INSTITUTIONAL AND COMMUNITY CHARACTERISTICS FOR CLIMATE CHANGE MITIGATION

A Thesis Presented

by

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to

The Faculty of the Graduate College

of

The University of Vermont

In Partial Fulfillment of the Requirements
for the Degree of Master of Science
Specializing in Community Development and Applied Economics

May, 2010

Accepted by the Faculty of the Graduate College, The University of Vermont, in partial fulfillment of the requirements for the degree of Master of Science, specializing in Community Development and Applied Economics.

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Abstract

Anthropogenic carbon dioxide (CO_2) and greenhouse gas (GHG) emissions already exceeds the sustainable scale of the earth's ecological waste absorption capacity, and accumulation of atmospheric stocks may soon carry the planetary system past a tipping point. At this point there exists a greater possibility of positive feedback loops such as methane release from thawing tundra, that could exacerbate rising sea levels, the rapid loss of sea ice, chaotic changes in climate, and constantly shifting shorelines. Reducing the anthropogenic flow of GHG emissions in all sectors, including the transportation sector, is recognized as a key component of mitigating climate change. The scope of this challenge demands that we examine all options available from the creation of new institutions to manage GHG emissions to redesigning our communities to encourage low-carbon travel behavior.

The articles in Chapters 2 and 3 address climate change from institutional and community perspectives. Chapter 2 examines the impacts of carbon offset credit markets upon cap-and-trade systems for GHG emissions, specifically, the sustainable flow of emissions with regards to the ecological waste absorption capacity, the costs associated with cap management, and the efficient allocation of resources to achieve least-cost emission reductions. How community characteristics in northern rural climates can encourage a significant shift towards alternative and sustainable transportation in northern rural climates is also unknown. This problem is compounded by research showing that individuals do not often consider climate change a salient issue and that motor cars are the most preferred mode for passenger road transport but the second greatest GHG emitters.

The first article, using a Vermont Common Asset Trust (VCAT) as a case study, quantifies the impact of four scenarios, an emissions cap with: (1) no carbon offset credit market, (2) an unlimited offset market, (3) a limited (capped) offset market, and (4) no offset market but with investments in complementary emission reduction projects. I compare the impacts of these scenarios across four parameters: emission reductions outside of an emissions cap, capital spent by emitting firms, rent accrued by offset providers, and revenue accrued by a trust. The second article utilizes data from the 2009 Transportation in Your Life survey and a logistic regression model to address the issue of microaccessibility and modal choice and the question of which specific community characteristics contribute to an increased probability of low-carbon travel behavior in northern rural climates.

Results from the first article include that if a VCAT were to engage in complementary payment for emission reduction projects, equivalent to those reductions otherwise achieved in a carbon offset credit market, these reductions could be accomplished at a cost savings of $329,000 while reducing Vermont's annual emission level to 0.07 MMtCO2e below the initial cap. Results from the second article include that 'the importance of places you can walk to' had significant effects on increasing the probability of low-carbon travel behavior in northern rural climates as well as climate change consideration and a preference for low-carbon modes.

The paper recommends that a VCAT not implement an offset credit market alongside an emission allowance cap and that northern rural communities should place an increased emphasis on the importance of places one can walk to.

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Chapter 1

LITERATURE REVIEW

1. INTRODUCTION

1.1. Exceeding Atmospheric Waste Capacity

Reducing the anthropogenic flow of carbon dioxide equivalent (CO_2e) emissions to a level that adheres to the sustainable scale of earth's ecological waste capacity is recognized as a key component of mitigating climate change. The scope of this challenge demands that we examine all options available: from the creation of new institutions and policies to manage CO_2e emissions to rethinking and redesigning our communities.

One new instrument for limiting carbon emissions is to cap total emissions then create tradable emissions permits in a form of carbon market. However, all existing cap and trade systems allow emissions to exceed the affected populations' fair share in global CO_2e absorption capacities. Furthermore, all existing systems allow firms to obtain more tradable emissions permits if they offset their emissions by funding other activities that sequester carbon dioxide or reduce emissions in regions with no caps.

Policies that allow for the use of offset credits in meeting compliance obligations within a cap on CO_2e emissions may contribute to humans exceeding the sustainable scale of our atmosphere. Furthermore, if we were to pass a tipping point this could result in overshoot and unavoidable "large climate impacts" (Hansen, 2008). Similarly, motor cars are the most preferred mode for passenger road transport but are also the second greatest contributor (the greatest is road freight) to greenhouse gas (GHG) emissions in the transport sector (WBCSD 2001 in Chapman, 2007).

1.1.1. Stock and Flow

Both the use of offset credits and carbon-emitting transportation modes are related to the atmospheric stock of CO2e, the inflow of new anthropogenic emissions, and the outflow resulting from the earth's atmospheric waste capacity for CO_2e. An increased flow of CO_2e emissions beyond the absorption rate of the atmosphere results in an increase in the stock of CO_2e emissions. Thus, if the emissions flowing in to the ecosystem (i.e. due to the issuance of emission permits or carbon-emitting transportation modes) are less than the emissions flowing out (i.e. through sequestration efforts and planetary waste absorption capacity) then establishing a sustainable scale may be possible. If the stock of atmospheric emissions exceeds a potential tipping point, estimated at greater than approximately 350 parts per million (ppm), due to an in-flow of emissions that is greater than the out-flow, this may result in chaotic changes in climate (Hansen, 2008). The timeframe in which such stocks remain in the atmosphere is discussed further in the first article.

1.1.2. Contributors to Emissions

Global contributors of CO_2e emissions include the power, transport, industrial, building, and agriculture sectors, as well as land use change. The first article, Carbon Markets and the Vermont Common Assets Trust: Offset Credits and Our Shared Future, will address emissions from all of these sectors. The second article, The Design of Low-Carbon Communities: Land Use Patterns and Transportation Modal Choice in Northern Rural Climates, will be limited in scope to just the transport sector.

Fourteen percent of global GHG emissions and twenty-six percent of global CO_2 emissions come from transport; furthermore, the transport sector is "one of the few industrial sectors where emissions are still growing" (Chapman, 2007 p. 355; Stern, 2008b). Furthermore, CO_2 emissions from road transportation are expected to double between 2005 and 2050 (Stern, 2008b).

1.1.3. Design Characteristics

Whether we are designing a cap-and-trade system or a low-carbon community, it is important to ensure that the characteristics of each system match the intent of the designers. If the intent of a cap-and-trade policy is to ensure sustainable scale, just distribution, and efficient allocation, then a thorough examination of the role of offset credits in this system is necessary. This is due to the fact that CO_2e emissions may impact the earth's climate for periods of time greater than many offset projects (Houghton, 2001). Furthermore there exist differences in biotic and fossil carbon and uncertainty surrounding the carbon cycle (Lohmann, 2006; Smith, 2007).

These issues of uncertainty can also be seen in the design of low-carbon communities, specifically surrounding how community design can increase the probability of low-carbon travel behavior in northern rural communities.

1.2. Research Contributions and Objectives

These two articles each emerged from two separate proposals: "Integrating Vermont's Common Assets Trust with Payments for Ecosystem Services" and "Mobility and Livability: Seasonal and Built Environment Impacts". The article in Chapter 2 contributes to the first proposal by presenting information to citizens of Vermont and state legislators to inform decisions about a Vermont Common Assets Trust (VCAT).

The article offers recommendations for a VCAT and other cap and trade systems based upon the impact of different variations of carbon offset credit markets.

The second article in Chapter 3 will contribute to the Mobility and Livability proposal by presenting data analysis and interpretation based upon the second Research Objective discussed below. In reporting and disseminating the results of this research, Chapter 3 will fulfill the proposed emphasis on non-motorized transportation in northern rural climates and the desire for such publications to speak to several different professional audiences (J. Kolodinsky, 2008) by exploring how community characteristics may impact the probability of an individual's consideration of climate change and low-carbon transportation behavior in Vermont, New Hampshire, and Maine.

While Chapter 2 examines institutional characteristics that may lead to the successful management of the earth's ecological waste absorption capacity, Chapter 3 examines how, in the absence of institutional structures or global agreements on comprehensive and mandatory CO_2e caps, or conversely, in the presence of institutional change, communities can still achieve emission reductions in the transportation sector. Thus, to meet the aforementioned research goals, this thesis aims to accomplish two central objectives:

1) Assess the potential impact of offset credits on revenue, scale, distribution, and efficiency in a Vermont Common Assets Trust (VCAT) to determine the extent to which offsets should be permitted.

2) Address the issue of microaccessibility and modal choice in northern rural climates through the question of which specific community characteristics might contribute towards an increased probability of low-carbon travel behavior (e.g. the use of low-carbon modes including biking, walking, or public transit).

1.3. Community Served

This project will contribute to the literature surrounding the impact of offset credit systems on cap-and-trade schemes and the impact of community design on low-carbon transportation modal choice. The first article will focus primarily on the offset credit system on a global scale but will also introduce a Vermont Common Assets Trust as a case study. The second article will focus on Vermont, in addition to Maine and New Hampshire, and will provide important information for policymakers and transportation planners in northern climates. This research is communicated here in the form of two journal articles, to be submitted for publication upon their defense.

2. REVIEW OF THE LITERATURE

2.1. Common Assets: Waste Absorption Capacity

Common assets will be defined, here, as those parts of "nature and society which we inherit jointly" and from which value is accrued (Barlow, 2003 p. 3) but which may or may not currently have a value in the market. The implication of this definition is that such assets should be owned and managed in common. The common asset of ecological waste absorption capacity (i.e. for CO_2e) is a rival and nonexcludable good. It is rival in that when one firm emits one extra unit (ton) of CO_2e emissions and it is absorbed by the atmosphere, this results in one ton less of CO_2e emissions that another firm can emit and be absorbed without exceeding the sustainable scale of the earth's ecological waste absorption capacity over a given time period (Daly, 2004; Hansen, 2008). The failure to ration the use of scarce, rival resources results in overuse, which, in the case of waste absorption capacity imposes serious ecological costs. Ecological waste absorption capacity is nonexclusive in that it is difficult or costly to "exclude individuals from benefiting from the good" (Nicholson, 2002 p. 670). Such difficultly is evident in the debate surrounding the issue.

Two approaches to climate change mitigation include rationing the consumption of this asset or allowing its continued open access consumption. Rationing asset consumption makes sense when a good is rival, like ecological waste absorption capacity, and its consumption results in less of said good for other consumers. This could take the form of a mandatory cap on CO_2e emissions, one policy which will be further discussed in the first article. Allowing open access consumption makes more sense in cases where the good under consideration is nonrival in that "others may use [these assets] at zero cost" (Nicholson, 2002 p. 226).

2.2. A Common Assets Trust (CAT): Institutional Characteristics

A CAT will be defined here as an institution, created by government laws and policy, which is given unequivocal property rights to a select group of assets. In the case of Chapter 2, one such group of assets will be the earth's ecological waste absorption capacity for CO_2e emissions. Such an institution would serve to establish a market value for common assets by charging fees to those who would otherwise utilize common assets and accrue economic rent from them (Barlow, 2003). Economic rent will be defined as "unearned income…[and] excess profits not due to work, risk, or enterprise"

(Flomenhoft, 2008, p. 3 p. 3) A CAT can utilize a variety of instruments or policies from which to manage these assets for the benefit of present and future generations.

There are many policy instruments available to a CAT; however, Chapter 2 will place an emphasis on only three. The first instrument is a cap on CO_2e emissions. The second is the auctioning off of tradable permits. The third is the distribution of auction-revenue as dividends to trustees or the investment of revenues for the common good. Each of these policies may serve as an instrument for achieving distinct goals, including sustainable scale, efficient allocation, and just distribution. Instruments available to a CAT that contribute to sustainable scale include placing a cap on CO_2e emissions and the explicit assignment of property rights to future generations. Assigning these property rights to all citizens also promotes just distribution, as does the distribution of revenue collected as a dividend, or spending of revenue on public goods such as emission reduction projects (i.e. energy efficiency or carbon sequestration), bike infrastructure, or investments in community characteristics for climate stabilization. Finally, internalizing externalities by auctioning off tradable permits is a tool for achieving efficient allocation, as currently, polluters benefit from carbon emissions while everyone else pays the costs. Dependent on how auction revenue is used, it may address distribution, allocation, or scale. Distributing a greater proportion of the revenue as a dividend would prioritize distribution, investing in public goods with the greatest marginal benefit would emphasize efficient allocation, and investing in emission reduction projects would prioritize sustainable scale.

