturers claim. The same is true for wind turbines. The amount of energy each resource type can generate will likely be lower than what is represented here. Likewise, the area in square meters of

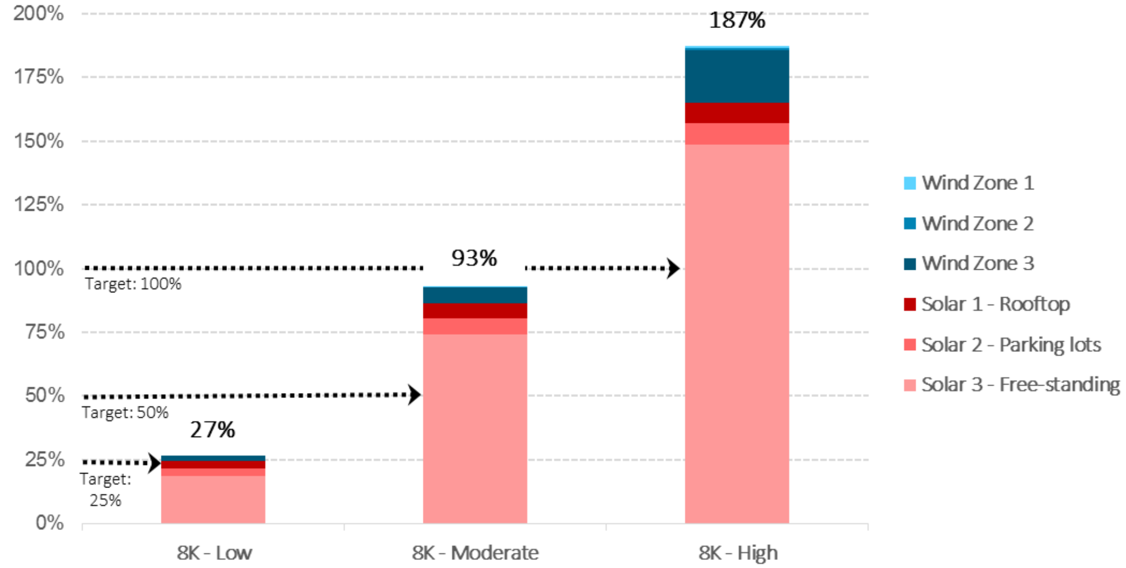


Figure 11. Summary of the total energy generated by the six resource types in each Eight-Kilometer Scenario.

each resource type is meant to provide a basic guideline; each type may need more or less area depending on the situation. For example, the footprints of the wind turbines were calculated based on spacing between turbines when placing several on the same plot of land, but if only one turbine was installed, it may not need as large a footprint.

The results and key findings from these scenarios will be discussed in the next chapter.

CHAPTER V

DISCUSSION

The six scenarios represent a wide range in the energy potential for Cedar City as well as a wide range of impacts. Looking at the Town Scenarios, it appears that the potential for energy production within the city boundary is fairly limited. Town Scenario 1 is not very land intensive and not intrusive upon the landscape, but is very limited and does little to move Cedar City in the direction of energy autonomy. This scenario meets 14% of Cedar City's annual energy consumption, which is respectable and certainly a step in the right direction, but by 2060, that drops to 5%. Town Scenario 2 and Town Scenario 3 both represent an increase in the amount of rooftops and land committed to energy generation. Each of these two scenarios is progressively more land intensive and involves a greater number of turbines and solar panels widely dispersed around the town, but without much gain in generated energy over the low scenario - 23% and 35% of the annual energy consumption respectively. None of the three scenarios met the targets they were constructed to hit.

Town Scenario 3, the most aggressive of the three, involves several wind turbines near the airport, on a ridge northeast of town, and one at the south end of town. This decentralized scattering of wind turbines around the town would be inefficient, requiring infrastructure and transmission to be established in multiple locations. Additionally, this configuration would be very visually prominent with wind turbines in multiple directions. And yet, because the height restrictions on much of this land would necessitate smaller turbines, the energy generated by these turbines scattered around town would not be very significant.

