Adoption of On-Farm Renewable Energy Production Systems: A National Study

by

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APPROVAL BY THESIS DIRECTOR

This Thesis has been approved on the dates shown below

Professor George Frisvold	Date

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ABSTRACT

Adoption of On-Farm Renewable Energy Production Systems: A National Study

This study first develops a U.S. atlas of adoption of nine types of on-farm renewable energy system: biodiesel, ethanol, geo-exchange, biomass, methane, small hydro, solar, wind turbines, and leasing of wind rights. The atlas maps systems adopted per farm as well as the geographical concentration of adoption. Hawaii had the most total systems per 100 farms (21.1), followed by Vermont (10.7), and Alaska (10.1). Arizona (5.1) ranked 20th among states. Next, the study uses multivariate regression analysis to examine how adoption rates vary by producer group, state renewable resource potential, electricity prices, and state renewable energy policies. Adoption rates vary significantly across farms producing different types of commodities. Higher electricity prices appear to increase adoption of wind turbines and solar panels, but not of other renewable systems. Renewable resource potential also explains adoption rates, although the relationship can be complex. For example, solar adoption rates are relatively high in Alaska and New England, with relatively low solar potential. This may be because of policies in those areas to encourage adoption or because solar potential measures need to be re-scaled based on length of growing season.

CHAPTER ONE

INTRODUCTION

Without energy the whole fabric of society would crumble; it is difficult to fathom the effects of a 24-hour electricity cut to a city and this only proves how totally dependent we are on that particularly useful form of energy. As populations grow, many faster than the average, the need for more energy is exacerbated. Enhanced lifestyle and energy demand rise together and the wealthy industrialized economies, which contain 25% of the world's population, consume 75% of the world's energy supply. ((ED.),1990)

The solution to the impending energy shortage and the rising of energy price is to make much more use of renewable energy sources and technologies. However, during the generation of such renewable energy it is also imperative to consider aspects of engineering practicality, reliability, applicability, economy, scarcity of supply and public acceptability.

Renewable Energy (RE) is commonly defined as energy that comes from resources that are naturally refilled on a human timescale such as sunlight, wind, rain, tides, waves and geothermal heat. Renewable Energy replaces conventional fuels in four distinct areas: electricity generation, hot water/space heating, motor fuels, and rural (off-grid) energy services.

Nowadays, Renewable Energy is being recognized for its ability to reduce greenhouse effect by reducing fossil fuel consumption, and replace high conventional energy prices. Based on REN21's 2014 report, renewables contributed 19% to our energy consumption and 22% to our electricity generation in 2012 and 2013, respectively. Modern renewables, such as wind, solar, biofuels and hydro contributed in about equal parts to the global energy supply. Worldwide investments in renewable technologies amounted to more than US$ 214 billion in 2013, with countries like China and the United States heavily investing in wind, hydro, solar and biofuels.

Renewable Energy resources are presented over wide geographical areas, in contrast to other energy sources, which are boiled down in a limited number of countries. Rapid deployment of renewable energy and energy efficiency is resulting in significant energy security, climate change mitigation, and economic benefits. There is strong support for promoting renewable sources such as solar power and wind power from international public opinion surveys. At the national level, at least 30 nations around the world already have renewable energy contributing more than 20 % of energy supply. According to the fact, national renewable energy markets are projected to continue to grow strongly in this decade and beyond.

While many renewable energy projects are large-scale, renewable technologies are also fitted to rural and remote areas and developing countries, where energy is often important in human development. However, the costs of energy from renewable energy is often higher than the conventional sources, and the institutions and systems which deliver such energy may disrupt development of alternative source. Nonetheless, there is strong support to promote the use of alternate energy from federal and state policies by reducing institute barriers and offering financial incentives which have led to an increase of electricity generated from renewable sources in US.

Based on the U.S. Energy Information Administration 2011, the use of alternative fuels for electricity has been increasing in the last decade both for utility scale eletricity production and smaller on-site consumer applications. Notciceably, wind generation in the electric power sector increased an average 33% year-on-year since 2000, while solar has seen a recent surge with an average 27% annual increase since 2007.

Moreover, all types of renewable energy production and consumption(Fig 1) show an upward trend. The use of wind energy is rising since 2008 and will reach 150 trillion Btu in 2015.

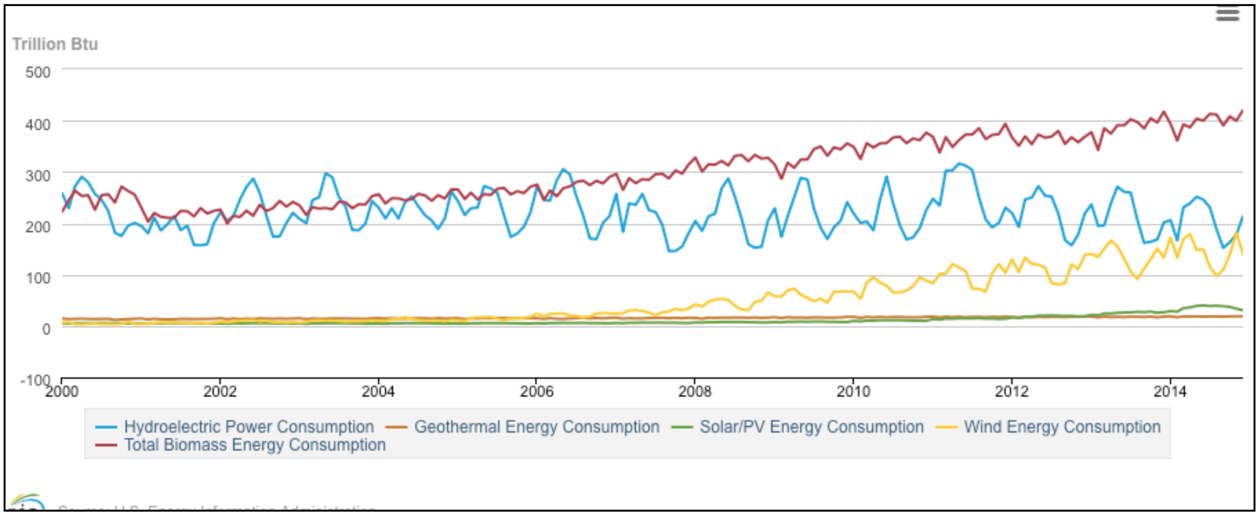


Fig 1: Renewable Energy Production and Consumption by Source

Renewable energy in agriculture

Agricultural sector has become more energy-intensive in order to supply more food to increasing population and provide sufficient and adequate nutrition. However, considering the limited natural resources available, it has become imperative to explore the use renewable energy in agriculture.

Agricultural producers have been early adopters of some renewable energy technologies, partly due to their convenient application for small and remote power needs. These applications include electric fencing and water pumping. Other on-farm applications include larger installations such as wind turbines, solar, ethanol, biodiesel etc. to stabilize commercial electricity prices. There is very little known about the characteristics of farm operations employing alternative fuel sources for electricity at the national level, and the impact of existing state policies in promoting renewable energy, (Lazarus, 2013)(Beckman 2014) and these studies only pertain to the use of solar and wind energy.

This study first develops a U.S. atlas of adoption of nine types of on-farm renewable energy system: biodiesel, ethanol, geo-exchange, biomass, methane, small hydro, solar, wind turbines, and leasing of wind rights. The atlas maps systems adopted per farm as well as the geographical concentration of adoption. This project analyzes data from recent census data where it categorizes the state farm operation into different technology adoption. Therefore, the project is able to resolve into elements more than the using only the state level data.

The study uses multivariate regression analysis to examine how adoption rates vary by producer group, state renewable resource potential, electricity prices, and state renewable energy policies. The study gives us an insight into important state characteristics, renewable resources potential, energy prices and policies on state level decision that are correlated with adoptions of the nine types renewable energy technology.

Through this study we deduce that adoption rates vary significantly across farms producing different types of commodities. Higher electricity prices appear to increase adoption of wind turbines and solar panels, but not of other renewable systems. Renewable resource potential also explains adoption rates, although the relationship can be complex. For example, solar adoption rates are relatively high in Alaska and New England, with relatively low solar potential. Such trend may be attributed to certain policies in those areas to encourage solar adoption or because solar potential measures need to be re-scaled based on length of the growing season.

CHAPTER TWO

LITERATURE REVIEW

Because of the rising of energy prices over the last two decades, many policies were created by government to promote the adoption of on-farm renewable energy. In this project, we would like to answer the question of how the renewable energy potential, the renewable energy related policies and electricity prices effects the adoption. The important thing of this project that none other has done before is we analyzed all five types of renewable energies in the U.S. In this section, I will go over the projects, which people have done before and they are related to the study.