2.3. Rurality and Travel Behavior

Rural regions have been shown to have a need for such investment in projects that reduce emissions from the transportation sector; research has shown that not only is the car the principal mode of travel in the U.S. (Pucher & Renne, 2005) but limited public transportation in rural areas greatly narrows transportation modal choices, resulting in an almost complete dependence on the car (Rosenbloom 2002 in J. Kolodinsky, 2008). Rural households face challenges not faced by urban households; these include decreased access to alternative modes, due in part to low populations densities and high costs (Federal Highway Administration 2001 in J. Kolodinsky, 2008), and increased travel distances to get where they need to go (Glascow and Blakely, 2000; McGrath, 1999; Newman in J. Kolodinsky, 2008).

2.4. Community Characteristics for Northern Rural Communities

With regards to transportation and modal choice, a low-carbon community could be planned and designed to integrate pedestrian and bicycle travel as well as public transit “into the community’s fabric” (Southworth, 2005 p. 248). An increased probability of low-carbon travel behavior may be accomplished through a community’s land use patterns including micro-accessibility, or the number of specific community characteristics within a set range of residences, density, and mixed land use (Ewing, 2001).

Specific neighborhood and community characteristics that have impacted mode choice include: access to public transportation stops and stations , parks (Kitamura, 1997), convenience stores (Cervero and Radisch 1996 in R. a. K. Cervero, K., 1997; Handy, 1993), banks, shops, restaurants, service outlets, and retail services (Cervero, 1989 in R. a. K. Cervero, K., 1997). Pedestrian friendly characteristics that have also impacted mode choice include: sidewalk and street light provisions, easy street crossing, and sidewalk continuity among others (Parsons Brinkerhoff Quade and Douglas, Inc., 1993 in Handy, 1996). In general, distance to destinations has been shown to greatly influence peoples' decisions whether to walk or drive (Funihashi 1985; Komanoff and Roelofs 1993; Handy 1996; Smith and Butcher 1994 in Southworth, 2005).

Density can reduce the carbon-impact of travel through an emphasis on compact neighborhoods (R. a. K. Cervero, K., 1997), increased residential and work densities (Cervero 1994 and Cervero 1994 in Ewing, 2001), and greater density of opportunities (Hanson 1982 in Handy, 1996). Mixed land use can similarly work towards low-carbon travel behavior by decreasing automobile use (Duerksen, 2008).

The majority of the research available surrounding community characteristics and modal choice has been conducted on the west coast. Kitamura's research was conducted in the San Francisco Bay area; Parsons et al.'s research was conducted in Portland, Oregon, Handy's (1993) research was conducted in the San Francisco Bay Area, Cervero and Radisch's (1996) research was conducted in the San Francisco Bay Area, and Cambridge Systematics' (1994 in R. a. K. Cervero, K., 1997) research was conducted in Los Angeles, California.

2.5. Consideration and Behavior in Northern Rural Communities

Encouraging changes in transportation behavior faces additional challenges beyond community design. Transportation problems are often regarded as "commons dilemmas" in which there is a divergence between short-run personal interests and long-run societal interests (van Vugt et al., 1995; Steg and Vlek in Anable, 2005). Similarly, across various studies, the link between environmental attitude and behavior is modest; such behavior is simply not often found alongside environmental intentions (Maloney & Ward, 1973 in Kaiser, 1999). However, what is known is that people are willing to consider most abstract problems, however, not willing to change their lifestyle with regards to driving behavior (Ladd 1990 and Doble et al. 1990 in Bord, 1998; Bord 1998). Beliefs and preferences, unlike consideration, *have* been shown to contribute to travel behavior (Stradling et al. 2000 in Anable, 2005; Kitamura 1994 in Handy, 1996).

3. RESEARCH PLAN AND METHODOLOGY

Below, I present the two primary objectives of this thesis and an overview of methodologies for the following two chapters:

(1) Assess the potential impact of offset credits on revenue, scale, distribution, and efficiency in a Vermont Common Assets Trust (VCAT) to determine the extent to which offsets should be permitted.

The first article consists of a qualitative literature review to assess challenges surrounding the implementation of carbon offset credit markets within a cap-and-trade system for CO2e emissions. Next, using a Vermont Common Asset Trust (VCAT) as a case study, I quantify the impact of four scenarios, a VCAT with: (1) no carbon offset credit market, (2) an unlimited offset market, (3) a limited (capped) offset market, and (4) no offset market with investments in complementary emission reduction projects. I accomplish this by analyzing prices, caps, and elasticities of both emission sources in

Vermont and comparable institutions. These scenarios all assume an 80% reduction in emissions by 2050 or a 3.85% annual decrease in a CO_2e allowance credit cap and hold the price elasticity of demand constant throughout the analysis. We compare the impacts of these scenarios through quantitative analysis across four parameters: emission reductions outside of an emissions cap, capital spent by emitting firms, rent accrued by offset providers, and revenue accrued by a trust.

(2) Address the issue of microaccessibility and modal choice in northern rural climates through the question of which specific community characteristics contribute towards an increased probability of low-carbon travel behavior (e.g. the use of low-carbon modes including biking, walking, and public transit).

To address this second objective, I established a recursive binary logistic regression model based upon data from a 2009 survey entitled, Transportation in Your Life. The model is recursive in that each of three dependent variables, including climate change consideration, preferred mode, and travel behavior are determined by a series of previously independent variables. The model is a binary logit because the dependent variable is presented as two choices or parts (Loutzenheiser, 1997).

Demographics, community characteristics, values, and constraints constituted groups of independent variables which determine the predicted probability that a respondent considered climate change when they traveled. The predicted probability variable for climate change consideration along with the preceding variables and two additional independent variables (beliefs and feeling of safety) determined the predicted probability that a respondent would prefer a low-carbon mode of transportation. Finally, the two predicted probability variables for consideration and preferred mode along with all the preceding terms, except for feeling of safety, and along with two new independent variables (rurality and weather) determined the predicted probability that a respondent would engage in low-carbon travel behavior (e.g. walking or biking, bus, public transit, trains, or motorcycles) at least once in their survey.

The independent variables that contributed to each subsequent regression are discussed more in depth in the second article. The entire system of equations was identified by satisfying the rank and order conditions and tested for multicollinearity showing a lack of collinearity within the model.

There exist several opportunities for climate change mitigation in Vermont and in northern climates, in general. Whether they take the form of new institutions and institutional characteristics or an increase in the probability of low-carbon travel behavior through community design, these articles will examine the challenges present within these approaches as well as the means to move beyond them.

Chapter 2

CARBON MARKETS AND THE VERMONT COMMON ASSET TRUST: OFFSET CREDITS AND OUR SHARED FUTURE

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Abstract - Anthropogenic carbon dioxide (CO2) and greenhouse gas (GHG) emissions already exceeds the sustainable scale of the earth's ecological waste absorption capacity, and accumulation of atmospheric stocks may soon carry the planetary system past a tipping point. At this point there exists the possibility of positive feedback loops such as methane release from thawing tundra, that could exacerbate rising sea levels, the rapid loss of sea ice, chaotic changes in climate, and constantly shifting shorelines. In the presence of a carbon market including an emissions cap and tradable emission allowances, the impacts of carbon offset credit markets upon the ecosystem service of ecological waste absorption capacity, the costs associated with its management, and the efficient allocation of resources within emissions trading systems is unclear.

Using a Vermont Common Asset Trust (VCAT) as a case study, I quantify the impact of four scenarios, a VCAT with: (1) no carbon offset credit market, (2) an unlimited offset market, (3) a limited (capped) offset market, and (4) no offset market with investments in complementary emission reduction projects. I accomplish this by analyzing prices, caps, and elasticities of both emission sources in Vermont and comparable institutions. I compare the impacts of these scenarios across four parameters: net emission reductions, capital spent by emitting firms, rent accrued by offset providers, and revenue accrued by a trust.

With the assumptions used, through the implementation of an emissions cap but not a carbon offset credit market, a VCAT could generate $120 million in revenue – an offsets market would reduce this revenue. If a VCAT were to subsequently engage in complementary payment for emission reduction projects, equivalent to those reductions achieved in an offset credit market, these reductions could be accomplished at a cost savings of $329,000. This would reduce Vermont's annual emission level to 6.33 MMtCO2e, or 0.07 MMtCO2e below the initial cap, contributing to the sustainable scale of ecological waste absorption capacity. Through these measures, a VCAT would also justly distribute the annual costs of ecological waste capacity management amongst emitting firms and minimize rent accrued to offset providers. These results are generalizable to any cap-and-trade scheme.

The paper recommends that an offset credit market not be implemented alongside an emission allowance cap and that more research is required surrounding the scale, methods, and costs of complementary emission reductions proposed. If an offset credit market is implemented, the paper recommends a rent extraction instrument to discourage the purchase of low-cost offset projects and encourage the use of higher-cost projects such as renewable energy initiatives.
Keywords: Common Assets Trust, Vermont, Offsets, Carbon Markets

1. PROBLEM STATEMENT

Anthropogenic carbon dioxide (CO_2) and greenhouse gas (GHG) emissions currently exceed the earth's ecological waste absorption capacity. As a result, atmospheric carbon stocks are accumulating. If atmospheric stocks reach a sufficient concentration, we may pass a tipping point; at this point, there exists the possibility of positive feedback loops that would result in runaway climate change, rising sea levels, the rapid loss of sea ice and "interdependent species and ecosystems," chaotic changes in climate, and constantly shifting shorelines, all "without additional climate forcing" (Hansen, 2008 p. 12, 16). Annual global emissions, in the long-run, must be decreased to below 5 GtCO2e as this is the sustainable flow of emissions that the earth can absorb without further increasing the GHG concentration; this would require emission reductions of over 80% (Stern, 2006a).

There is debate surrounding sustainable concentrations of CO_2e in the atmosphere, where sustainable is defined as levels that will not cause runaway climate change through positive feedback loops (e.g. thawing tundra leading to methane release, or melting ice-caps reducing albedo thus accelerating warming), significantly decrease agricultural yields, or lead to unacceptable sea level rise. At one end of the spectrum, Hansen (2008) argues that we cannot remain above 350 ppm of CO_2 as this imposes unacceptable risks and may trigger any or all of the above changes, among others. The Stern Review (2006b), in contrast, estimates that the risk of catastrophic impacts from climate change can be significantly decreased if the stock of atmospheric GHGs were stabilized between 450 – 550 ppm CO_2e, which corresponds to CO_2 levels of

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approximately 350 – 440 ppm (Metz, 2007). Stern cites models which estimate the risk of severe climate change (defined as greater than 3 degrees centigrade) as 32% at 550 ppm and 6% at 450 ppm (Stern, 2006a), though we must always be skeptical concerning probability estimates when dealing with complex and largely unpredictable systems. Whether such risks are acceptable is of course a normative issue. The current atmospheric CO_2e level has been widely accepted as 430 ppm CO_2e, increasing at approximately 2.5 ppm annually and accelerating. At current emissions, we are on pace to reach 750 ppm by the year 2100 and there is a 50% probability that the atmospheric stock of ppm CO_2e will stabilize at a temperature 5°C greater than the earth's current temperature. Stern estimates that in the case of such a temperature increase, a "disastrous transformation of the planet" would be highly probable (Stern, 2008a p. 4-5) To stabilize GHG concentrations in the range of 450-550 ppm CO_2e would require a 70% decrease in 2005 emissions levels by 2050 (Stern, 2006a), with additional reductions further on.

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Existing institutions that aim to stabilize GHG levels are currently not positioned to establish a stabilized stock or flow of CO_2e emissions; voluntary markets do not require compliance with any carbon cap and mandatory market caps such as The Regional Greenhouse Gas Initiative (RGGI) and The European Union Emissions Trading Scheme (EU ETS) currently do not adhere to limits advocated by prominent climatologists. Furthermore, the instruments with which many institutions aim to mitigate carbon flow require further attention. This paper will concentrate on a carbon cap and auction system and variations of one such instrument, a carbon offset credit market.

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Just say that existing institutions are not currently positioned to stabilize atmospheric stocks at acceptable levels.

One approach to stabilizing GHG emissions is through an annual cap on CO_2e emissions. This would place a set limit on GHGs emitted in the area(s) or sector(s) capped. Cap and trade systems establish such caps then create tradable emission permits in the form of a carbon market. So long as the number of emission permits issued is less than the demand to emit carbon, scarcity is created in the market and a non-zero price for a permit is established. Such permits are often referred to as allowances.