Solar energy has much greater potential within the town boundary than wind, and would be much less intrusive. Rooftop solar panels are an excellent source for on-site generation at point of use, and the energy could be used by the building itself to offset demand from the grid. Parking lot canopies are also worth investing in to produce power at the point of use while shading vehicles and pavement and reducing the heat island effect. By developing solar projects on and around public buildings and offsetting the energy consumption of those facilities, the city could reduce its energy costs, which would benefit the taxpayers. The option of installing solar panels within town is a worthwhile idea that is common to both the Town and the Eight Kilometer Scenarios.

In contrast to the Town Scenarios, the Eight Kilometer Scenarios nearly met or exceeded their targets and could possibly meet a large portion if not all of Cedar City's energy needs. The large parcels to the west clearly have a huge impact on the city's ability to generate energy on its own land. In fact, there is so much land available there that there's little incentive to look anywhere else. These parcels would allow the city to centralize its energy production near, but not too near town in a location that is not as visually striking as the ridges and mountains east of town. Figure 12 shows the location, size, and site conditions of these parcels.

Eight-Kilometer Scenario 3 lies at the other end of the spectrum from Town Scenario 1. This scenario is extreme, very land intensive, and would involve major changes to the landscape that would substantially alter the visual experience of the city.

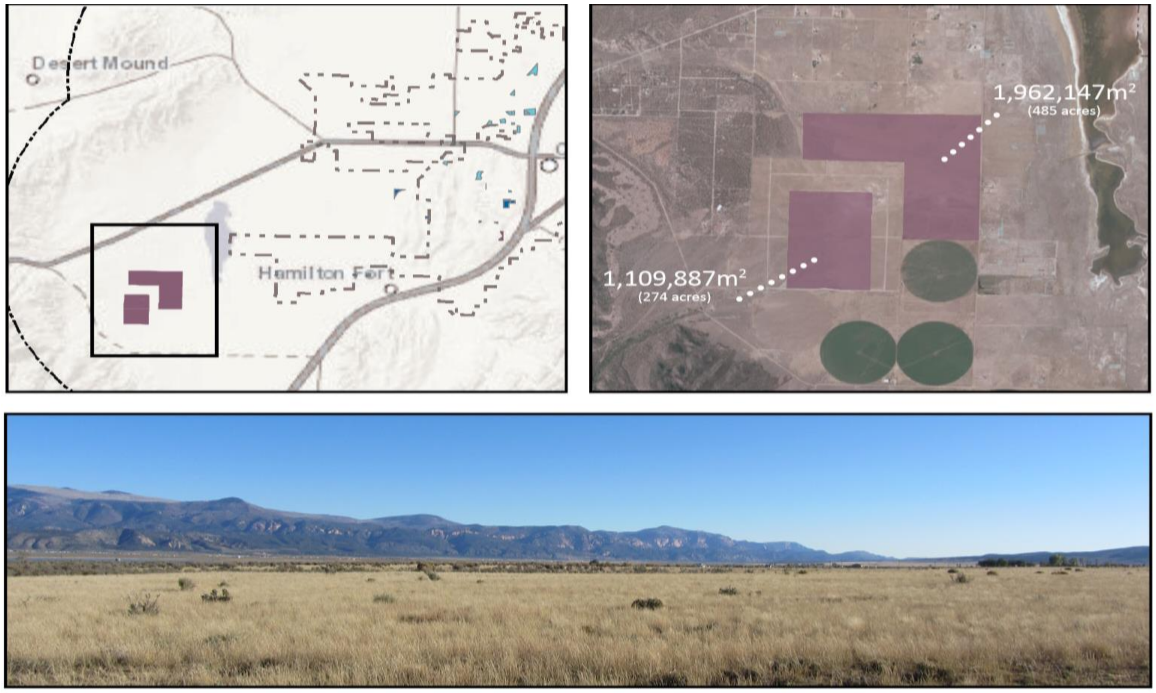


Figure 12. Location, size, and site conditions of the large parcels to the west of town.