Firstly, three articles below are the study of adopting renewable energy in general.

1. Menz and Vachon (2006), they did the first State-level evaluation of how utility-scale renewable electricity capacity relates to State policies. They considered renewable portfolio standards (RPS), generation disclosure, a mandatory green power option, public benefit funds, and choice of electricity source. The results show that renewable portfolio standards (RPS) and green power options were positively related to wind power development.

2. Adelaja and Hailu (2008), they furthered the analysis by adding State socioeconomic and political characteristics. They found that RPS has a significant effect on wind development, as do the State's wind potential, economic conditions, and political structure.

3. Shrimali and Kniefel (2011), they considered the impact of RPS, government green power purchasing, and financial incentives along with resource, economic, and political measures on wind, biomass, geothermal, and solar generation capacity. They found that RPS impact varied by type of renewable and was negative for combined renewables.

Based on these three projects, Renewable Portfolio Standard (RPS) has a significant effect towards the renewable energy adoption.

Secondly, another three articles that I will mention down below, they did the analysis focusing on on-farm renewable energy adoption.

1. Irene M. Xiarchos (2012), her topic is "Factors Affecting the Adoption of Wind and Solar-Power Generating Systems in U.S. Farms; Experiences at the State Level". Her study is the first study that analyzed the State level renewable energy related policies for example Net-metering (also in this project analysis), RPS and electric cooperatives. She studied on the adoption rates of solar and wind systems in the U.S. In addition, RPS is found to increase the adoption, which is similar to what Adelaja and Hailu (2008) found.

However, for financial incentive like rebates, grants, tax credits and production incentives, she did not find the relationship between them and the adoption of wind and solar. The rational behind that which she provided was the State level might not influence the adoption rates. It is also true that the effective at the farm level are not large to induce a significant impact.

For Net metering and Interconnection, the policies did not influence the adoption at the State level. However, her hypothesis, net metering increases the positive flow of revenues from the renewable electricity system and reduce its payback period.

For electric cooperative, she found that it has a negative relationship to renewable energy adopting, which highlights the essential of policy formulation.

2. Beckman and Xiarchos (2013), this analysis gave comprehensive into variables that are correlated with adoption of solar and wind technologies on U.S. farms. They investigated farmer, farm operation and state characteristic effect on the probability of on-farm renewable energy generation. They also did the correlation between the explanatory variables, which are average retail electricity price, net metering, interconnection, cost incentives, product incentives, co-op and DG set-aside in RPS and found that none of them have a correlation greater than 0.4.

Results recommend that farm characteristic for example; live stock operations, owned acreage, operators with Internet access. Organic operations and newer farms have a positively relationship with the wind and solar adoption. The results from state characteristics show that solar resources, per capita income levels and predominantly democratic voting increase the propensity of adoption.

For state policy inference, the combined of net metering and interconnection policies are shown to increase the propensity of adoption. However, they did not find the cost incentives and RPS relationship towards the adoption. Moreover, for co-op, it could affect farm level renewable energy adoption but because of the limited of data, they could not find an explicit relation of the adoption.

3. Borchers and Beckman (2013)

All the studies above are not on farm and household characteristics in isolation, which should be expected to determine technology adoption until Borchers and Beckman (2013) offered the first national examination of the determinants of adoption of wind and solar energy generation on U.S. farming operations.

They used the multilevel logit model to analyze the determinants of solar and wind technology adoption on U.S. farm. In the study, they have “on-farm renewable energy production survey” together with the “state policies for on-farm renewable energy development”.

In the survey, electricity represented 18% of total energy consumed on-farm and 2.5% of average farm expenditures. In their hypothesis, using the renewable energy to generate the electricity could reduce the electricity expenditure as well as fuels expenditure.

For state policies, they considered the financial incentives, RPS, net metering, interconnection standards and these variables are the explanatory variables in our study as well.

Results suggest that, in terms of farm characteristics, they are robust with the results from Beckman and Xiarchos (2013); livestock operation, operators with internet access, organic operations increase the propensity of adopt solar and wind generation.

The results from state policies, the combination of net metering and interconnection is shown to increase the adoption.

CHAPTER THREE: DATA AND VARIABLES

As mentioned in the previous section, the study's goal is to consider how adoption rates of on-farm renewable energy generation vary by producer group, state renewable resource potential, electricity prices, and state renewable energy policies. Before describing the data and variables, we introduce the model that used in the econometric analysis first. Let i = farm type as classified under the North American Industry Classification System (NAICS). There are 12 different farm types. Also, let t = type of renewable energy produced on the farm. In the analysis, five different types of renewable energy systems were considered: solar, small hydro, wind rights, wind turbines, and methane. Four of these were direct electricity production systems. By leasing wind rights, a farmer receives payments to let others install and operate wind turbines on his or her land.

The dependent variable

Data on adoption rates by state, farm type by NAICS, and renewable energy system come from the most recent, 2012 Census of Agriculture. This is the first year the Census of Agriculture reported such renewable energy adoption data. Adoption rate, $y_{i, s, t}$ is the proportion of those farms from industry *i* in state *s* to adopt technology, *t*. For each technology there are potentially 50 (for states) x 12 (for industries) = 600 observations. This is what the data from Census looks like,

The first set of data contains: year, state, type of farm (by NAICS) and number of farms in that NAICS group. We used this number as the denominator for the adoption rate. The next set of data (Fig.3) contains year, state, type of renewable energy, type of farm, and number of farms adopting that particular type of renewable energy. We used this number as the nominator. Figure 3 is a subset of figure 2. The adoption rate for biodiesel in farm type (1113) is

$$\text{Adoption rate for biodiesel} = \frac{3}{877}$$

Studies of aggregate technology adoption and diffusion often transform data using a logistic function:

(1) $y_{i, s, t, z} = [\, 1 - e^{-a - bz}]^{-1}$

where the proportion adopting is a function of time, denoted here by c. This function assumes that with the passage of time, aggregate adoption follows an S-curve, characterized by a slow initial growth, followed by rapid growth after a certain take-off point, and then again a slow growth towards an upper limit (Figure 2).

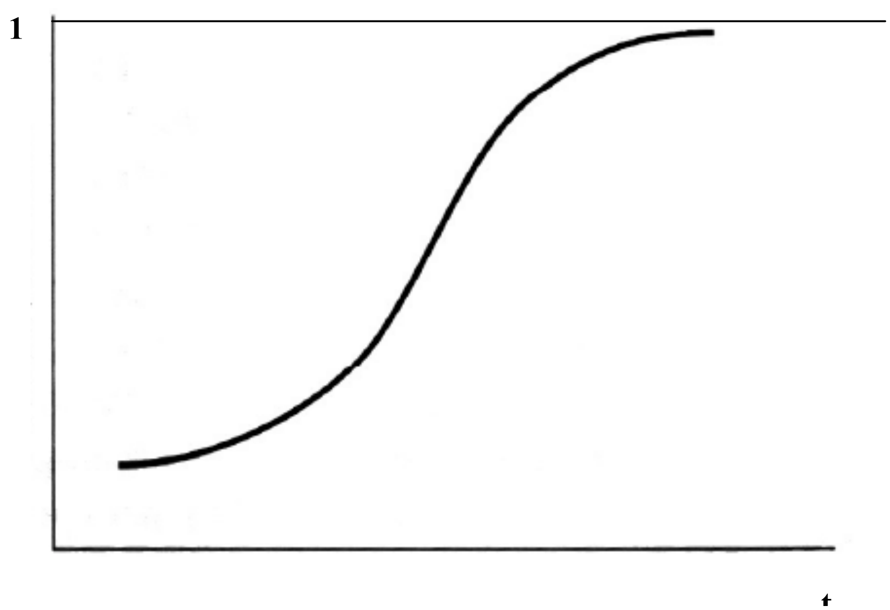


Fig 2: The S-curve

There is no time dimension in the data because 2012 is the first year data is reported. We use the logistic transformation anyway because it may become useful in future research. In addition, the logistic transformation fit the data in regressions better. Equation (1) is highly non-linear, but it can be transformed so that