One characteristic that all current cap-and-trade systems have in common and which is included within almost every piece of proposed climate legislation is carbon offsets (Markey *The Role of Offsets in Climate Legislation*, 2009). Carbon offset credits are obtained by firms through the funding of other activities that sequester carbon or reduce emissions in regions or sectors with no caps. Within many cap-and-trade schemes, offset credits are treated as substitutes for allowance credits, and though their use is often limited, they can provide firms and industrialized countries flexibility in their approach to reduce carbon emissions in accordance with specific compliance obligations. Such flexibility can result in lower costs for firms and money saved by consumers if such cost reductions are passed on. Consequently, offsets have gained political popularity in the U.S., with wide ranging support from congressmen, environmental groups, and big business alike (Hogue, 2009).

There are several existing mechanisms that issue and oversee offset credit markets within the context of cap-and-trade systems. One is the Clean Development Mechanism (CDM), available to all signatories of the Kyoto Protocol. The CDM Executive Board oversees the carbon offset regulatory and approval process for the European Union Emission Trading Scheme (EU ETS), the largest carbon emissions trading market in the world (de Jonge, 2009). Another is the Regional Greenhouse Gas Initiative (RGGI), a mandatory effort among Northeastern and Mid-Atlantic states, which includes Vermont, to place a decreasing cap (10% by 2018) on CO_2 emissions from the power industry (Schrag, 2009a). RGGI, like the EU ETS, also allows for the use of offset credits as a means of firms meeting their compliance obligations, with a specific regulatory authority within each state overseeing the offset credits issued. Within Vermont, this is the job of the Agency of Natural Resources (RGGI).

One challenge with existing cap-and-trade systems is that the caps are too high; in other words, the annual emission limits for a region are greater than that region's fair share of the earth's ecological waste absorption capacity, and there is little evidence that they will be tightened rapidly enough to avoid greater than two degree centigrade climate change. The earth's ecological waste absorption capacity includes the ability of marine and terrestrial carbon sinks to absorb CO_2e emissions.

Most caps in existence were not designed to capture the true cost of carbon emissions in the first place but were instead based on political feasibility. Consequently, they are prone to influence from lobbyists which might take the form of "overstating historical emissions, or negotiating opt-outs and loopholes" (Reyes, 2009 p. 1). Both the EU ETS and RGGI have faced intense lobbying surrounding the issuance of allowance permits in their initial years of operation. In the first phase of the European Union Emission Trading Scheme (EU ETS), too many allowance permits were issued, the price per allowance crashed to near zero, and no emissions reductions were made (Reyes, 2009). Similarly, before RGGI's implementation in January 1, 2009, it was subject to political pressure leading the Staff Working Group to assert that RGGI would be just barely short (i.e. baseline emissions just barely greater than allowances issued) at its commencement (Patrick, 2006).

Ineffective offset credits may also result in actual net emissions exceeding the cap. Offset credits would prove ineffective if the carbon sequestered or emission reductions resulting from an offset project are less than the total projected; this may be due to uncertainty surrounding the atmospheric lifetime of carbon, overly flexible offset criteria (Archer, 2005; Houghton, 2001; D. e. a. King, 2003; Lohmann, 2006) or other challenges facing offset markets. These challenges are further discussed in section 1.3 Sustainable Scale. Such ineffective offsets may be akin to a leaky cap, implying that CO_2e emissions, beyond those anticipated by a cap-and-trade system, would be emitted.

Given the large role that carbon sequestration plays in many offset credit projects, one key distinction that must be made is the difference between geological and biological carbon. Above-ground biotic carbon is connected to the atmosphere in a categorically different way than below-ground fossil carbon. More specifically, the carbon contained in grass, biomass, durable wood products, paper, or soils at differing depths, are all separated from the atmosphere in different ways and with different risks associated with them (Lohmann, 2006). Essentially, all carbon is not created equal. The differences between fossil and biotic carbon are owed partially to the fact that the transference of inert reserves of carbon (e.g. fossil fuels) to active, atmospheric carbon is like a one way street, with the return route to the carbons' previously inert state requiring a "millennia-long geological process that transformed it into fossil fuel in the first place" (Smith, 2007, p. 20).

One challenge with offset credits accrued through carbon sequestration projects is that the lifetime and subsequent "atmospheric burden" resulting from the release of geologically sequestered GHGs are orders of magnitude greater than the lifetimes of many land uses, land use changes, or forestry-based offset projects; furthermore, the lifetimes of such land uses may be further shortened by social risks, political risks, or technical risks (e.g. pests, disease epidemics, fires, climate events, or shorter than expected lifetimes for durable wood products) (Lohmann, 2006, p. 250).

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In determining a single lifetime estimate for GHGs, CO_2 appears to be the most challenging. According to the Intergovernmental Panel on Climate Change (IPCC), "No single lifetime can be defined for CO_2 because of the different rates of uptake by different removal processes," though the lifetime is estimated at between five and two hundred years (Houghton, 2001). Others disagree with the IPCC estimate. Archer (2005) proposes that CO_2 emissions may impact the earth's climate for hundreds of thousands of years and estimates that the average lifetime of fossil fuel CO_2 is approximately 30-35 kiloyear (kyr), with one kyr equaling one thousand years.

Furthermore, the lifetime any given GHG depends not only upon the gas itself but also upon where in the atmosphere the gas resides (e.g. the lower or upper troposphere), during what season the gas resides there, chemical feedbacks and interactions, and the "chemical and physical processes" surrounding its atmospheric removal (Houghton, 2001 p. 247).[1]

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[1] For example, the atmospheric lifetimes of greenhouse gases such as CH4 and HCFC-22 can be over a decade while N2O can remain for over a century, an order of magnitude greater than CH4 or HCFC-22. Similarly, CH4 (Methane) is removed by different means than N2O; specifically, chemical processes and solar radiation respectively, with processes ranging in time "from years to millennia" (Solomon, 2007 p. 125).

1.1. A Vermont Common Assets Trust

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The VCAT bill was first proposed before the Vermont State Senate in 2007 (Miller, 2007) and will likely be brought forward again in 2010. Of all the instruments available to a VCAT, a carbon offset credit market is a likely consideration; offsets can be found in "every existing cap-and-trade system…[and] are also a part of virtually every piece of proposed climate legislation" (Markey *The Role of Offsets in Climate Legislation*, 2009 p. 4). To contribute towards the literature regarding institutional and instrumental models for GHG stabilization, such as future cap-and-trade systems, this paper will focus on a single aspect of a proposed VCAT: ecological waste absorption capacity for CO_2e emissions. The chapter will examine specific policies, from the perspective of ecological economics, surrounding the inclusion of a carbon offset credit market, its impact on the common asset of ecological waste capacity, and the potential social and economic implications.

If created, a VCAT would have a number of policy instruments available to it to achieve its goals (i.e. mitigating Vermont's flow of carbon emissions) while simultaneously addressing sustainable scale, just distribution, and efficient allocation. Three of these instruments are a cap on GHG emissions, the auctioning of tradable permits, and the distribution of auction-revenue as dividends. Each of these instruments contributes to the three tenets of ecological economics (sustainable scale, just distribution, and efficient allocation) in multiple ways. If created, a VCAT would be bound to preserve and protect common assets such as ecological waste absorption capacity "for the benefit of present and future generations" (Miller, 2007, p. 1 p. 1).

Consequently, any decisions made by a VCAT board of trustees would reflect such an ethos.

When deciding on a cap for GHG emissions, a VCAT board would represent both emission-victims and emission-beneficiaries, and would be forced to balance both costs and benefits of emissions. Furthermore, any permits issued would be done so not according to political feasibility, but according to the physicochemical state of the atmosphere, economic and regional impacts, and measures taken by other countries (Barnes, 2001, p. 70). While a conventional cap-and-trade system could give away tradable permits to emitting firms, resulting in corporate ownership of the atmospheric commons with no compensation to either the federal government or its citizens, a VCAT board would be obliged to auction these permits off, securing revenue for VCAT shareholders. Lastly, dependent on the scale and priorities of the trust, the revenue could be used to address any of the three tenets by investing in emission reduction projects (scale), issuing dividends (distribution), or providing public goods or outputs which offer the greatest marginal social benefit (allocation).

Other policy instruments and variations of those stated above would also be available under a CAT system. One such policy is a carbon tax. Kahn and Franceshci (2006) support a gradually imposed carbon tax over command and control systems such as cap and trade as they believe that this would reduce the risk of macroeconomic shocks, provide greater incentives for technological novelty, and result in an increased probability of participation by developing countries. An effective carbon tax, however, would prove both difficult and improbable; trying to determine the right level of taxation to reduce emission levels to within the necessary bounds would be economically complicated, politically challenging (Barnes, 2001), and result in a constantly changing tax level and target as emissions would rise and fall with the economy's level of production. Furthermore, there exists the political challenge associated with raising taxes, as required.

1.2. An Ecological Economics Perspective

The current neoclassical perspective on carbon offset credit markets has largely ignored the two desirable ends of sustainable scale and just distribution (Costanza, 2008). One reason for this is that neoclassical economists believe that ecological services such as the waste absorption capacity of the atmosphere can be supplanted by future technologies, a belief that ecological economists do not share (Costanza, 2008, p. Chapter 2). Current neoclassical thought takes into account only the efficient allocation of resources among alternative products on the production side, and the efficient allocation of products among consumers on the consumption side, where efficiency is defined solely as the maximization of monetary value. Emitting firms, in most cases, do not choose to account for the ecological waste absorption capacity as an input. As producers, emitting firms tend to choose low cost and high emission alternatives, paying little attention to sustainable scale or just distribution. Similarly, as waste absorption consumers, emitting firms prefer lower cost offsets to emission allowances, resulting in similar challenges.

1.3. Sustainable Scale

Sustainable scale considers the natural capacity of a given ecosystem (Costanza, 2008) with regards to four categories of ecosystem services: provisioning, regulating, supporting and cultural/information (Cox, 2009; de Groot, 2002; Swinton, 2007; Wallace, 2007), however, the scope of this paper is concerned with only the regulating services of climate regulation and waste absorption of outputs such as CO_2 and GHG emissions. The sustainable scale of these ecosystem services are related to both the stock and flow of carbon emissions. If the flow of carbon emissions into the atmosphere is greater than the ecological waste absorption rate, accounting for all emission reduction measures, then the stock will eventually exceed sustainable scale. Furthermore, the proper balance of atmospheric gasses is responsible for keeping the earth's temperature within a very narrow range conducive to life (Barnes, 2001).

Before an offset credit market can be considered for implementation alongside an emissions allowance market in any cap-and-trade system the gaming behavior in offset markets and questions regarding the legitimacy of certain offset projects' additionality must be examined.

Carbon offset markets, like nutrient credit markets, are different from conventional markets in that they require trade regulators in order to function as intended. The reason for this is the common economic interest amongst the buyers and sellers within carbon offset markets to minimize the price and the cost of production respectively (D. e. a. King, 2003). Consequently, as the quality of criterion imposed on offset credits decreases, the economic returns to these buyers and sellers increases (D. King, 2002). This shared interest forces emissions markets to operate with buyers and sellers aligned against the trade regulators who now must "impose quality control on behalf of everyone else" (D. e. a. King, 2003, p. 3 p. 3). Consequently, issues such as overly-flexible offset criteria, and/or unassigned liability for ineffective offset credits may arise, causing unnecessary risk to the general public, in the form of exceeding the sustainable flow of emissions in the earth's ecological waste absorption capacity (D. e. a. King, 2003).

The additionality of offset projects is another possible contributor to our society exceeding the sustainable flow of emissions into the earth's ecological waste absorption capacity. Additionality is defined here as the ability of a project to reduce emissions beyond what would have taken place in the absence of carbon funding (Smith, 2008). Within the EU ETS, the legitimacy of certain offset projects' additionality has been called into question; these projects are approved by CDM. One survey "found that 76 per cent of projects were already completed by the time they were approved as eligible to sell credits" (Redman, 2008). Another survey, conducted in 2006, found that one third of projects in India, which constituted five percent of CDM credits generated in 2007, were non-additional (Smith, 2008). If the majority of offset projects approved by CDM are not representing truly additional emission reductions, then this could eventually result in CO_2 emissions exceeding the sustainable stock of the earth's ecological waste absorption capacity.

1.4. Just Distribution

The current costs for maintaining the ecological integrity of the atmospheric commons may be unjustly distributed upon citizens and communities; thus, any potential emission trading system must be sure to distribute the associated costs of atmospheric commons management fairly (Barnes, 2001; Lohmann, 2006). Just distribution can be defined as the division of a resource among people and generations which reduces inequity to a satisfactory level for stakeholders of all levels of income, future generations, and other species (Costanza, 2008). In the case of common assets such as the ecological waste absorption capacity, the stakeholders are vast and diverse, thus, establishing just distribution is especially complex.