The prominence of renewable energy in this scenario would indicate a major commitment to achieving energy autonomy and resiliency. This scenario could potentially generate as much as 187% of the city's energy consumption, which seems excessive. But when the future electricity consumption of Cedar City is considered, the picture changes a little bit. As Cedar City continues to grow, by 2060 this aggressive scenario will generate 67% of the annual consumption. This highlights the necessity of thinking ahead about what the city's priorities are and how the city plans to handle future growth.

In considering other areas for wind turbines, as stated earlier there seems to be little need to look elsewhere when the large parcels to the west have such potential. Developing wind turbines near the airport would create the possibility of conflict with airport operations, and it would be necessary to seek the approval of the FAA. The

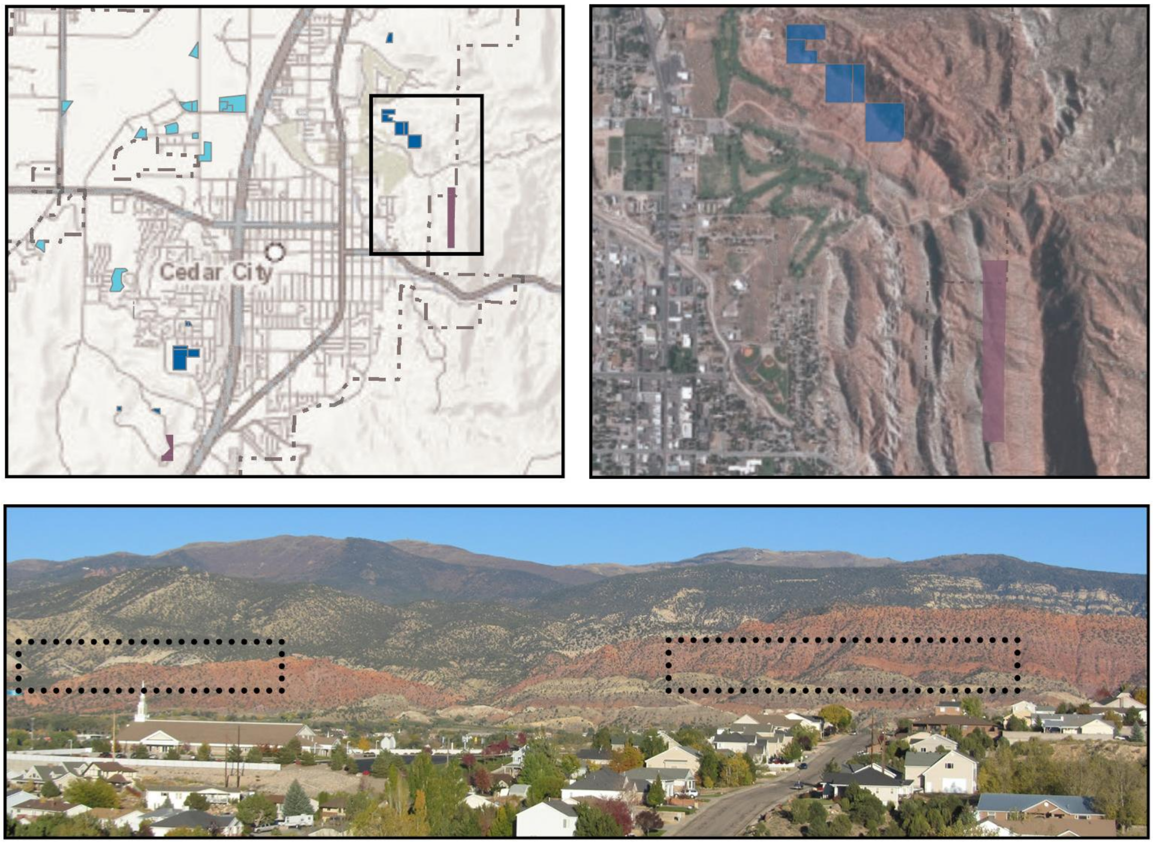


Figure 13. Location of the parcels on the hills east of town. Wind turbines placed in these areas would be very prominent visually.

several small squares on the hills to the northeast have interesting potential, but turbines located there would impact the views of the mountains. Figure 13 shows these parcels as well as the parcel on the ridge below The Red Hill. Placing wind turbines on these hills would depend in large part on how the community wants to see itself. It may want to preserve the hills and viewshed as is, which is understandable because they are beautiful. But wind turbines on the hills would have a different (if perhaps controversial) kind of beauty, and would send the message that Cedar City places a priority on clean renewable energy and energy autonomy.