(2) $\ln (y_{i,s,t} / (1 - y_{i,s,t}) = a.$

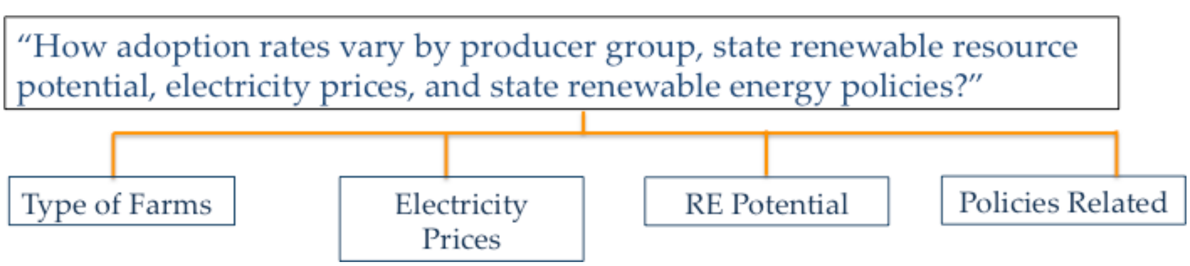
We make two further adjustments. First, the constant a will be a linear function of explanatory variables $\boldsymbol{X'}\beta$ where $\boldsymbol{X}$ is a vector of explanatory variables and β is a vector of regression coefficients. So, one can think of a regression equation as follows

(3) $\ln (y_{i,s,t} / (1 - y_{i,s,t}) = a + \boldsymbol{X'}\beta + \varepsilon$

where ε is a stochastic error term. There is one remaining problem to address. For many technology / industry / state combinations, no farms adopt the renewable energy technology. Equation (3) cannot be estimated in this case because ln (0) is not defined. We, therefore use the adjustment recommended in Pindyck and Rubinfeld (1998) where 0.5 is added to the numerator and denominator of the dependent variable, so that the regression equation becomes

(4) $\ln [(y_{i,s,t} + 0.5) / (1.5 - y_{i,s,t})] = a + \boldsymbol{X'}\beta + \varepsilon$

Independent Variables



In the analysis, there are four main categories of explanatory variables: farm type, electricity price, renewable resource potential, and policy-related variables.

1. Type of Farms

1. Oilseed and grain farming (1111)

This comprises of establishments primarily engaged in (1) growing oilseed and/or grain crops and/or (2) producing oilseed and grain seeds. These crops have an annual life cycle and are typically grown in open fields. This category includes corn silage and grain silage.

2. Vegetable and melon farming (1112)

This comprises of establishments primarily engaged in one or more of the following: (1) growing vegetables and/or melon crops, (2) producing vegetable and melon seeds, and (3) growing vegetable and/or melon bedding plants.

3. Fruit and tree nut farming (1113)

This comprises of establishments primarily engaged in growing fruit and/or tree nut crops. These crops are generally not grown from seeds and have a perennial life cycle.

4. Greenhouse, nursery, and floriculture production (1114)

This comprises of establishments primarily engaged in growing crops of any kind under cover and/or growing nursery stock and flowers. ‘‘Under cover’’ is generally defined as greenhouses, cold frames, cloth houses, and lath houses. Crops grown are removed at various stages of maturity and have annual and perennial life cycles. The category includes short rotation woody crops and Christmas trees that have a growing and harvesting cycle of 10 years or less.

5. Other crop farming (1119)

This comprises of establishments primarily engaged in (1) growing crops such as tobacco, cotton, sugarcane, hay, sugar beets, peanuts, agave, herbs and spices, and hay and grass seeds, or (2) growing a combination of the valid crops with no one crop or family of crops accounting for one-half of the establishment’s agricultural production (value of crops for market). Crops not included in this category are oilseeds, grains, vegetables and melons, fruits, tree nuts, greenhouse, nursery and floriculture products.

6. All other crop farming (11199)

This comprises of establishments primarily engaged in (1) growing crops (except oilseeds and/or grains; vegetables and/or melons; fruits and/or tree nuts; greenhouse, nursery, and/or floriculture products; tobacco; cotton; sugarcane; or hay) or (2) growing a combination of crops (except a combination of oilseed(s) and grain(s)); and a combination of fruit(s) and tree nut(s) with no one crop or family of crops accounting for one-half of the establishment's agricultural production.

7. Beef cattle ranching and farming (112111)

This comprises of establishments primarily engaged in raising cattle (including cattle for dairy herd replacements).

8. Cattle feedlots (112112)

This comprises of establishments primarily engaged in feeding cattle for fattening.

9. Dairy cattle and milk production (112120)

This industry comprises establishments primarily engaged in milking dairy cattle.

10. Poultry and egg production (1123)

This industry group comprises establishments primarily engaged in breeding, hatching, and raising poultry for meat or egg production.

11. Sheep and goat farming (1124)

This industry group comprises establishments primarily engaged in raising sheep, lambs, and goats, or feeding lambs for fattening.

12. Animal aquaculture (1125)

This comprises of establishments primarily engaged in the farm raising of finfish, shellfish, or any other kind of animal aquaculture. These establishments use some form of intervention in the rearing process to enhance production, such as holding in captivity, regular stocking, feeding, and protecting from predators.

2.) Electricity Price

The influence of economic factors on renewable energy adoption has been assessed at the state level (Hailu, 2008). We consider energy prices that directly impact the return for renewable energy installations. We deflated electricity prices from year 2008 – 2012 and then took the average to get the electricity price variable. The price varied across States, ranging from $3 /kWh to $23/kWh.

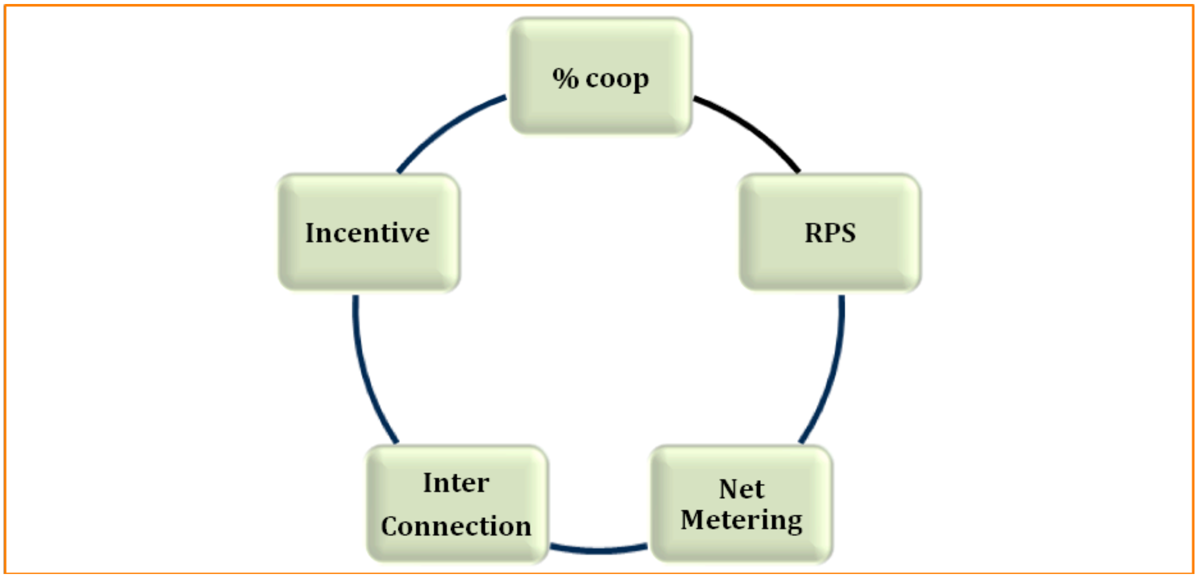
3.) Renewable Energy Potential:

The economics of a renewable energy installation are dependent on the resource potential available for energy production. We used the potential data from The National renewable Energy Laboratory (Lopez et al., 2012).

- For Solar potential, $\{(\textbf{Urban Utility} - \textbf{scale PV (GW)})/(\textbf{Urban Utility} - \textbf{scale PV (km2)})\}$ is used as a variable for solar potential.
- For Wind Rights and Wind Turbines potential, $\{\frac{\textbf{Onshore Wind (GWh)}}{\textbf{Onshore Wind (km2)}}\}$ is used as a variable for wind potential.
- For Small Hydro potential, $\{\frac{\textbf{Hydropower (GWh)}}{\textbf{Land}}\}$ and $\{\frac{\textbf{Hydropower (Count of Sites)}}{\textbf{Land}}\}$ are used as a variable for hydro potential.
- For Methane potential, $\{\frac{\textbf{Biogas}}{\textbf{Land}}\}$ and $\{\frac{CH_4}{\textbf{Land}}\}$ are used as a variable for methane potential.

Renewable resource potential explains adoption rates, although the relationship can be complex. For example, solar adoption rates are relatively high in Alaska and New England, with relatively low solar potential.