Most emitting firms in Vermont are currently not required to assess their use of the earth's ecological waste absorption capacity as an input when making decisions; however, a cap-and-auction system would internalize these costs. The just distribution of atmospheric commons ownership and the associated capital flow can be achieved by equally dividing the total revenue from the sale or auction of emission allowances among all members of a CAT (Barnes, 2001), however, inclusion of a carbon offset credit market would affect such distribution. A carbon offset credit market could alter the division of ownership and distribution of the atmospheric commons in two ways. First, an offset market could distribute an increased burden upon communities in which offset projects are implemented (Lohmann, 2006). The implementation of carbon offset projects have been known to impact local inhabitants through changes to property rights, farming practices, land access, resource availability, social networks, and cultural and spiritual practices (Lohmann, 2006). A growing consensus is also emerging showing the negative impacts that plantation projects have on biodiversity, groundwater use, and soil fertility (Smith, 2007, p. 25).

However, a carbon offset credit market could also encourage sustainable development in these same communities, and therefore alleviate some of this burden (Taiyab, 2006). Carbon offset projects have the potential to improve standards of living, education, incomes and wages within communities (Lohmann, 2006, p. 268). One project in north-eastern Bolivia expanded the Noel Kempff Mercado National Park, protected over 600,000 ha of "biologically diverse lowland forest," provided infrastructure investment, and generated income and opportunities for the community (Asquith, 2002 p. 325).

Second, an offset market could also suppress the price of carbon, thereby redistributing the cost of responsibility for emitting firms upon citizens and trust shareholders. The distributional impact of carbon offset credit markets on shareholders and firms is closely tied to the price of carbon emission allowances with respect to carbon emission offsets credits. Hansen (2008) states that in order to achieve a decrease in atmospheric CO_2 necessary to achieve climate stability, a rising price for carbon emissions is needed. The challenge, he argues, is that offset credits suppress the true price of carbon emission allowances. The impact of such allowance price suppression is great. A suppressed allowance price would reduce dividends to VCAT shareholders by transferring potential trust revenue to emitting firms in the form of reduced costs of meeting compliance obligations. A suppressed allowance price could discourage innovation surrounding climate change mitigation and encourage the continued use of carbon-intensive fossil fuel energy sources. Such price suppression is, of course, favored by emitting firms, but does not appear to coincide with either the sustainable scale established earlier or a just distribution of atmospheric responsibility amongst resource stakeholders.

The price triggers written into RGGI's offset credit market offer a relevant example of further price suppression (Ard, 2006) that may result in inequitable distribution of income amongst participating state governments and emitting firms. As costs of compliance are suppressed through price triggers and escape clauses, less of the burden falls upon the shoulders of emitting firms to maintain the earth's ecological waste absorption capacity.

Participating power plants in RGGI have an initial limit of 3.3 % of compliance obligations that can be met through offsets, however, if the price of RGGI allowances reaches or rises above $7.00/ton for a period of twelve months, this limit is increased to 5.0 %. Given RGGI's regulatory scope of electric power generators, and an elasticity of demand (E_D) for electricity of -0.2 (Boyce, 2007), a 1.7 % increase in offset use could result in a decrease in the price of allowances by 8.5 %. Price elasticity of demand is equal to the percentage change in quantity for each one percent change in price. A further price trigger of $10.00/ton allows for participating RGGI firms to extend non-compliance with RGGI emission reduction obligations for a period of one year (Schrag, 2005) further reducing offset efficacy. All of these escape clauses result in inaccurate price signals and market uncertainty surrounding the true cost of CO_2 emissions. RGGI's price triggers complicate forward modeling, abatement investment decision-making, equipment installations, and process changes (Ard, 2006) which also contributes to inefficient allocation of firm resources.

Another way that offset credits can consistently assume a price less than allowance credits is through the use of future value accounting which counts expected future CO_2 savings as savings made today (Smith, 2007). Timeframes and discount rates for carbon offset projects utilizing future value accounting are often opaque and for good reason: timeframes can be longer than desired and risks are wide-ranging. Assumptions of timeframe and risk, if accurate and transparent would likely increase the price of offset credits. Instead, as more emissions are "offset," an accumulation of supposed carbon savings over time may emerge parallel to the continued release of CO_2 emissions into the atmosphere (Smith, 2007).

1.5. Efficient Allocation

Only once social decisions regarding fair distribution are made and sustainable ecological limits are set should the efficient allocation of a resource be pursued as efficient allocation of a resource does not ensure that scale or distribution will be addressed (Costanza, 2008). Only in the case of a CAT, with its mission to preserve and protect common assets, "for the benefit of present and future generations," will the issue of efficient allocation be sure to remain secondary to issues such as sustainable scale and just distribution (Miller, 2007, p. 1 p. 1). However, because the harm resulting from an unsustainable stock of GHG emissions is nonexcludable, the allocation of waste absorption capacity according to individual preferences, does not guarantee maximized monetary value. Thus, social preferences must determine the extent of its provision. Offset credit markets, however, may distort social preferences if offsets do not provide real GHG reductions or are not "permanent, quantifiable, verifiable, enforceable and additional" (Markey and Matsui *The Role of Offsets in Climate Legislation*, 2009).

Private rent capture by offset providers can also lead to inefficient allocation of resources as the market price of the offset may be greater than is required to bring the good (e.g. a certified emission reduction (CER) offset credit in the EU ETS) to market. Thus it may be more efficient for a CAT or government entity to pay for the costs of these reductions than for individual firms to make these reductions in the context of an offset credit market.

The EU ETS and CDM have in the past been accused of encouraging rent-seeking behavior (Redman, 2008). The problem of rent seeking behavior has occurred partially because, despite the large range for costs of production for offset credits, all offset credits sell at a single market price, dictated, in theory, by the highest marginal cost of production; the quantity supplied would adjust to the price and offset credit suppliers in primary markets would only supply offsets if the cost of production did not exceed the current market price. Consequently, offset initiatives such as hydro fluorocarbon (HFC) destruction and landfill energy projects have received priority treatment due to carbon markets' propensity for "low-cost, high-volume projects" (Taiyab, 2006 p. 7).

HFC destruction offset projects offer a good example of rent seeking behavior. Because "every molecule of HFC-23 causes 11,7000 times more global warming than a molecule of CO2…chemical companies can earn almost twice as much from selling CERs as from selling [these] refrigerant gases" (McCully, 2008 p. 3). One study estimated that $7.3 billion USD in pre-tax revenues worth of offset credits (CERs) were generated for Chinese and Indian manufacturers to destroy about $157 million USD worth of HFC gases. This is due to the fact that a carbon offset credit market, such as CDM, incorporates both production costs and producer surplus into the price per tCO_2e, while the payment required to mitigate these HFCs only requires the cost of production, or in this case, the cost of destruction. Thus, all of this offset rent was subsidized by taxpayers and consumers of CDM-participating countries (McCully, 2008). Loopholes allowing HFC-23 facilities to be eligible for CDM credits, however, are no longer in effect (Reuters, 2009).

2. METHODS

2.1. Research Goals

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Insert a new heading that is Goals and Objectives. State the general goal of providing information to Vermont citizens and legislature, then the more specific goal of assessing the impacts of offsets on revenue, scale, distribution and efficiency. Next state very briefly in list format your objectives, which are the steps necessary: e.g. develop alternative scenarios, estimate elasticities, calculate impacts on revenue, scale, distribution and efficiency.

This chapter aims to assess the potential impact of offset credits on revenue, scale, distribution, and efficiency in a VCAT to determine the extent to which offsets should be permitted. By providing the background research necessary for Vermont citizens and legislators to make informed decisions surrounding the atmospheric commons, institutions and instruments can be created that reflect a sustainable, just, and efficient emissions trading scheme.

2.2. Scenario Descriptions

This chapter will work towards these goals through the analysis of four scenarios that examine various implementations of an offset credit system in a VCAT. The chapter uses a VCAT as a case study but the subsequent analysis may be applicable to a range of cap-and-trade systems. Scenario 1 (section 4.2.) will examine a VCAT institution which implements a cap-and-auction policy with no offset credits permitted. Scenario 2 (section 4.3) will present an identical VCAT institution but includes an offset credit system with no limits to the number of offsets that may be used to meet compliance obligations. Scenario 3 (section 4.4) will examine a VCAT with a set limit for offset credit use. Finally, Scenario 4 (section 4.5) will look at a cap-auction-and-invest approach in which a VCAT would use some of its revenue in a payment for complementary emission reduction projects scheme. Each of these scenarios will be compared in terms of emission reductions outside of a cap (scale), social capture of rent through the auction of allowances (revenue obtained), money spent by emitting firms (distribution) and rent/producer surplus accrued by offset providers (efficiency). All four scenarios assume an initial value of 6.67 million metric tons of annual CO_2 emissions ($MMtCO_2$) (Strait, 2007), an 80% reduction in emissions by 2050, corresponding to a 4.00% annual cap reduction, as advocated by Hansen (2008) and Stern (2006a) among other prominent climatologists, and a constant price elasticity of demand (E_D) for carbon emissions of -0.26 (Boyce, 2007).

2.3. Procedure: Elasticity, Qualitative, and Quantitative Analysis

In order to establish an accurate representation of VCAT's revenue, fairness of distribution, and rent, it was necessary, first, to estimate an appropriate E_D for carbon emissions in Vermont. This was accomplished by gathering elasticity data for allowance permits in comparable institutions including the EU ETS and RGGI, as well as elasticities for a range of CO_2 emitting energy sources in Vermont. The average annual price values for the EU ETS's European Union Allowances (EUAs) were gathered from a periodic sampling of EUA prices in the primary spot market from August, 16, 2005 to January 22, 2010. (European Energy Exchange, 2010). We accomplished this through the graphical analysis of available market data, extrapolating prices approximately every forty-four days. EU ETS cap forecasts were gathered from Point Carbon (Point Carbon, 2009).

Qualitative discussions of the dual effect on elasticity of tighter caps and new technologies over time, the influence (or lack thereof) of arbitrage and price convergence on offset credit and allowance prices, and the impact of offset caps on the four parameters of emission reductions outside of the cap, social capture of rent through the auction of allowances, money spent by emitting firms, and rent/producer surplus for the producers of offset credits will also contribute towards this paper's recommendations.

4. RESULTS

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Since no states have yet developed a CAT (Farley, 2008), we reviewed the elasticity of allowances within other emission reducing institutions and CO_2 emission sources in Vermont to aid in the assessment of the impact of offset credits on a VCAT. If cap reductions and E_D for carbon emissions in Vermont are known then prices, emission reductions outside the cap, total revenue, rent, and money spent by emitting firms can be estimated.

4.1. Elasticities and Pricing in Comparable Institutions

This paper found that the E_D for EU ETS allowances in the primary spot market to be 0.01, implying that as the cap for EUAs decrease so would the price. The primary spot market is the core market in which physical commodities (e.g. allowances) are traded, as oppose to derivative markets which includes futures and options trading (ECX "European Climate Exchange," 2010). Much of this final positive elasticity value can be contributed to a few factors. In early 2006, the combination of the initially modest emission reduction goals of the EU ETS, along with less than expected emissions from several member states, resulted in the price of both trial- and second-period EUAs dropping drastically and unexpectedly. Over the next year, the price of EUAs steadily decreased to zero Euros per ton of CO_2 due to the banking restrictions on trial-period EUAs and the subsequent lack of arbitrage which would have allowed the prices of trial- and second-period EUAs to converge (Ellerman, 2008). These prices decreases as well as the increase in EU ETS member states [2] from 2007 to 2008 (the cap increased by 0.95% during this period) contributed to the positive elasticity value of 0.01. Table 1 presents the average prices per ton of CO_2 (in Euros) for the years 2005 to 2009, the corresponding caps implemented each year within the scheme, and the resulting elasticities.

Table 1. Price Elasticity of Demand in the EU ETS from 2005-2009

Year	Avg. Euros/t CO2[a]	Cap [b]	% Change in Cap	% Change in Price	Elasticity of Demand
2005	€ 21.67	2101.20			
2006	€ 18.63	2089.20	-0.57%	-14.03%	0.04
2007	€ 0.88	2109.00	0.95%	-95.28%	-0.01
2008	€ 4.28	2126.10	0.81%	386.36%	0.00
2009	€ 12.70	2114.10	-0.56%	196.73%	0.00
				Average E_D	0.01

Note [a]. Data Source European Energy Exchange (2010). Prices extrapolated from Figure.
Note [b]. Data Source Point Carbon (2009).