Again, though, the large parcels west of town obviate the need to use any of the other parcels for wind energy generation. One of the benefits of this large area of land is the possibility of combining wind turbines with solar panels to create an integrated renewable energy project that minimizes the amount of land used while maximizing energy production. Wind and solar are both intermittent sources of energy, and that intermittency contributes to a variability of electrical load. However, wind and solar energy tend to occur at different and complementary times. Wind tends to be stronger and to generate more energy at night and during the winter, while solar energy is only available during the day and is at its height during the summer. Therefore combining wind and solar in the same facility can have the effect of stabilizing and evening out the load. In addition, by combining wind turbines and solar panels on the same site, they can both use the same infrastructure such as transformers and transmission lines, which cuts down on costs.

Cost is of course one of the primary determining factors in developing renewable energy projects. The cost of developing enough renewable energy capacity to offset a substantial portion of the annual energy consumption would be considerable, the kind of cost that is usually taken on by independent developers rather than municipalities. Developing the large parcels would allow economies of scale for either wind turbines or solar PV arrays, since large projects are less expensive per megawatt to build than smaller ones. Given the relatively marginal wind speeds in the Cedar City area, solar might be a better choice, though within that option, there are other choices to be made. There is a trade-off between choosing different solar panel tilts. Solar panels at a 10° tilt yield a lower annual energy production than those at 37.7°, but that tilt would allow more panels to be installed within a given space, so that option may end up yielding more energy. However, more panels also means an increase in expense. So the decision becomes more panels, less land intensive, and higher cost versus fewer panels, more land intensive, and lower cost.

If the desire to be a resilient, sustainable community is a primary motivating factor, there are also other costs to consider: the cost of making solar panels versus the cost of manufacturing wind turbines, the amount of energy that is consumed in the making of the products, and the environmental cost of the manufacturing process. The city would have to do an in-depth cost analysis to really make the decision on whether to install wind or solar or both.

Local support or lack thereof is another factor that plays a strong role in the development of these large parcels. There are a number of homes nearby, along the foot of the hills to the west. Local homeowners might object to the intrusion of renewable energy technology into their rural lifestyle. Several years ago, a wind energy developer was exploring the possibility of building a wind project nearby between Cedar City and neighboring New Harmony, according to Christine Mikell of Wasatch Wind (personal communication, April 8, 2013). The project was scrapped largely due to public opposition which stemmed from concern over protecting the visual qualities of the area. Soliciting comment, gauging community interest, and gathering support would be critical in pursuing energy development in this area.

One of the biggest challenges in establishing a community renewable energy project in Cedar City would be negotiating with Rocky Mountain Power, the current electrical power supplier. As stated before, Cedar City does not have its own municipal power company and would need come to an agreement with Rocky Mountain Power when there is little incentive for the utility to make accommodations for the city's own power generation. Cedar City would have to be able to use Rocky Mountain Power's transmission lines and depend on the utility to provide or deliver power when there is not enough renewable energy to meet demand. Likewise, there is also not a mechanism in place whereby Cedar City could sell excess power back to Rocky Mountain Power. Major changes would need to be made in how the utility operates for Cedar City to truly achieve energy independence.

Now is the time to investigate these issues in order to have a plan in place as the city grows. With the population of the city projected to reach 44,812 by 2030 and nearly 80,000 by 2060, the character and pattern of the city will be altered. The boundaries of development will spread outwards and encroach upon undeveloped areas such as the large parcels west of town. Cedar City presently has the ability to make decisions on the best use for this land and whether using it for renewable energy generation is a priority before development makes that difficult or impossible. In the process of identifying the places that are best for energy production, the city can also identify land to be set aside for industrial or residential development as well as land to be preserved as green space or for agricultural purposes.