4. Policies Related Variables



The variables that we used are similar to other studies of solar and wind technology (Beckman 2014). Xiarchos (2013) claimed that Federal and state policies have played an important role in the growth of renewable energy production over the last two decade. State policies promoting renewable energy development vary from state to state, and therefore some states or policies may be more effective at encouraging adoption than others may.

4.1 Percentage customers serviced by Electric Cooperative (% co-op)

The percentage of electric customers served by an electric cooperative (% coop) is included as an indicator of the prevalence of cooperatives in the electricity generation for each state. Electric cooperatives have distinct characteristics that can affect renewable energy adoption by farms. Additionally, electric cooperatives, unlike Investor-owned utilities (IOUs) are not required by the

Public Utility Regulatory Policies Act of 1978 (PURPA) to interconnect with and purchase power at avoided cost from customers with excess onsite generation. Many States exclude cooperatives from regulations governing net metering, interconnection, and renewable portfolio standards (RPSs). We used four dummy variables to account for the following policy effects. Following Xiarchos and Beckman (2013), we consider the effects of net metering, interconnection and renewable portfolio standards and create distinct variables that characterize whether net metering and interconnection policies have be effective.

4.2 RPS

Renewable Portfolio Standards (RPS) require a minimum amount of renewable electricity sales, or generating capacity, that electricity utilities must achieve according to a specified schedule of dates and mandates. By December 2009, 29 States and the District of Columbia had established an RPS. The specified target amount and date to meet the requirements varied by State. Some States also provided specific solar and/or distributed generation (DG) "set asides." A "set-aside," also called a "carve-out," is a provision within an RPS that requires utilities to use a specific renewable resource to meet a certain percentage of their RPS. While RPS policies are designed to encourage utility-scale investments, those set-aside provisions provide incentives specifically for DG. Sixteen States and the District of Columbia have such set-asides implemented.

4.3 Net metering

Net metering or net energy metering (NEM) allows electricity customers who wish to supply their own electricity from on-site generation to pay only for the net energy they obtain from the utility. NEM is used for solar photovoltaic (PV) systems at homes and businesses (other distributed generation (DG) customers may have access as well). Because the output of a PV system may not perfectly match the on-site demand for electricity, a home or business with a PV system will export excess power to the electric grid at some times and import power from the grid at other times. The utilities bill customers only for the net electricity used during each billing period. Alternately, if a customer has produced more electricity than they have consumed, the credit for that net excess generation will be treated according to the NEM policy of the state or utility. Consequently, net metering can have positive financial implications for renewable energy adoption (IM Xiarchos, 2011). The specific rules, however, vary significantly in design from State to State. Of the 41 States and the District of Columbia with net-metering policies in 2008, only 26 States were considered by freeing the Grid to have "effective" net-metering policies based on their scoring methodology. The norm in net metering is a single bi-directional meter; however, it is possible that the electricity provider requires two meters: one that measures the flow of electricity from the grid and the other into the grid. For such a purchase-and- sale arrangement, the customer is required to receive only the utility's avoided cost for the excess electricity, which is a much lower price than the retail rate. In 2008, only 29 States and the District of Columbia offered retail electricity price for the excess electricity generated.

4.4 Interconnection

State interconnection procedures are a critical component of a state's policy. They specify the technical requirements, timeframe, fees and process for connecting renewable energy systems to the utility grid. As a result, restrictive, costly procedures can significantly impede a state's renewable energy growth by discouraging otherwise feasible projects. IREC has led the effort to improve interconnection procedures in states across the country. IREC plays a key role in facilitating extensive stakeholder processes in states such as California and Hawaii, where substantial revisions to interconnection procedures have been established to increase the efficiency of the review process, even in the face of increasing penetrations.

Two particularly significant process improvements were adopted in the last few years: the application of a higher penetration screen that looks at minimum instead of peak load, and is applied through the supplemental review process; and the implementation of a pre-application report to enable developers to better choose appropriate project locations. Rules vary by State. According to the scoring methodology used in Freeing the Grid, only 14 of the 37 States and the District of Columbia implemented interconnection standards considered "effective" and met the requirements for satisfactorily having removed interconnection market barriers for renewable energy development (Rose 2008).

4.5 Financial Incentives

Tax incentives, rebates, and grants are offered by States to encourage the use of renewable electricity by making its installation more cost effective and attractive. Installation tax credits are corporate and personal tax credits expressed in terms of percent of expenses for renewable electricity installations. Rebates and grants are direct payments: they offer a payment or discount that reduces the cost of renewable electricity installations. However, tax credits with low limits of payment act more like rebates. Lastly, production incentives (or performance-based incentives) provide payment per generated kilowatt-hours (kWh).

Twenty-seven states were identified to have some State incentive (incentive) that supported small-scale renewable distributed generation in 2008: 11 had tax credits (ITC); 19 had grant and rebate programs (DP); and 8 had production incentives (PI). The table below is an example of data that we take into account for analyzing the adoption rate for each type of farm in each state.

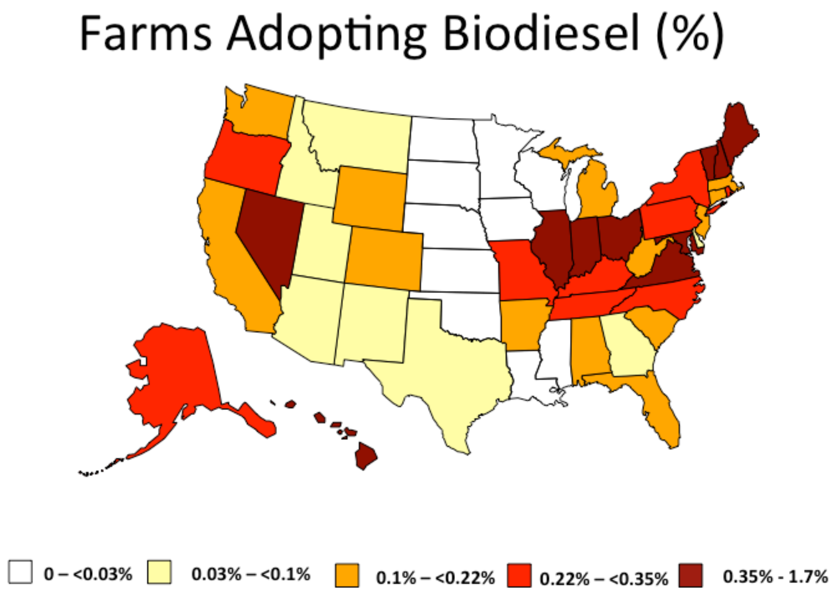
State	Net Metering	Interconnection	Incentive	RPS	S DG RPS
Alaska					
Alabama					
Arkansas	Effective	Yes			
Arizona	Effective	Effective	ITC, DP	Yes	Yes
California	Effective	Effective	PI	Yes	
Colorado	Effective	Effective		Yes	Yes
Connecticut	Effective	Yes	DP	Yes	Yes
District of Columbia	Effective	Effective		Yes	Yes
Delaware	Effective	Yes	DP	Yes	Yes
Florida	Effective, Exempt	Exempt			
Georgia	Yes	Yes			
Hawaii	Yes	Yes		Yes	
Iowa	Effective, Exempt	Exempt	PI	Exempt	
Idaho					
Illinois	Exempt	Effective, Exempt	DP	Exempt	Yes
Indiana	Exempt	Exempt	DP		
Kansas			ITC	Exempt	
Kentucky	Effective				
Louisiana	Effective	Yes			

Table 1: Example of Select Policy Variables for U.S. States

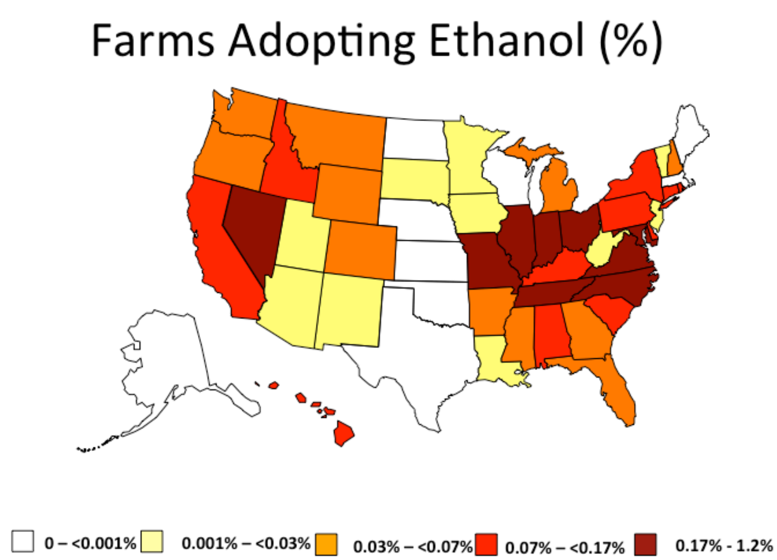
5. Land area per farm

This variable $\frac{\text{Total land area in the states}}{\text{number of farm}}$ characterizes how remoteness affects farm-level renewable energy adoption.