In Table 2, Point Carbon (2009), established the following cap and price forecasts for the years 2009 through 2012. These projections foresee a constant elasticity value of -0.01 arising over this time period. This value is both a highly inelastic demand for EUAs and a marked differential from the positive elasticity shown above.

Table 2. EU ETS Phase 2 Cap, Price, and Elasticity Forecasts

Year	Cap (Mt/yr.)	EUA Price	% Change in Cap	% Change in EUA Price	Elasticity of Demand
2009	1923	12.00 €	-	-	-
2010	1911	18.00 €	-0.62%	50.00%	-0.01
2011	1905	22.00 €	-0.31%	22.22%	-0.01

[2] The number of Member States in the EU ETS increased from twenty-three to twenty-eight from 2007 to 2008.

2012	1900	26.00 €	-0.26%	18.18%	-0.01
				Average E_D	-0.01

Note. Data Source Point Carbon (2009).

Like the EU ETS, RGGI began with modest emission reduction goals. RGGI caps will not decrease from their initial emissions budget of approximately 188 million short tons of CO_2 until the year 2015 (RGGI *Overview of RGGI CO2 Budget Trading Program*, 2007), thus preventing this paper from formulating any non-zero estimate of the initiative's E_D until that year. As shown in the EU ETS, institutions that implement only modest emission reduction goals may be more likely to see price volatility or reduced prices in the case of slight downturns in emissions by participating firms (Ellerman, 2008). RGGI's 2009 permit auction prices have ranged from a high of $3.51 in March 2008 to a low of $2.05 per short ton of CO_2 in December 2009. The latest auction in March 2010 resulted in a price of $2.07 per short ton of CO_2, approximately a 33% decrease in the price with no change in the cap (Schrag, 2009b).

This study follows Maddison (2009) who used fuel elasticities from Boyce and Riddle (2007) and applied these elasticities to the Vermont Greenhouse Gas Inventory (Strait, 2007) to determine the price elasticity of demand for emission allowances in a VCAT. A weighted average of these elasticity estimates provides us with an elasticity of demand equal to -0.26. It is important to note here that there are likely to be differences between the markets for allowances and for fuel, and hence differences in price elasticity of demand. Within an institution that places a cap on carbon emissions to create a carbon market, the new total cost of carbon-emitting fuel will be the price of the fuel plus the price of the allowance permits required due to the associated carbon emissions. This paper, assumes that elasticities for fossil fuels will be equivalent to elasticities of demand for the combined price of permits or offsets plus fossil fuels.

Table 3. Emission Sources, Totals and Elasticities in Vermont

CO2e Source	Total Emissions[a] (MMtCO2e)	Elasticity of Demand[b]
Gasoline (per gallon)	3.15	-0.26
RCI fuel use (per gallon)	2.24	-0.27
Natural Gas (thousand cubic ft.)	0.44	-0.20
Diesel fuel (per Gallon)	0.67	-0.26
Jet Fuel (per Gallon)	0.17	-0.25
Total	6.67	-0.26[c]

Note [a]. Data Source Strait (2007).
Note [b]. Data Source Boyce and Riddle (2007).
Note [c]. This number is the weighted average of the elasticities and emissions provided.
Note. Initial methodology source Maddison (2009).
Note. The Total Emissions column accounts for approximately seventy four percent of total CO2e emissions in Vermont and does not account for emissions from agriculture (0.96 MMtCO2e), waste management (0.29 MMtCO2e) or local industrial processes (0.44 MMtCO2e).

Thus, taking into consideration the elasticities evidenced in the EU ETS from Tables 1 and 2, and the framework established by Maddison (2009) (See Table 3) the likely initial elasticity for a VCAT (after the price has risen above zero) could range anywhere from -0.01 to -0.26. This implies that a 1% change in the cap could result in a percentage change in the price of allowances ranging from 100% to 3.84%. The former extremely inelastic estimate of -0.01 would seem a more likely value in the latter stages of a cap while the estimate of -0.26 would seem a more likely value in the period between cap creation but well before the cap begins to approach an economic threshold. A positive elasticity as, shown in the first years of the EU ETS, due to overly modest emission reduction goals would seem unlikely, in the time period between 2009 and 2012, given the significant annual cap reductions evidenced in these scenarios. All four scenarios below will adhere to the more elastic of these estimates in year one, -0.26, though elasticity is likely to change over time due to the dual effects on elasticity of tighter caps and the emergence of new technologies. It is also worth noting here, that fossil fuel demand and hence demand for CO_2 emissions is highly sensitive to economic conditions, thus, making it particularly difficult to isolate the effects of price and quantity changes and hence to calculate elasticities.

There are three primary determinants of price elasticity of demand relevant to this analysis, which consists of how essential the good or service is, its substitutability, and the share of income dedicated to its purchase. Agriculture is a good example of a sector that emits carbon and is also essential: "People need to eat no matter how high the price" (Daly, 2004). Thus, the demand for food is quite inelastic: a small change in the quantity supplied will lead to a big change in price. The expectation for carbon emissions is that as the supply of CO_2e emissions permits becomes scarce due to a tightening of the cap, the demand for such permits becomes increasingly inelastic with respect to price (Daly, 2004). As emissions permits become scarce, we will need to give up more and more important uses, and prices will rise accordingly. If emissions permits become too scarce, society will have to sacrifice essential uses, such as food production, at which point demand will becomes extremely inelastic. Demand cannot become perfectly inelastic due to budget constraints, but when measured in quality of life terms, the marginal costs of continued emissions reductions beyond this point become immeasurably high. This is the case in the absence of any mitigating effects on elasticity, such as the emergence of new technologies.

Substitutability is another determinant of elasticity. Many leading energy analysts believe that there are currently no adequate substitutes for fossil fuels at the scale required to maintain our current economic system and consumption levels, or even to produce the food required for 7 billion people (Deffeyes, 2003; Hall, 2009; Heinberg, 2003). However, as the price for emission permits increases, there will be incentives to develop new technologies that provide low carbon substitutes . Truly new technologies including resource-saving and resource-substituting technologies stand to affect the demand for carbon-emitting energy sources. While such novelty resembles evolutionary change and is thus unpredictable (Faber, Proops, & Manstetten, 1998), in recent history scientific and technical knowledge have increased rapidly and constrained resources (e.g. caps on emissions) have been shown to encourage innovation. Though we can't say with any certainty whether new technologies will increase the elasticity faster or slower than tightening caps increase its inelasticity, if we wish to encourage technological change further, we can design policies that are likely to speed up technological change, (e.g. market incentives, public support for technology, education, and social awareness of environmental issues). However, the cautious and flexible introduction of new technologies is recommended so as not to establish processes that do more harm than good (Faber et al., 1998).

If new technologies' effect on elasticity dominates the tightening cap's effect on elasticity, this can be expected to increase the elasticity of the demand for carbon emissions and shift the asymptote associated with economic collapse leftwards accordingly. In other words, society will be able to reduce emissions by a total of 80% before atmospheric CO_2 stocks surpass the level associated with two degree centigrade climate change without crossing the threshold of economic collapse.

If the tightening cap's effect on elasticity dominates new technologies' effect then constant decreases in the cap would result in larger and larger increases in price. However, at a certain level of emission reductions, only producers of emissions that provided highly essential goods and services (e.g. agriculture) would still emit as the price would be too high to produce non-essential goods and services. As a baseline case, this paper assumes that the contrasting effects of new technologies and the tightening cap will neutralize each other and price elasticity of demand for CO_2 emissions will remain constant at 0.26. It also qualitatively assesses potential outcomes of increasing and decreasing price elasticities of demand.

A third determinant of elasticity is the share of income devoted to the good or service being considered. Resources that account for only a small share of expenditures generally exhibit more inelastic demand, while resources that account for a large share exhibit more elastic demand. As prices for fossil fuels plus permits increase, elasticity of demand is likely to increase as well.

A constant elasticity value, such as the value of -0.26 used in this analysis, means that, over a range of changes in the permit price, within and across scenarios, the elasticity value remains the same (Nicholson, 2002). A 10% decrease in the cap will correspond to a 26% increase in the price of an allowance/offset credit throughout this analysis. For the following scenarios, this paper assumes that the Vermont market would show the same initial price (€13.43 or $18.83 at an exchange rate of €1=1.41 U.S. dollars) as the EU market as of January 19, 2010 (European Energy Exchange, 2010). Initial pricing was drawn from the EU ETS as this market is the largest and longest running multiple-sector cap on CO_2, thus, in theory, it embodies the most complete price of carbon emissions to date.

It is important to note that when establishing a new cap-and-trade scheme, initial price forecasts are often inaccurate. Though the cap is known at the beginning, demand for allowances, or expected aggregate emissions, are often unknown; only once the first release of emissions data is made public will prices accurately reflect demand as opposed to expectations of demand (Ellerman, 2008). Furthermore, fuel costs are highly unstable and the relevant price to an emitting firm is the sum of fuel costs plus permit costs.

4.2. Scenario 1: No Offset Credit Market

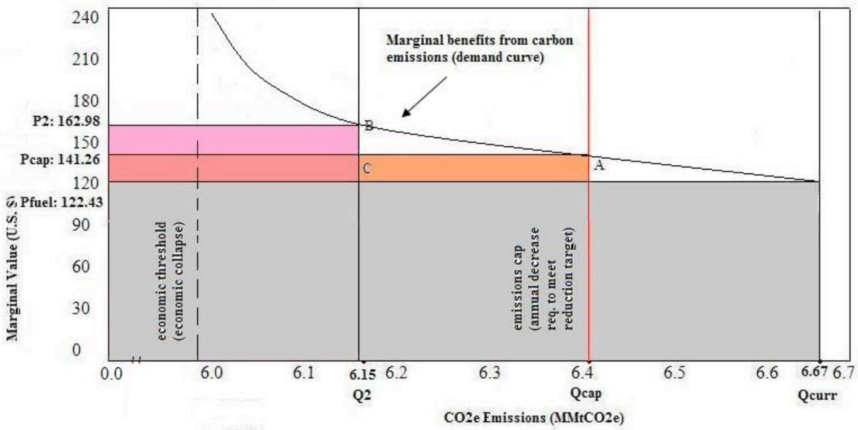
Figure 1 presents the first scenario in which no offset credit market is implemented. The x-axis depicts Vermont's current CO_2e emissions, from the aforementioned emission sources, totaling 6.67 $MMtCO_2$e (Strait, 2007). The Y-axis depicts the price of fossil fuel (P_{fuel}) plus the price of a permit. The price of oil, shown in the figures below as $122.43, serves here as a proxy for fossil fuels in general to adhere to the initial projection of $18.83 per allowance credit and the assumption of a constant level of elasticity (-0.26) throughout the graphs. This price corresponds to 1.55 barrels of oil, at current prices of $78.62 per barrel (Energy Information Administration, 2010), which is still less than the amount of gasoline required to emit one ton of CO_2; $122.43

worth of oil at current prices, would result in only 0.65 tons of CO_2 emissions at 0.01 tons of CO_2 per gallon (Maddison, 2009). Thus, P_{fuel} reflects a price greater than current oil prices but less than a price that would accurately portray the price per ton of CO_2 in oil.

In theory, for any emissions cap greater than or equal 6.67 $MMtCO_2e$, a VCAT allowance would cost $0.00 (assuming there does not exist a minimum price per emissions credit) as there would not yet exist any market scarcity; any tightening of the cap, however small, would result in a movement from a zero permit price to a positive price.

As depicted in figure one, an initial emissions cap reduction of 4.00%, of current emissions, Q_{curr}, would establish a demand equal to Q_{cap}. The revenue accrued to a VCAT under this first cap would be equal to $[(Q_{cap} \text{ x } (P_{cap}-P_{fuel})]$ or approximately $120 million. Tightening the cap to Q_2 or 6.15 MMtCO2e would generate revenue of $[Q_2 \text{ x } (P_2-P_{fuel)]}$, or approximately $249 million. Costs to businesses, in this scenario, would be equal to the revenue accrued by the VCAT. VCAT would not fund any emission reduction projects in this scenario. Given the absence of an offset credit market, no rent would be accrued to offset providers.

Figure 1. VCAT with No Offset Credit Market: Short Run



Note. The emission quantities expressed in this figure are not intended to present an accurate estimate of the levels at which an economic threshold may be reached.