And in fact, energy generation can be compatible with some of those uses. Wind energy generation is compatible with farming - turbines can be placed in among the crops so that one parcel of land can serve multiple functions, which increases sustainability and adds economic value. Renewable energy generation can also be integrated into land set aside as green space. The concept of green infrastructure refers to a network of natural areas or green space that is preserved to treat stormwater, protect wildlife habitat, clean the air, provide recreational opportunities, and foster a healthier urban environment, and energy generation can and should be included as another element of such a network. Integrating energy generation with stormwater management, biodiversity protection, and food production strengthens the connections between natural processes and human habits and needs, which in turn strengthens the sustainability of a region.

Conclusion

This study argues in favor of distributed renewable energy generation at the community scale, which requires a new way of structuring our energy systems in order for cities to produce what is needed locally. Local production of renewable energy reduces the emission of pollutants from fossil fuel-fired power plants, limits transmission losses, and increases energy autonomy, helping communities to become more resilient. But there are a number of challenges associated with distributed renewable energy generation, from cost and regulatory practices to lack of public understanding or support. It will take some big changes in the way we think and the way we prioritize energy alternatives to overcome some of those obstacles.

We are at a critical time for a transition of the electricity sector from the old model to a new, clean alternative. Renewable energy technology is getting better and costs are going down, and as the technology evolves, renewable energy generation may become less land intensive and more efficient. Smart grid systems will better monitor energy use and forecast demand in order to use our resources more efficiently. Producing energy at the local level will become more feasible. But we need to think about and plan for that generation now, as populations increase, communities sprawl outwards, and the demand for resources grows.

As the professionals tasked with shaping the built environment, landscape architects and planners must begin to think of energy as an integral part of the processes and resources specific to the place. We must consider how energy generation ties into the urban fabric when planning and laying out our infrastructure. This necessitates an understanding of the technology involved and the spatial and infrastructure requirements of that technology. Planners and landscape architects at the community level must craft planning approaches that take inventory of available resources both in terms of land and sources of energy; evaluate alternatives and quantify the outcomes; and make strategic decisions on land and resource use. We must also advocate for zoning that supports distributed renewable energy generation and cultivate political and public support. By doing so, we can drive the discussion on a community's resources and help make decisions on how those resources will be used.

As this study has shown, a city may have a number of options provided by its own assets. Communities that want to achieve some level of energy independence by generating energy locally may have resources already at their fingertips in publicly held land. In the process of analyzing Cedar City's resources, it was found that the city could conceivably meet some or perhaps all of its energy needs locally. Furthermore, the city has the potential to implement energy generation at different scales, from installing solar panels on the roofs of schools to offset the buildings' energy needs, to implementing large scale wind or solar projects that can meet a substantial portion of the community's energy consumption.

This study brings up questions and issues that invite further investigation. The financial feasibility of generating energy at a community scale is perhaps the biggest piece in question - what would it cost to achieve 10%, 25%, 50%, or even 100% of a community's electricity needs? If a community can generate more electricity than it needs, how might the sale of that excess production offset the cost of the project? A better understanding of the cost of community energy production is needed to understand whether such an undertaking is truly possible.

Other factors deserve further study in order to understand the feasibility of community renewable energy projects. Public acceptance and support of community renewable energy projects would be key to whether or not a project is implemented. Perception studies and visualizations could be used to help inform the public about the impacts of renewable energy generation and to help gauge their willingness to support energy generation in their community.

Another potential avenue of future study is the design of a pilot renewable energy community, such as the one proposed by Carlisle et al. (2008). This pilot community could be designed to combine a number of different principles such as local community-owned renewable energy generation, net zero-energy buildings, solar panels on homes and buildings, and the integration of plug-in electric vehicles as a means of energy storage. Such a pilot community could incorporate other sustainability practices such as low-water landscaping, green infrastructure to handle and treat stormwater runoff, passive solar design of buildings, and community design that promotes walking, biking, or alternative transportation.

This study demonstrates that any city may have untapped and unrecognized resources that can be developed if the community takes an active role in energy planning.

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