(3.3) Adoption Map Overview

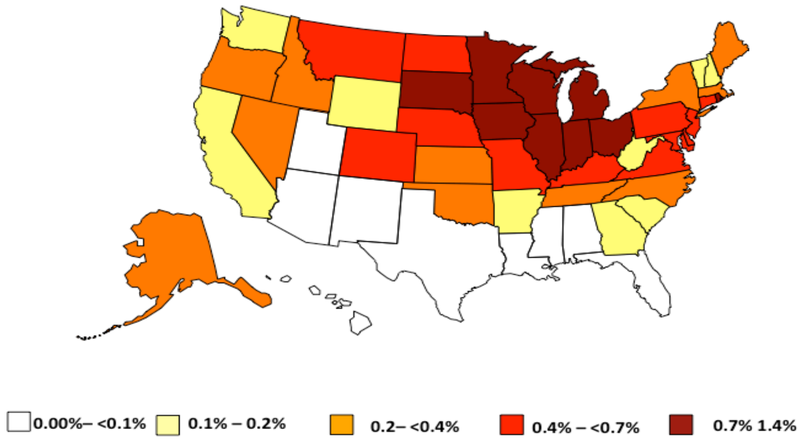


For farms adopting Biodiesel, high adoption rate is mainly in the East Side and some States from the Mid-West. In the Southern part, the adoption rate of Biodiesel is very low.



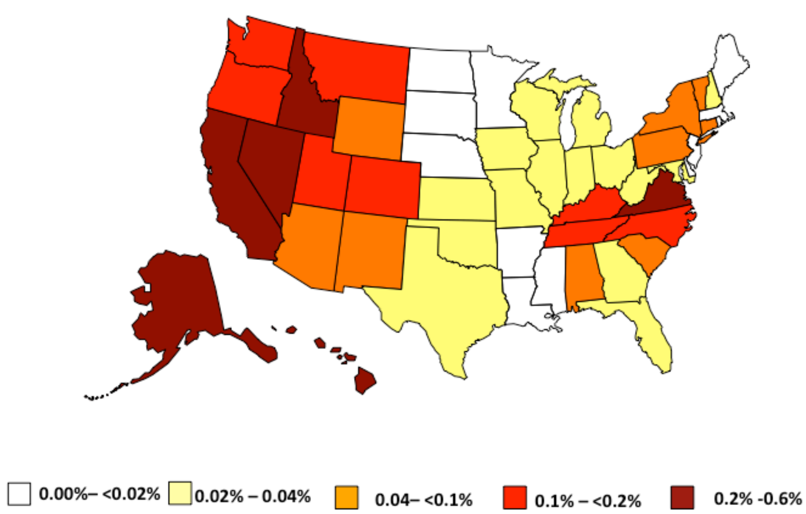
For farms adopting Ethanol, the rate is high in the Mid-West and South Atlantic for example Virginia, North Carolina and Tennessee. In the West Side, the adoption rate is moderate except Nevada, where the adoption rate is high. Alaska and West South Central, the adoption rate is very low.

Farms Adopting Geoexchange (%)

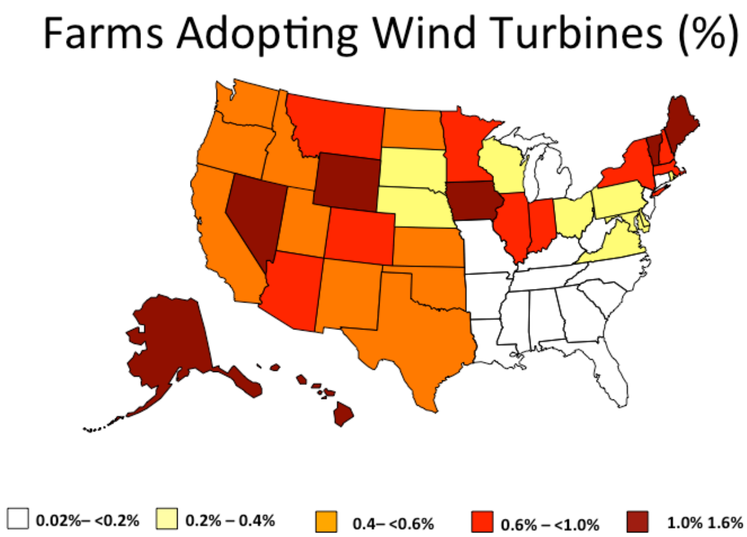


For farms adopting Geoexchange, almost the entire region in the Mid-West area has high adoption rate. While the Southern part, for instance, Texas, Arizona and Florida, has very low adoption rate. Both East and West side area have moderate adoption rates.

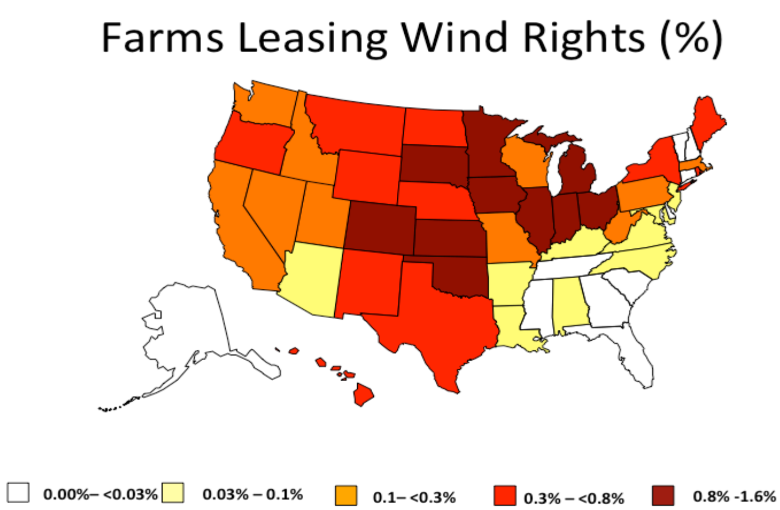
Farms Adopting Small Hydro(%)



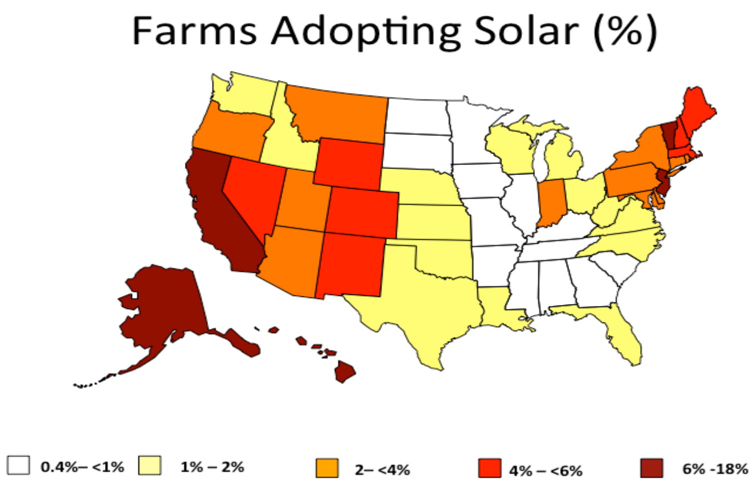
For farms adopting small hydro, the rate is high in the West area like Nevada, California, and Wyoming. Hawaii and Alaska also show high adoption rate. We can observe the low to very low adoption rate in the Mid-west and in the South Atlantic region.



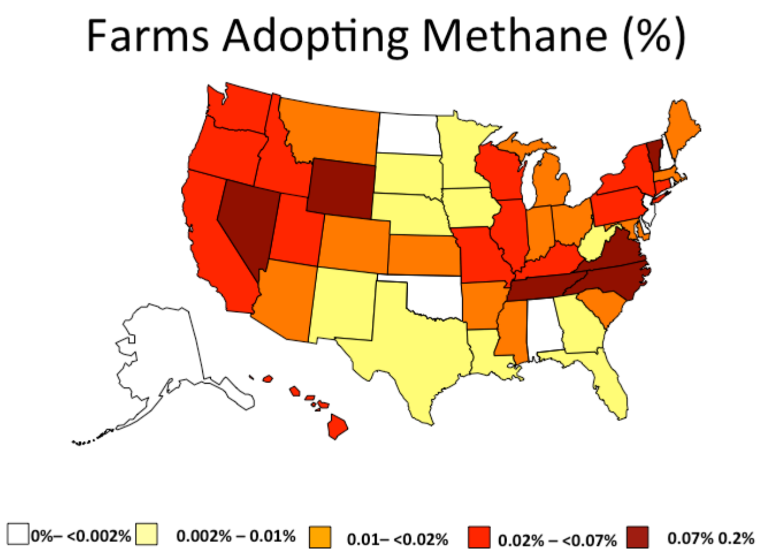
For farms adopting wind turbines, the rate is high in Alaska, Nevada, Iowa, Hawaii and Maine. There is a moderate adoption rate noticed mostly in the West region. In the South Atlantic region, the adoption rate is very low.