4.3. Scenario 2: Unlimited Offset Credits

Scenario 2 presents a VCAT which includes a carbon offset credit market. Such an offset market would have no caps on the number or percentage of offset credits (in relation to the allowance cap) that may be used by firms or sectors to meet their compliance obligations. The supply of available offsets projected to be issued in Vermont is based on the ratio of average number of CERs issued annually from 2000 through 2012 to the average cap in the EU ETS from 2000-2012 (See Table 4).

Table 4. Offsets (CERs) Issued as a % of the EU ETS Cap

Year	Cap	CERs issued	CERs as a % of
2005	2001.2		
2006	2089.2	241 (from 2000-2008)	1.45%
2007	2109.0		
2008	2126.1		
2009	2114.1	46 (from 2009-2012)	0.55%
2010	2102.0		
2011	2081.0		

2012	2076.4		
Average	2087.4	23.9*	1.14%

Note. * 23.9 is the total number of CERs issued from 2000-2012 divided by the average annual cap.

(Point Carbon, 2009)

The market for carbon emissions during this timeframe will reach equilibrium where the quantity of carbon emitted, Q_{off} (See Figure 2), meets the supply of allowances plus offsets credits. Assuming a supply of offset credits is equal to 1.14% of the VCAT allowance cap (6.40 $MMtCO_2e$), the number of offsets supplied will equal 0.07 $MMtCO_2e$.

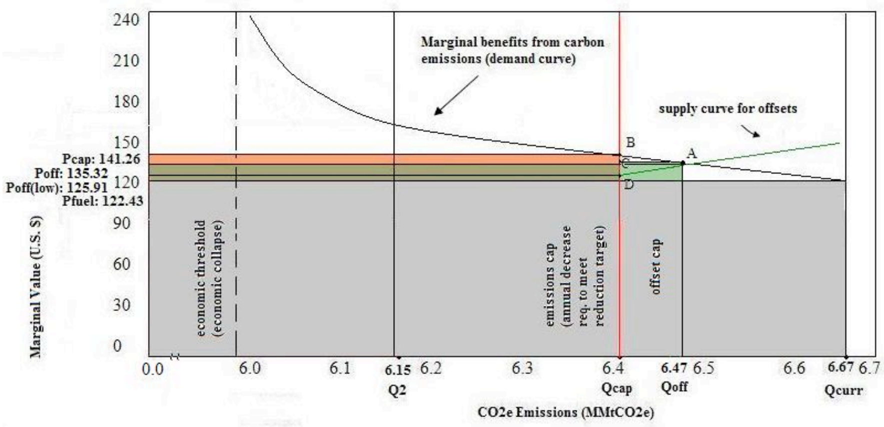
It is worth noting that Figure 2 and subsequent analysis will portray the supply curve for offsets as upward sloping. If Vermont were to participate in an offset credit market, the state would be a price-taker for offsets or in other words, Vermont would be unable to affect the price for offsets credits. Vermont, however, is not alone. China, which accounted for 62% of Certified Emission Reduction (CER) credits in the CDM market in 2007 (Smith, 2008) still does not have the necessary "market power to set the equilibrium market price" for CER offsets (Xuemei Liu, 2010). The implication of this is that the while a global market for offsets would have an upward sloping supply curve, the demand curve for offset providers in Vermont could be a horizontal line bound by the equilibrium price of offset credits (Xuemei Liu, 2010).

In this figure, with a fixed cap, allowance credits would cost P_{cap} and revenue generated by an emissions cap of Q_{cap} (represented by the red line) would still equal [P_{cap}-P_{fuel}) x Q_{cap}] or $120 million. However, offsets increase the allowed supply of CO_2e emissions above the cap therefore the demand for CO_2e in the presence of an offset credit market would be Q_{off} or 6.47 $MMtCO_2e$. The price per tCO_2e at Q_{off} would equal $12.89

per tCO_2e or ($P_{off} - P_{fuel}$). The supply curve for offsets also starts at a positive price as presumably there would be no offsets available for free. The revenue generated for a VCAT with an unlimited offset credit market will be equal to [(P_{off} - P_{fuel}) x Q_{cap}] (shaded in a sickly red green) or approximately $82.5 million. Revenue accruing to offset providers will be equal to [($Q_{off} - Q_{cap}$) x ($P_{off} - P_{fuel}$)], shaded in green, and totaling approximately $902,300.

Of this revenue, the upper left triangle will constitute the rent accrued by these providers. Point $P_{off\ (low)}$ represents price of the lowest cost offset projects (point D), which would likely take the form of HFC and N_2O projects. Liu (2010) writes that in China these types of projects constitute 78.45% of all CDM projects undertaken and that the price of CERs in China currently ranges from €2.47 to €5.5 or $3.48 to $7.75. Thus, $3.48 will serve as the low price for offset credits [P_{off} (low)] and will equal P_{fuel} + $3.78, corresponding to point D in Figure 2 below. The rent accrued to offset providers would equal ½ x ($P_{off} - P_{off\ (low)}$) x ($Q_{off} - Q_{cap}$) or approximately $329,350.

Figure 2. VCAT with Unlimited Offset Credit Market: Short-Run



Thus far, this analysis has shown that, in theory, the introduction of an offset credit market will result in a price convergence between emission allowances and offset credits. In the case of Figure 2 this can be seen as the point P_{off}. Such price convergence, however, has not been the case in emission trading schemes such as the EU ETS. In the EU ETS, there has always been a price gap, between the allowance price and the offset price.

Several possible explanations have been presented for the lack of converging prices of allowances (EUAs) and offset credits (CERs) in the EU ETS. Although the Linking Directive gave firms in the EU ETS the ability to use CERs and Emission Reduction Units (ERUs) in place of EUAs, because these seemingly homogenous assets exhibit different levels of risk (technological, economic, and political), uncertainty (surrounding revenues, costs, credit lifetime, and discount rate), transparency, varying transaction costs, and require different levels of planning, the arbitrage necessary to result in a price convergence does not occur (de Wolff, 2006). Thus, unless these differences are reconciled within a VCAT, the convergence of allowance and offset credit prices seems unlikely, though how such asset homogenization might occur is beyond the scope of this paper.

4.4. Scenario 3: Limited Offset Credits

Scenario 3 presents a VCAT that would include both an emissions cap and a set limit on offset use. Though capping the number of offset credits is considered by some to be a distortion of the market (de Wolff, 2006) in recent history, such limits have been the rule, rather than the exception. The offset cap for Phase 2 (2008-2012) of the EU ETS is 13.5% of the allowance cap but is different for each member state.[3] The offset limit for RGGI is initially set at 3.3% but subject to price triggers that can increase this cap and expand offset project eligibility (Zapfel, 2009). Within Figure 3, an offset limit of 1%, or 64,000 tCO_2e, is presented at $Q_{off}{}^{1}$. While this limit may appear low in comparison to other emission trading institutions, it is worthwhile to recall that, in the EU ETS, the offset credits that have been issued up through the year 2012 have only averaged approximately 1.14% of the average annual cap over this same timeframe (caps are based on Point Carbon (Point Carbon, 2009) forecasts for years 2009-2012).

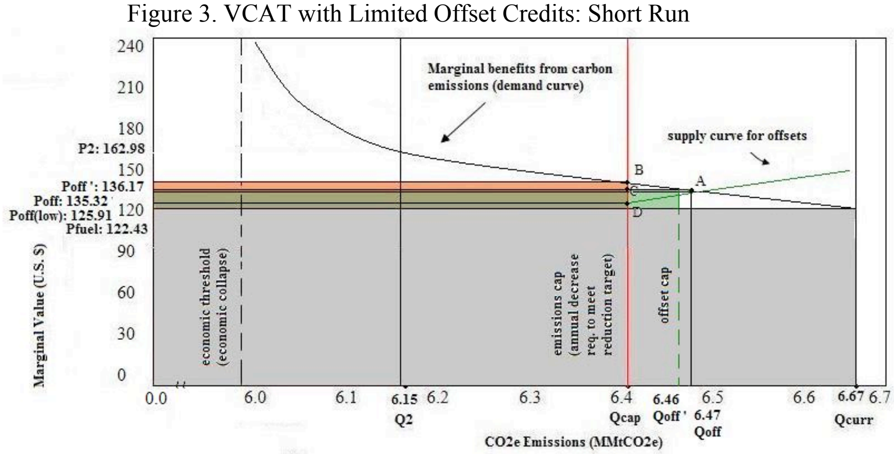
In this figure, the green-dotted line represents the emissions cap plus the offsets cap. $P_{off}{}^{1}$ is greater than P_{off} due to the limit on offset purchases. Because of the limit on offsets, there will be a price gap between the consumer reservation price (willingness to pay for offsets) and the producer reservation price (willingness to sell offsets). Therefore

[3] For example, in Phase 2 of the EU ETS, Spain and Ireland's offset cap is 50% of allocated EUAs; Germany's cap is 12%, Sweden's is 20%, and the Netherlands is 8% (de Wolff, 2006) (de Wolff, 2006)

the new price of offsets will be $P_{off}{}^1$, equal to the consumer reservation price as well as the price of the permit, as all credits, in theory, would sell at a single market price.

In this scenario, a VCAT would accrue approximately $87.9 million in revenue from an allowance auction. This revenue can be seen in the area of $[(P_{off}{}^1 - P_{fuel}) \times Q_{cap}]$ shaded in sickly red green. Carbon sequestered by offset providers would total 64,000 tCO_2e, constituting the entirety of the available offset cap. Money spent by firms on offset credits would total $824,400 and is shaded in green. Of this total, $388,400, or almost half of the total spent by emitting firms on offset credits, will constitute rent accrued by offset providers. This area is shown by the trapezoid in the upper left corner of the green shaded area.

Figure 3. VCAT with Limited Offset Credits: Short Run



4.5. Scenario 4: Complementary Emission Reduction Projects

Scenario 4 will look at the effects of a VCAT using some of its revenue in a payment for complementary emission reduction services scheme. This scenario is based upon the data presented in Scenario 1 (section 4.2) in which no carbon offset credit market was established. In Scenario 4, a portion ($573,300) of the revenue accrued to a VCAT from allowance auction revenue ($120 million) would be spent on complementary emission reduction projects. This would result in emission reductions (.07 MMtCO2e) equivalent to Scenario 2 in which an offset market with no cap was in effect. A VCAT could fund these emission reduction projects for substantially less than emitting firms operating within a carbon offset credit market could. This is because it would presumably be unnecessary for a VCAT to pay the producer surplus/rent accrued by the offset providers under an offset market system; a VCAT would only need to pay for the costs of production.

Thus, if these emission reduction projects are simply funded without the implementation of an offset credit market, a VCAT could accrue an additional $36.9 million, reduce emissions by an additional .07 MMtCO_2e below the initial cap level of 6.40 MMtCO_2e to an emissions level of 6.33 MMtCO_2e, and still leave a substantial VCAT surplus for of $119.4 million for alternative uses (See Table 5).

Table 5. Potential Impacts of an Offset Credit Market on a VCAT

Scenario Description	Carbon Emission Reductions (MMtCO2e)	Money Spent by Firms on Allowances	Rent Accrued by Offset Providers	Revenue Accrued by a VCAT
1 - No Offsets	0.00	$120,000,000.00	$0.00	$120,000,000.00
2 - Unlimited Offsets	0.07	$83,402,300.00	$329,000.00	$82,500,000.00
3 - Limited Offsets	0.06	$88,724,400.00	$388,400.00	$87,900,000.00

4 –Emission Reduction Prj. Funding	0.07	$120,000,000.00	$0.00	$119,426,700.00

5. DATA ANALYSIS

5.1. Significance of Results

In Scenarios 2 and 3 (sections 4.3. and 4.4.), offset credit markets resulted in the emission of 0.07 $MMtCO_2e$ and 0.06 $MMtCO_2e$ respectively beyond the initial cap. These emissions would negate between 1.1 and 1% of the VCAT's initial cap. Within these same scenarios, VCAT revenue from an allowance auction would decrease by $37.5 million and $32.1 million respectively. This revenue, previously accrued by a VCAT in Scenario 1 (section 4.2), would instead go to emitting firms and offset providers as reduced costs and producer surplus or rent respectively. To the extent that the offsets are not perfect substitutes for emission reductions, the firms have returned the costs of carbon emissions to the public. In placing a cap on the offsets, Scenario 3 (section 4.4) would contribute to sustainable scale through further emission reductions (as compared to Scenario 2 (section 4.3)) but subsequently, it would also increase the price of an offset credit and increase the rent accrued by offset providers. Emitting firms in Vermont would likely rally behind Scenario 2 (section 4.3) because they would be essentially permitted to emit 1.1% above the cap for approximately 70% of the cost, when compared to Scenario 1 (section 4.2). Offset providers, conversely, would likely support Scenario 3, in which they accrue nearly four-hundred thousand dollars of unearned profit.

Scenarios 1 and 4 (sections 4.2 and 4.5) appear to offer the greatest benefits to Vermonters in terms of achieving a sustainable flow of emissions, just distribution, and efficient allocation within a VCAT. Scenario 1 is shown to accrue the greatest revenue to a VCAT allowing greater dividend checks and/or investments into climate change mitigation measures and other priorities. Scenario 4 (section 4.5) would result in the greatest level of emission reductions and/or carbon sequestered, decreasing the annual emission level in Vermont to 6.33 $MMtCO_2e$, 0.07 $MMtCO_2e$ below the initial cap by spending a portion of these revenues on emission reduction projects. Such sequestration and/or emission reductions are necessary if Vermont intends to continuously reduce annual emissions by the 4.00% necessary to achieve 80% reductions by 2050. These results have made clear that: (a) an offset credit market would not contribute to a VCAT's goals of achieving sustainable scale, the just distribution of the associated costs, or the efficient allocation of resources; and (b) a VCAT can more efficiently allocate its resources through the complementary funding of emission reduction and sequestration projects. In Vermont, such complementary funding of renewable energy and fuel efficiency programs has already been implemented in the form of H.520 the Energy Efficiency and Affordability Act of 2008 partially funded from $2.4 million in revenues from RGGI. Such investments in the home and business efficiency market is anticipated to result in nearly 3 to 1 returns for the families and firms who make these changes (Coriell, 2008). A VCAT could consider an offset credit market only if Vermont intended to target a higher atmospheric stock such as 550 ppm, rather than if a VCAT targeted an 80% emission reduction target by 2050.

5.2. Alternatives and Desirable Solutions

It is clear that the complementary funding of emission reduction projects by a VCAT is capable of reducing carbon emissions for a fraction of the cost of emitting firms operating within a carbon offset credit market. If this approach to reducing emissions in Vermont was adopted by a VCAT, citizens of Vermont and the world would be well served with regards to the challenges of achieving sustainable scale, just distribution, and efficient allocation. However, given the fact that offset credit markets are so ingrained in the current carbon market paradigm, it is worthwhile to explore other strategies for achieving sustainable scale, just distribution, and efficient allocation within the context of an offset credit market.

Liu (2008) has proposed an instrument in which the Chinese government might effectively extract rent from low-cost CDM offset projects which are providing limited sustainable development benefit to developing countries; such an instrument may have direct implications for a VCAT's management of an offset credit market. A "resource tax/fee rate" structure (Xuemei Liu, 2010 p. 1007) could generate significant revenue in cases where production costs are low and the CER price is high (X. Liu, 2008). If a VCAT board of trustees was intent on implementing an offset credit market as an instrument to lower costs of compliance for Vermont firms, a resource tax either targeting specific offset project types (e.g. low cost projects) or all offset projects could be used to reclaim the rent accrued by offset providers. Such extracted rent could be utilized by a VCAT for goals similar to those of the Chinese government; specifically, to support "activities related to climate change" (Xuemei Liu, 2010 p. 1007). Liu (2010) recommends funding emission reduction projects with higher costs and greater sustainable development benefits (e.g. energy efficiency improvement, renewable energy, and methane recovery projects) in China through the CDM. Such funding of only high-cost offset projects, which generate the least amount of rent, through the rent extraction from low-cost projects, which generate the greatest amount of rent (X. Liu, 2008; Muller, 2007), would seek to decrease the rent accrued to offset providers and increase the rent accrued to a VCAT. Such a mechanism could improve market efficiency (efficient allocation), increase the quality of offset projects (sustainable scale), more justly distribute the costs of atmospheric commons management (beyond a simple offset cap or funding of emission reduction projects) and still maintain lower costs for Vermont firms.

If a VCAT were to fund emission reduction projects with or without the aid of an offset credit market, acting in the interest of present and future generations, the trust would be obliged to ensure that any investments in emission reduction projects were real, measurable, verifiable, and additional (de Jonge, 2009) as these investments should prove to be greater than the opportunity cost of alternative investments.

6. CONCLUSIONS AND RECOMMENDATIONS

Based upon the results presented here, this paper recommends three policies to guide the future development of a VCAT.

1) If a VCAT is implemented, this paper would recommend that a carbon offset credit market not be implemented alongside an emission allowance cap as an offset market contributes to carbon emissions above the cap, unjustly distributes the burden of atmospheric commons management, and reduces market efficiency.

2) If a carbon offset credit market is implemented within a VCAT, a mechanism which would extract rent from low-cost projects would be a powerful tool in working towards the just distribution of the cost of maintaining the earth's ecological waste absorption capacity.

3) If a carbon offset credit market is not implemented within a VCAT, the complementary funding of emission reduction projects would appear to be the least costly method to achieving additional carbon sequestration and emission reductions. More research is required regarding the scale of complementary reductions that a VCAT might propose.

Acknowledgements – I thank Joshua Farley, Gary Flomenhoft, and John Todd for their help, guidance, and support during this research.

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Chapter 3

THE DESIGN OF LOW-CARBON COMMUNITIES:

LAND USE PATTERNS AND TRANSPORTATION MODAL CHOICE

IN NORTHERN RURAL CLIMATES

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Abstract - Anthropogenic carbon dioxide (CO_2) and greenhouse gas (GHG) emissions may soon exceed the sustainable scale of the earth's ecological waste absorption capacity, and past a tipping point at which point there exists the possibility of positive feedback loops that could would result in rising sea levels, the rapid loss of sea ice, chaotic changes in climate, and constantly shifting shorelines. Reducing the anthropogenic flow of GHG emissions in the transportation sector is recognized as a key component of mitigating climate change; this may take the form of voluntary actions, (e.g. behavioral change) or governmental policies that reduce greenhouse gas emissions. This paper examines three problems surrounding transportation and climate change: (1) Individuals do not often consider climate change a salient issue; (2) motor cars are the most preferred mode for passenger road transport but the second greatest GHG emitters; and (3) a significant shift towards alternative and sustainable transportation modes is a challenging and complex endeavor. This paper utilizes a multivariate binary logistic regression model to address the issue of microaccessibility and modal choice in northern rural climates and the question of which specific community characteristics might contribute to a modal shift towards low-carbon modes such as biking, walking, or public transit. Access to public transportation had a significant effect on increasing the probability of low-carbon travel behavior; however, improving access to public transportation would not be the best solution for northern rural climates due to high costs and geographical restrictions. Instead, to successfully plan, design, or re-design a low-carbon community in a northern rural climate, with regards to travel behavior, it is necessary to instill in our community members, the importance of places one can walk to. Keywords: land use pattern; micro-accessibility; modal choice; northern rural community; climate change; consideration

1. INTRODUCTION

Anthropogenic carbon dioxide (CO_2) and greenhouse gas (GHG) emissions may soon exceed the sustainable scale (an estimated stock of approximately 350 parts per million (ppm)) of the earth's ecological waste absorption capacity, and pass a tipping point. Past this tipping point, there exists the possibility of positive feedback loops that could result in rising sea levels, the rapid loss of sea ice and "interdependent species and ecosystems," chaotic changes in climate, and constantly shifting shorelines, all "without additional climate forcing" (Hansen, 2008 p. 12, 16). Reducing the anthropogenic flow of carbon dioxide equivalent (CO_2e) emissions in the transportation sector is recognized as a key component of mitigating climate change. The transportation sector is a significant contributor to the flow of greenhouse gas emissions into the atmosphere. "Transport accounts for 14% of global greenhouse gas" emissions and "26% of global CO_2 emissions and is one of the few industrial sectors where emissions are still growing" (Chapman, 2007; Stern, 2008b); CO_2 emissions from road transportation are expected to double between 2005 and 2050 (Stern, 2008b). The majority of experts believe that the time is now for both people and nations to take action in decreasing human contributions to climate change. This action may take the form of voluntary actions, (e.g. behavioral change) or governmental policies that reduce greenhouse gas emissions (Bord, 2000b). There are three specific problems that this paper will address:

(1) Individuals do not often consider climate change to be a salient issue (Bord, 2000b). Bord (2000a) found that, when compared to other issues and risks that people consider (e.g. social, personal, and environmental), global warming was ranked last and second to last by respondents according to their perceived likelihood of societal and personal harm, respectively, resulting from the issues.

(2) Motor cars are the most preferred mode for passenger road transport but are also the second greatest contributor (the greatest is road freight) to GHG emissions in the transport sector (WBCSD 2001 in Chapman, 2007). This preference and subsequent reliance on motorized transportation is quickly moving the earth's stock of GHG emissions closer to a tipping point (Chapman, 2007) and increasing the probability of catastrophic climate change (Stern, 2008a).

(3) Perhaps due in part to individuals' lack of climate change consideration and preference for motor cars, a significant shift towards alternative and sustainable transportation modes is a challenging and complex endeavor. Even though a substantial share of the public is committed to the environment, "participation in environmentally-supportive behavior rarely mirrors the strength of this stated commitment" (Kennedy, 2009 p. 151). Kollmuss (2002 p. 242) states that there usually does not exist a correlation between "attitudes toward climate change and driving behavior; …even people who are very concerned about climate change tend to drive." Chapman (2007 p. 357) has also shown that it is essential but difficult to change attitudes regarding transportation modal choice.

Individual communities cannot solve the complex problem of global climate change alone; though many communities have sought to address these challenges over the last decade, few have truly addressed the long-term consequences (Duerksen, 2008) due to a belief that markets, governments and institutions will address GHG emissions from the top-down (Lerch, 2008). Handy (1996) has shown the relationship between urban form and travel behavior to be significant; however, research regarding the specific aspects of urban form which influence travel behavior and in what ways, in northern rural communities, is lacking.

This paper will provide important information for policymakers and transportation planners in northern climates to reduce community contributions to global warming and prepare and position communities to address future climate change challenges. Specifically, I aim to contribute to the literature surrounding the designing and planning for low-carbon communities with regards to travel behavior by assessing which community characteristics should be offered and emphasized when planning, designing, or redesigning communities for GHG emission mitigation in northern rural climates. This research is communicated in the form of a thesis article, to be submitted for publication upon the author's defense at the conclusion of the spring 2010 semester. This paper will focus upon two key questions:

(1) Which specific characteristics, when offered by a community, might contribute to an increased probability of low-carbon travel behavior such as walking, biking, or the use of public transportation in northern rural climates?

(2) Which community characteristics have the greatest impact on the probability of an individual's low-carbon travel behavior when compared to their consideration of climate change and mode preference?

2. LITERATURE REVIEW

2.1. Land Use Patterns and Transportation Modal Choice

Mode choice has been shown, above all other travel variables (including local densities, origin and location densities, vehicle miles traveled (VMT), vehicle hours traveled (VHT), and others), to be most impacted by local land use patterns (Ewing, 2001). Ewing et al. (2001) characterizes land use patterns as residential densities in activity centers, the level of mixed land use (within neighborhoods and activity centers) and microaccessibility, or the number of specific community characteristics within a set range of residences. All three of these descriptors have been shown to impact non-motorized modal choices.

2.2. Micro-accessibility

Several studies have been conducted that examined the effects of land use patterns on travel behavior; however, studies documenting the impact of specific community characteristics on modal choice are less frequent. Kitamura (1997) surveyed five sites in the San Francisco Bay Area and gathered micro-scale data on location and types of commercial institutions, distance to the nearest bus stop, rail station, grocery store, gas station, and park, and whether or not a community offered sidewalks and bike paths. These neighborhood descriptors were shown to contribute to the explanatory power of Kitamura's model; more specifically, fraction of transit trips were associated with distance to the nearest rail station, fraction of car trips were associated with the distance to the nearest bus stop, park, and streets that are pleasant for walking, and fraction of non-motorized trips were associated with distance to the nearest bus stop and park.

Individuals in pedestrian friendly communities have been shown to have an increased nonautomobile mode share as compared to less pedestrian friendly communities; these pedestrian friendly communities were rated higher in terms of ease of street crossing, sidewalk continuity, local street characteristics, and topography (Parsons Brinkerhoff Quade and Douglas, Inc., 1993 in Handy, 1996). Similarly, the quality of a communities' walking environment (including sidewalk and street light provisions; plentiful planted strips; short average block lengths and distances between street lights; flat terrain; and high walking accessibility to neighborhood shops) along with transit service intensity have been shown to increase the likelihood of individual's making personal-business trips by walking, biking, or transit modes (R. a. K. Cervero, K., 1997).