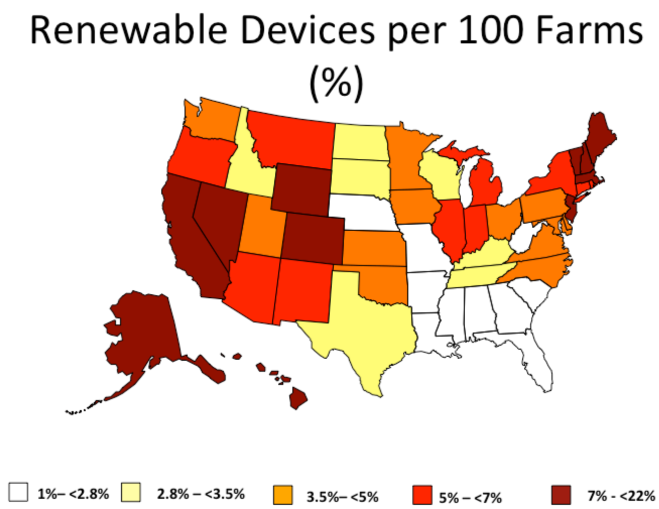
For farms adopting (leasing) wind rights, the high rate is mostly in located in the Mid-West region, for example Minnesota, Wisconsin and Illinois. While in the East and West coast, the adoption rates are slightly moderate to low.



For farms adopting solar, Alaska, California, New Jersey and Vermont shows highest adoption rate. Mid-West and South Central regions show low adoption rate. While in the East and West coast, the adoption rate is moderate.



For farms adopting methane, the rate is high in Nevada, Wyoming, Vermont, and in the South Atlantic area. In the Mid-West region and Alaska, the adoption rate is moderate to low. While in the west side, the adoption rates are slightly high.



Lastly, Renewable Devices per 100 Farms (%): New England, California, Alaska, Nevada, Wyoming and Utah has highest renewable adoption rate. While in the south Atlantic shows very low adoption rate. In the Mid West region, the adoption rate is moderate.

From the maps shown above, adoption rates vary significantly across farms producing different types of farms. For example, solar adoption rates are relatively high in Alaska and New England, with relatively low solar potential. We suspected that may be because of policies in those areas to encourage adoption or because solar potential measures need to be re-scaled based on the length of the growing season.

CHAPTER FOUR

MODELS AND METHODS

The adoption of a technology measured in terms of the cumulative number of adopters usually conforms to an exponential curve. The exponential growth pattern may be of three types:

(i) simple exponential
(ii) modified exponential
(iii) S-curve.

Out of these three growth patterns, the simple exponential pattern is not applicable for the dissemination of renewable energy technologies, as it would imply infinite growth. The modified exponential pattern (with a finite upper limit) is more reasonable, but such a curve may not match the growth pattern in the initial stage of adoption. Empirical studies have shown that in a variety of situations the growth of a technology over time may conform to an S-shaped curve, which is a combination of simple and modified exponential curves.

The S-shaped curves are characterized by a slow initial growth, followed by rapid growth after a certain take-off point and then again a slow growth towards a finite upper limit to the dissemination.

Lastly, the purpose of this project is to analyze the determinants of small hydro, solar, wind rights, wind turbines and methane technology adoption examining type of farm, state policies, electricity price, and renewable energy potential.

4.1) The distribution of dependent Variables

The proportion of farm adoption ranges from 0 to 1. After we calculated the adoption rate from the raw data, we ran proc univariate from SAS 9.4 software in order to get the histogram of all technologies. In each technology (total 8 technologies), we have

$$(50\ states \times 12\ type\ of\ farms) = 600\ observations.$$

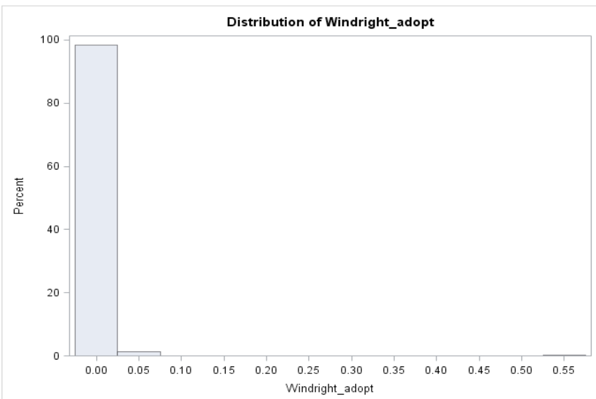


Fig 12: Distribution of the wind rights adoption

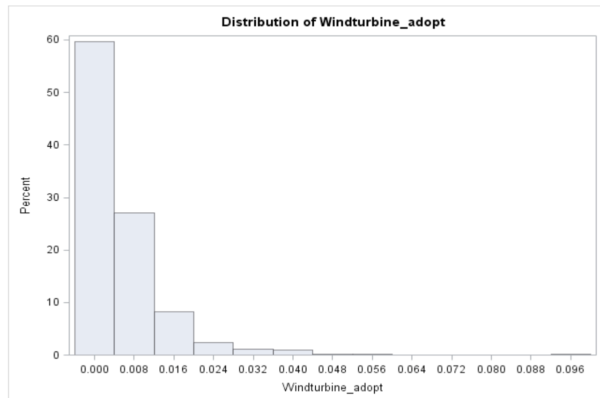


Fig 13: Distribution of the wind turbines adoption

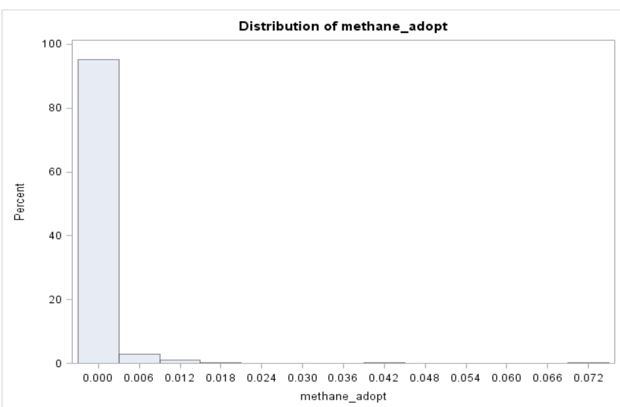


Fig 14: Distribution of the methane adoption

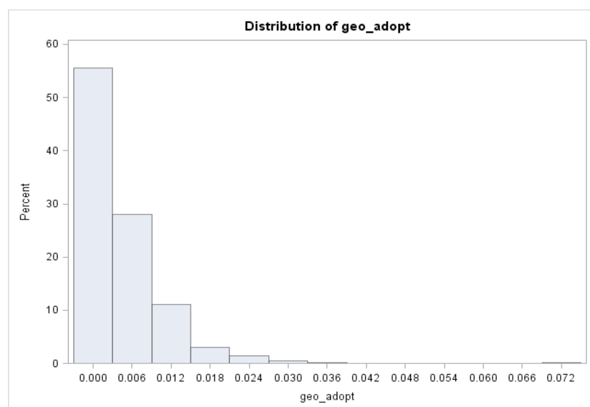


Fig 15: Distribution of the geoexchange adoption

From all histograms above, the distribution of the adoption rate are not normal and there are many "0" adoption observations. In addition, if the dependent variable is censored (e.g. zero) for a significant fraction of the observations, parameter estimates obtained by conventional regression methods (e.g. OLS) are biased. Consistent estimates can be obtained by the method called “Tobit” model. Therefore, in this study, we use Tobit model to analyze the determinants of technology adoption.

(4.2) Introduction of Tobit Model

The Tobit model is a statistical model proposed by James Tobin (1958) to describe the relationship between a non-negative dependent variable y_i and an independent variable (or vector) x_i. The term *Tobit* was derived from Tobin's name by truncating and adding *-it* by analogy with the probit model.

The model supposes that there is a latent (i.e. unobservable) variable y_i^*. This variable linearly depends on x_i via a parameter (vector) β which determines the relationship between the independent variable (or vector) x_i and the latent variable y_i^* (just as in a linear model). In addition, there is a normally distributed error term u_i to capture random influences on this relationship. The observable variable y_i is defined to be equal to the latent variable whenever the latent variable is above zero and zero otherwise.

$$y_i = \begin{cases} y_i^* & \text{if } y_i^* > 0 \\ 0 & \text{if } y_i^* \leq 0 \end{cases}$$

where y_i^* is a latent variable:

$y_i^* = \beta x_i + u_i, u_i \sim N(0, \sigma^2)$ (Wikipedia, 2014)

As we have the adoption data for 5 technologies, there are 5 Tobit model equations. All equations contain these following explanatory variables:

1. 8 type of farm (Dummy variables)
2. $\ln\left(\frac{Total\ Area}{Farm}\right)$
3. Net Metering & Interconnection
4. Renewable Incentives
5. RPS Distributed Set Aside
6. In (Electricity Prices)
7. % Electricity Cooperatives
8. Renewable Energy Potential

CHAPTER FIVE

RESULTS AND DISCUSSION

(5.1) Results

	Solar based variables		Solar potential added		Solar potential added	
	Coefficient	T-Stat	Coefficient	T-Stat	Coefficient	T-Stat
Intercept	-1.421	-33.25	-1.415	-15.98	-1.148	-11.98
Vegetable	0.104**	4.38	0.104**	4.36	0.098**	4.23
Fruit & Nut	0.086**	3.61	0.086**	3.59	0.080**	3.44
Greenhouse	0.083**	3.48	0.083**	3.47	0.077**	3.31
Other Crop	0.032	1.36	0.032	1.35	0.026	1.13
Beef Cattle Ranching	0.048**	2.01	0.048**	2	0.042	1.81
Cattle Feedlot	0.108**	4.42	0.108**	4.4	0.103**	4.34
Dairy	0.036	1.53	0.036	1.52	0.030	1.31
Hog	0.053**	2.23	0.053**	2.22	0.047**	2.03
Poultry & Eggs	0.093**	3.88	0.092**	3.87	0.086**	3.73
Sheep & Goats	0.067**	2.79	0.066**	2.78	0.060**	2.61
Other Animal	0.050**	2.09	0.050**	2.08	0.044	1.89
Total Area / Farms	0.030**	6.48	0.030**	5.74	0.023**	4.46
Net Metering & Interconnection	0.012	0.9	0.012	0.9	0.008	0.64
Renewable Incentives	-0.017	-1.44	-0.017	-1.44	-0.013	-1.14
RPS Distributed Set Aside	-0.001	-0.12	-0.001	-0.12	0.000	-0.03
In (Electricity Price)	0.079**	5.08	0.078**	4.79	0.054**	3.31
% Electricity Cooperatives	-0.001	-1.38	-0.001	-1.3	-0.001	.
Solar potential			-0.079	-0.08	-17.803**	-5.95
Solar potential squared					298.896**	6.26
pseudo - R squared	0.193		0.193			0.244

Table 2: Modeling Results for Solar Adoption Rates

For Solar adoption, we ran 3 equations: based variables, Solar potential included, Solar potential and Solar potential squared included. Comparing with Grain and Oilseed farm, other farm types tends to adopt more Solar technology significantly. (Total Area / Farm) has a significant and positive relationship to the Solar adoption while Net metering & Interconnection has a positive effect but not significant. Electricity Price has a negative and significant effect to the adoption of Solar. The Electric Cooperative Prevalence, Incentives and RPS set aside also has a negative effect but not significant. Interestingly, Solar potential has a significantly negative effect to the adoption while the squared term of Solar potential has a significantly positive effect.

	Small Hydro		Small Hydro		Small Hydro	
	Coefficient	T-Stat	Coefficient	T-Stat	Coefficient	T-Stat
Intercept	-1.100	-345.7	-1.094	-219.44	-1.101	-237.36
Vegetable	0.001	0.6	0.001	0.6	0.001	0.6
Fruit & Nut	0.000	-0.04	0.000	-0.04	0.000	-0.04
Greenhouse	0.001	0.68	0.001	0.68	0.001	0.68
Other Crop	0.001	0.49	0.001	0.49	0.001	0.49
Beef Cattle Ranching	-0.001	-0.44	-0.001	-0.46	-0.001	-0.44
Cattle Feedlot	-0.001	-0.46	-0.001	-0.48	-0.001	-0.46
Dairy	-0.001	-0.64	-0.001	-0.64	-0.001	-0.64
Hog	-0.001	-0.33	-0.001	-0.33	-0.001	-0.33
Poultry & Eggs	0.000	0.21	0.000	0.21	0.000	0.21
Sheep & Goats	0.002	0.85	0.002	0.85	0.002	0.85
Other Animal	0.005**	2.87	0.005**	2.87	0.005**	2.87
Total Area / Farms	0.000	1.27	0.000	0.04	0.000	1.21
Net Metering & Interconnection	0.000	0.12	0.000	0.28	0.000	0.09
Renewable Incentives	0.000	-0.08	0.000	-0.37	0.000	-0.02
RPS Distributed Set Aside	0.000	0.56	0.001	0.8	0.000	0.52
In (Electricity Price)	0.000	0.01	-0.001	-0.93	0.000	0.15
% Electricity Cooperatives	0.000	-0.68	0.000	-1.4	0.000	.
Gwh / Land			0.267	1.52		
Count / Land					-0.208	-0.2
pseudo - R squared	0.036		0.039		0.036	

Table 3: Modeling Results for Small Hydro Adoption Rates

For the adoption of Small Hydro Renewable Energy Technology, we found that only other Animal farm type adopting the technology more than Grain and Oilseed farm significantly. Other variable aspects for example Net metering & Interconnection, Incentive etc. has no effect towards the adoption. According to the Small Hydro potential, we found that (Gwh / Land) has positive but not significant relationship to the adoption while (Count / Land) has insignificant negative effect.

	Wind Rights		Wind Rights	
	Coefficient	T-Stat	Coefficient	T-Stat
Intercept	-1.053	-57.54	-1.100	-41.62
Vegetable	-0.042**	-4.07	-0.042**	-4.08
Fruit & Nut	-0.044**	-4.28	-0.045**	-4.31
Greenhouse	-0.044**	-4.27	-0.045**	-4.29
Other Crop	-0.036**	-3.55	-0.037**	-3.56
Beef Cattle Ranching	-0.038**	-3.67	-0.038**	-3.69
Cattle Feedlot	-0.032**	-3.05	-0.032**	-3.08
Dairy	-0.037**	-3.62	-0.038**	-3.63
Hog	-0.036**	-3.52	-0.037**	-3.53
Poultry & Eggs	-0.041**	-4.03	-0.042**	-4.05
Sheep & Goats	-0.043**	-4.2	-0.044**	-4.21
Other Animal	-0.041**	-4.01	-0.042**	-4.02
Total Area / Farms	-0.001	-0.73	-0.002	-0.89
Net Metering & Interconnection	-0.004	-0.68	-0.004	-0.73
Renewable Incentives	0.005	0.93	0.005	1.05
RPS Distributed Set Aside	-0.002	-0.51	-0.003	-0.64
In (Electricity Price)	0.005	0.82	0.005	0.75
% Electricity Cooperatives	0.000	-0.54	0.000	-0.83
Gwh / Km2			0.004**	2.51
pseudo - R squared	0.056		0.067	

Table 4: Modeling Results for Wind Rights Adoption Rates

There are two equations for the Wind Rights adoption, which are the based equation, and potential included equation. In the table 5, all type of farm adopted the Wind Rights energy significantly less than Grain and Oilseed. The Electric Cooperative Prevalence seems to have no effect toward the adoption in both equations. (Total Area / Farm), Net metering & Interconnection and RPS set aside has an insignificantly negative relationship with the adoption while Incentive and Electricity Price have an insignificantly positive relationship. Lastly, the Renewable Energy potential, (Gwh / Km^2), has a significantly positive effect toward the adoption.

	Wind Turbines		Wind Turbines	
	Coefficient	T-Stat	Coefficient	T-Stat
Intercept	-1.113	-149.47	-1.146	-107.27
Vegetable	0.008	1.81	0.008	1.83
Fruit & Nut	0.002	0.5	0.002	0.52
Greenhouse	0.003	0.78	0.003	0.74
Other Crop	0.001	0.25	0.001	0.27
Beef Cattle Ranching	-0.001	-0.35	-0.001	-0.35
Cattle Feedlot	0.003	0.73	0.003	0.72
Dairy	0.001	0.12	0.001	0.13
Hog	0.000	0.03	0.000	0.04
Poultry & Eggs	0.003	0.76	0.003	0.78
Sheep & Goats	0.000	0.01	0.000	-0.01
Other Animal	-0.002	-0.43	-0.002	-0.44
Total Area / Farms	0.005	6.63	0.005**	6.31
Net Metering & Interconnection	0.000	0.15	0.000	0.08
Renewable Incentives	-0.005**	-2.54	-0.005**	-2.31
RPS Distributed Set Aside	0.000	0.21	0.000	-0.08
In (Electricity Price)	0.000	-0.17	-0.001	-0.24
% Electricity Cooperatives	0.000**	-5.33	0.000**	-5.67
Gwh / Km2			0.003**	4.31
pseudo - R squared	0.106		0.130	

Table 5: Modeling Results for Wind Turbines Adoption Rates

The variables for Wind Turbines adoption are similar to the Wind Rights adoption in the previous page. We have 2-model equation: based model and potential variable added model. The results shown that only Beef Cattle Ranching and Other Animal farm type adopted less Wind Turbines than Grain and Oilseed farm type insignificantly. Renewable Incentives has a significantly negative effect towards the adoption. In addition, Electric Cooperative Prevalence is significant but the value of the coefficients is zero. Moreover, for the Electricity Price, RPS set aside and net metering, the coefficient values are all zero and insignificant. Lastly, for the energy potential, it has the significant positive effect toward the adoption.

	Methane		Methane	
	Coefficient	T-Stat	Coefficient	T-Stat
Intercept	-1.107	-383.46	-1.107	-323.43
Vegetable	0.004	1.92	0.004	1.92
Fruit & Nut	0.000	-0.08	0.000	-0.08
Greenhouse	0.000	0.13	0.000	0.13
Other Crop	0.000	0	0.000	0
Beef Cattle Ranching	0.000	0.01	0.000	0.01
Cattle Feedlot	0.001	0.32	0.001	0.32
Dairy	0.006**	3.15	0.006**	3.15
Hog	0.004**	2.3	0.004**	2.3
Poultry & Eggs	0.001	0.4	0.001	0.4
Sheep & Goats	0.000	-0.03	0.000	-0.03
Other Animal	0.000	0.11	0.000	0.11
Total Area / Farms	0.001**	2.58	0.001**	2.5
Net Metering & Interconnection	0.000	-0.08	0.000	-0.07
Renewable Incentives	0.000	0.35	0.000	0.34
RPS Distributed Set Aside	-0.001	-0.56	-0.001	-0.55
In (Electricity Price)	0.000	-1.19	0.000	-1.12
% Electricity Cooperatives	0.000**	-2.18	0.000	.
Crop / Land			0.061	0.03
CH4 / Land				
Biogas / Land				
pseudo - R squared	0.082		0.082	

Table 6.1: Modeling Results for Methane Adoption Rates

	Methane		Methane	
	Coefficient	T-Stat	Coefficient	T-Stat
Intercept	-1.106	-381.53	-1.108	-357.97
Vegetable	0.004	1.93	0.004	1.93
Fruit & Nut	0.000	-0.08	-0.0001	-0.08
Greenhouse	0.000	0.13	0.0003	0.13
Other Crop	0.000	0	-0.000	0
Beef Cattle Ranching	0.000	0.01	0.000	0.01
Cattle Feedlot	0.001	0.33	0.0006	0.32
Dairy	0.006**	3.16	0.006**	3.16
Hog	0.004**	2.3	0.004**	2.3
Poultry & Eggs	0.001	0.4	0.001	0.4
Sheep & Goats	0.000	-0.03	-0.00005	-0.03
Other Animal	0.000	0.11	0.0002	0.11
Total Area / Farms	0.001**	2.4	0.001**	2.38
Net Metering & Interconnection	0.000	-0.18	-0.000	-0.35
Renewable Incentives	0.000	0.37	0.000	0.26
RPS Distributed Set Aside	0.000	-0.52	-0.001	-0.73
In (Electricity Price)	0.000	-1.39	-0.001	-1.75
% Electricity Cooperatives	0.000**	-2.45	-0.000**	-2.29
Crop / Land				
CH4 / Land	-0.003	-1.37		
Biogas / Land			0.129	1.34
pseudo - R squared	0.086		0.0846	

Table 6.2: Modeling Results for Methane Adoption Rates

Table 6.1 and 6.2: Methane adoption renewable energy technology, we ran separate 4 equations: based model, (Crop / Land) potential included, (CH4 / Land) potential included and (Biogas / Land) potential included. All 4 regressions, the result shows that Dairy and Hog farm type adopted significantly more than Grain and Oilseed. The area, where it is remote, has adopted the Methane Technology significantly more than the concentrated area. All three types of technology potentials, two of them: which are (Crop / Land) and (Biogas / Land) have insignificantly positive effect to the adoption. (CH4 / Land) has the insignificantly negative relationship to the adoption. The rest of the variables have no effects towards the adoption as their magnitude are zero or close to zero.

(5.2) Discussion

Adoption of Renewable Energy for generating electricity installations has increased greatly, especially since 2005, following a trend in increased policy attention and investment in renewable energy. In 2009, policy support intensified as the American Recovery and Reinvestment Act of 2009 (ARRA) provided new incentives for the adoption of renewable energy systems, while an increasing number of States continue to adopt incentives to promote renewable energy installations.

Our results suggest that for almost all types of renewable energy, the energy potentials have a significant positive relationship with its adoption. Only (Count / Land) which is one of the potential resources for Small Hydro and (CH_4 / Land) which is one of the potential resources for Methane have a negative relationship and not a significant relationship with its adoption.

Moreover, we found that for Solar Technology, the Cattle Feedlot farm type is the significant highest adopter. For Small Hydro, the Other Animal farm type is the significant highest adopter.

When it comes to overall technology, the more remote an area is, the more significantly higher the adoption rates are.

For Net Metering & Interconnection variables, the results show that all forms of technology, except for Wind Rights, show positive relationships to its respective adoption rate but none of the effects of such adoptions are significant. From Beckman 2013, he found that Net Metering & Interconnection are shown to increase the likelihood of farm Renewable Energy adoption rate. He also claimed that the policy is most effective when enacted in combination-Net Metering provides cost incentives for adoption when connected to a utility grid, while Interconnection standards reduce institutional and infrastructure barriers to grid installed applications. However, according to Yin and Powers (2010), they showed that Net Metering and Interconnection was not effective in increasing renewable generation.

To evaluate the incentive relation with its adoption, we found that it has a significant and negative effect with Wind Turbines technology. For other technology, the relationship is not clear in terms of significance and magnitude. It is possible that the effective incentives are not sufficiently large to induce a significant impact.

For the RPS set aside, none of the technologies shows a significant relationship towards its adoption. Our results are different from Menz and Vachon (2006), Adelaja and Hailu (2008), and Yin and Powers (2010), who found RPS to be important for renewable electricity adoption. Net metering, Interconnection and RPS fail to reveal a systematic relationship with renewable electricity adoption rates. The results suggest that the relevance policy variables, RPS could not explain Renewable Energy adoption, but it may be because RPS targeted utility scale investment.

Moving on, for Electricity Price, the relationship is different for different types of technology. The hypothesis of our study was that the adoption would be high in places where electricity price is high. For Solar technology, the electricity price has a positively significant effect towards the adoption. The rest of the technology in this study does not show a degree of significance.

Electric Cooperative Prevalence, the results show that Solar technologies has a negative relationship to the adoption share, which underlines the importance of policy formulation. While the rest of the technology does not show any relationship between the Electric Cooperative Prevalence and its adoption.

(7.) Future Work

The study is the first which gives an in-depth insight into how the nine different types of on-farm renewable energy system: Biodiesel, Ethanol, Geo-exchange, Biomass, Methane, Small Hydro, Solar, Wind Turbines, and Leasing of Wind rights are adopted, not only at the State level, but also its geographical concentration of adoption. It contributes to the literature of policy impacts on the States' renewable energy investment by providing insights on the effect of policies geared towards distributed generation, specifically on renewable electricity production in agriculture.

Future work, in the short run, should further focus on marginal effects on each of the variables and testing the heteroskedasticity of the data. Moreover, according to the results, the pseudo R-squared is low and therefore, including more variables could be a benefit in terms of explaining the determination of its adoption.

In the long run, once the census data includes more aspect of farm characteristics, for instance the age of the farmer, income, education, etc., the analysis could consider these variables and see its effects on the adoption rate. More detailed data can provide a fuller and a more realistic interpretation of the determinants for the adoption of renewable energy generation.

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