Research has shown that the distance to destinations is the greatest factor in peoples' decisions to walk or drive (Funihashi 1985; Komanoff and Roelofs 1993; Handy 1996; Smith and Butcher 1994 in Southworth, 2005). This has been further supported by Lamont's (2001 in Southworth, 2005) study of walkability in four neighborhoods in San Francisco in which distance was shown to highly influence walking frequency. Types of activities that people may walk to, if accessible within their neighborhood, include shops, cafes, banks, laundries, grocery stores, day care centers, fitness centers, elementary schools, libraries, and parks (Southworth, 2005).

When a neighborhood offers a convenience store (Cervero and Radisch 1996 in R. a. K. Cervero, K., 1997; Handy, 1993), or a suburban office setting offers restaurants, shops, or service outlets, a modal shift away from vehicular travel and towards non-motorized travel (e.g. walking and biking) and ride-sharing, respectively, is intuitive (Cervero, 1989 in R. a. K. Cervero, K., 1997). One study of 59 areas of employment found that employment centers with on-site or nearby retail services exhibited high walking and low drive-alone commuting rates (Cervero, 1989 in R. a. K. Cervero, K., 1997). Similarly, Cambridge Systematics (1994 in R. a. K. Cervero, K., 1997) found that commuters traveled by transit 3.6% more often when their destination had convenience-oriented services available.

Studies of cities served by the Bay Area Rapid Transit (BART) system, which provides services throughout the San Francisco metropolitan area, have shown that access to rail stations resulted in approximately a five-fold increase in a residents' likelihood to commute by rail transit beyond that of an average resident-worker in a given city; proximity of housing to stations was also shown to impact rail travel (R. Cervero, 1994). Southworth (2005) has also advocated for a well-connected pedestrian network which offers quick and easy access to others modes such as buses and other public transportation.

Greater accessibility, however, has not always been shown to result in a modal shift away from automobile usage. Instead, Ewing et al. (1994 in Handy, 1996) conducted a study in which they determined that greater accessibility had resulted in less vehicle-hours-traveled.

2.3. Density and Mixed Land Use

Density and mixed land use usually exist side-by-side and thus it is often difficult to determine which of these community features is the catalyst for specific changes in transportation behavior (Ewing 1994 in R. a. K. Cervero, K., 1997); thus, these two features will be discussed concurrently. Communities that are dense (R. Cervero, 1994), mixed-use, and pedestrian friendly will more often result in transit riding than a community that is not dense and auto-centric (R. a. K. Cervero, K., 1997)

Cervero and Kockelman (1997) have discussed how compact neighborhoods can decrease the number of motorized trips and encourage non-motorized trips by increasing opportunities to leave one's car at home and offering higher quality transit services. Hanson (1982 in Handy, 1996) has also shown how greater density of opportunities has been shown to result in less overall travel (with the exception of social and recreational travel). Rail transit commute share has also shown to be greater for higher density residential and work settings (Cervero 1994 and Cervero 1994 in Ewing, 2001).

New Urbanists have encouraged mixed use developments to decrease automobile use and subsequently help reduce CO_2 emissions (Duerksen, 2008). Cervero and Kockelman (1997) have also found that mixed land uses would be positively associated with the travel choices of shared-rides, transit, and non-motorized modes. Conversely, if land use patterns are tailored to high-speed auto travel this may result in an environment that is not safe for pedestrian or bicycle use (Southworth, 2005).

2.4. Consideration, Beliefs, and Preferences

Values and attitudes are important variables in establishing pro-environmental behavior (Kollmuss, 2002). Chawla (1998 in Kollmuss, 2002) found that factors that influence individuals, who are aware of (e.g. consider) environmental issues, include pro-environmental values held by the family, role models (e.g. friends or teachers), and education among others; however, Americans have been shown to support almost any abstract problem presented in the form of a survey (Ladd 1990 in Bord, 1998; Bord 1998). Past research shows that such support for climate change has not translated into low-carbon travel behavior; initiatives that threaten car use such as restrictions on fuel use or driving have been found to only garner support from environmentalists (Doble et al. 1990 in Bord, 1998; Bord 1998).

Kitamura's (1994 in Handy, 1996) study of five communities in the San Francisco area found that the attitudes, (e.g. beliefs) (Newhouse, 1991 in Kollmuss, 2002) of the respondents actually contributed more towards their travel behavior than their communities' characteristics, thus highlighting the importance of changing attitudes in addition to community characteristics. However, the impact of attitudes on travel behavior has been found to vary (Kollmuss, 2002).

Though, research into travel behavior and mode choice, unlike the study of consumer behavior and marketing, does not often use psychological make-up or preferences, to distinguish between distinct populations, Anable (2005) has shown that a major reason that individuals do not engage in other modes of transportation besides the automobile is a psychological attachment and reliance on the car. Stradling et al. (2000 in Anable, 2005) have also shown that inclinations (e.g. preferences), together with opportunity and obligation, influence travel decisions. Fuhrer et al. (1995 in Kollmuss, 2002) have hypothesized that a person's values, or preferences, are shaped by their immediate social net (e.g. family, friends, and neighbors) as well as the media and other political organizations

2.5. Summary

In total, specific neighborhood and community characteristics that have impacted mode choice include: access to public transportation stops and stations , parks (Kitamura, 1997), convenience stores (Cervero and Radisch 1996 in R. a. K. Cervero, K., 1997;

Handy, 1993), banks, shops, restaurants, service outlets, and retail services (Cervero, 1989 in R. a. K. Cervero, K., 1997). Pedestrian friendly characteristics that have also impacted mode choice include: sidewalk and street light provisions, easy street crossing, and sidewalk continuity among others (Parsons Brinkerhoff Quade and Douglas, Inc., 1993 in Handy, 1996). In general, distance to destinations has been shown to greatly influence peoples' decisions whether to walk or drive (Funihashi 1985; Komanoff and Roelofs 1993; Handy 1996; Smith and Butcher 1994 in Southworth, 2005). Density can reduce a community's carbon-impact from travel through an emphasis on compact neighborhoods (R. a. K. Cervero, K., 1997), increased residential and work densities (Cervero 1994 and Cervero 1994 in Ewing, 2001), and greater density of opportunities (Hanson 1982 in Handy, 1996). Mixed land use can similarly work towards low-carbon travel behavior by decreasing automobile use (Duerksen, 2008). The majority of the research available surrounding community characteristics and modal choice, however, has been conducted on the west coast. Kitamura's research was conducted in the San Francisco Bay area; Parsons et al.'s research was conducted in Portland, Oregon, Handy's (1993) research was conducted in the San Francisco Bay Area, Cervero and Radisch's (1996) research was conducted in the San Francisco Bay Area, and Cambridge Systematics' (1994 in R. a. K. Cervero, K., 1997) research was conducted in Los Angeles, California. People are willing to consider most abstract problems, however, not willing to change their lifestyle with regards to driving behavior (Ladd 1990 and Doble et al. 1990 in Bord, 1998; Bord 1998). However, beliefs and preferences, unlike consideration, have been shown to contribute to travel behavior (Stradling et al. 2000 in Anable, 2005; Kitamura 1994 in Handy, 1996).

3. METHODS

3.1. Sample

The data analysis presented in this paper will use a data set based upon the 2009 Transportation in Your Life Poll. This survey was informed and developed by findings from focus groups conducted in the Fall of 2008. This survey was approved by the University of Vermont's Institutional Review Board (IRB). A sample for the survey was obtained from a contact list of Vermont, Maine, and New Hampshire respondents, from a survey, previously conducted survey by the New England Transportation Institute (NETI). Respondents had to be over the age of eighteen to be interviewed. This work was funded (in part) by the USDOT through the University Transportation Center (UTC) at the University of Vermont.

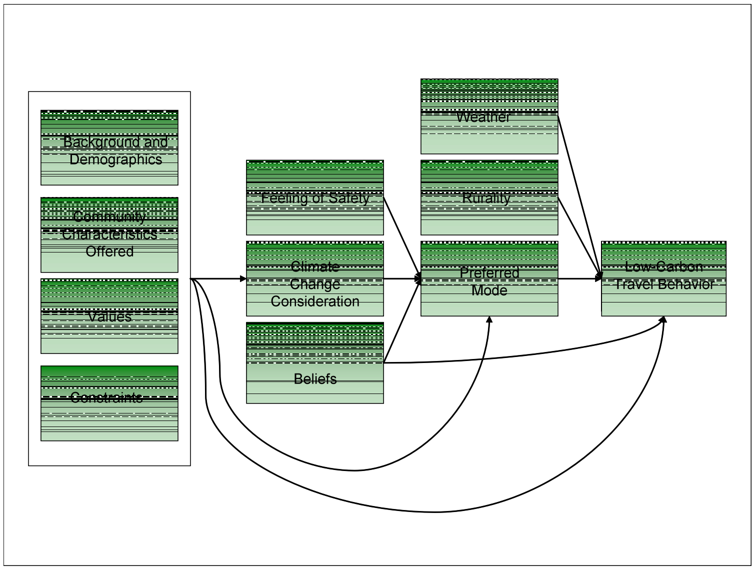
3.2. Procedure

This survey was completed using the survey methods of computer-aided telephone interviewing (CATI) and online polling. Letters were mailed out on Friday, May 22, 2009 to potential respondents. These letters contained a short description of the survey, and alerted potential respondents to the availability and web address of the online survey. All computer-aided telephone interviews were conducted between Tuesday, May 26, 2009 and Wednesday June 10, 2009, Monday through Friday from 4:00 p.m. until 9 p.m. All procedures were conducted with the Statistical Program for Social Sciences (SPSS), version 17.0.

3.3. Proposed Model

A recursive binary logistic regression model is presented in Figure 1. The model is recursive in that each of three dependent variables, including climate change consideration, preferred mode, and travel behavior are determined by a series of previously independent variables. The model is a binary logit because the dependent variable is presented as two choices or parts (Loutzenheiser, 1997). For example, demographics, community characteristics, values, and constraints are the groups of independent variables which determine the predicted probability that a respondent considered climate change when they traveled. This predicted probability variable for climate change consideration (subsequently coded nominally) along with the preceding variables and two additional independent variables (beliefs and feeling of safety) determined the predicted probability that a respondent would prefer a low-carbon mode of transportation. Finally, the two predicted probability variables for consideration and preferred mode (both coded nominally) along with all the preceding terms, except for feeling of safety, and along with two new independent variables (rurality and weather) determined the predicted probability that a respondent would engage in low-carbon travel behavior (e.g. walking or biking, bus, public transit, trains, or motorcycles) at least once during the day they were surveyed for. The independent variables that contributed to each subsequent regression are discussed below, at length in section 3.3.1, 3.3.2, and 3.3.3. Figure 1, however, presents a summary of the types of variables involved in each of the three models. The entire system of equations was identified by satisfying the rank and order conditions and tested for multicollinearity showing a lack of collinearity within the model. Both of these processes will be discussed below in section 3.4.

Figure 4. Logit Regression Modal for Low-Carbon Travel Behavior



3.3.1. Climate Change Consideration

The first step in developing a regression model to predict low-carbon transportation modal choices was to assemble the independent variables that may impact an individual's consideration of climate change when they travel. These variables included demographics such as: age (AGE), gross annual household income (INCOME), gender (GENDER), and individuals with education at least equal to a bachelor's degree (EDUCATION). Age and income were coded as continuous variables while gender and education were coded on a nominal scale. Modal constraints also were hypothesized to contribute to an individual's consideration of climate change. Modal constraints in the model included: number of motor vehicles owned, leased, or available to people in your household (MOTOS), number of functional bicycles owned by members of your household (BIKES), and access to public transportation in your community (PUBLICTRANS). Number of motor vehicles and functional bicycles were both coded on a continuous scale while access to public transportation was coded nominally.

Frequency analyses of two questions corresponding to the importance of natural surroundings and the importance of places you can walk to in your community were conducted to identify three tertiles of respondents: those who valued natural surroundings and places you could walk to at a low-, middle-, and high-level. Respondents who assigned a middle- (IMPNS MID and IMPWALK MID) or high-level (IMPNS HIGH and IMPWALK HIGH) of importance, as compared to those who assigned a low-level of importance, to this characteristic were included in the model. To account for the interaction between the importance of places you can walk to and how well your community provided this characteristic, a third set of variables was created (INTERACTION MID and INTERACTION HIGH) by multiplying the ordinal (1-10) responses to importance and presence variables together, conducting a frequency analysis of the resulting variable, and including the mid- and high-level tertiles (as compared to the low-level tertile) in the model.

The micro-accessibility indicators established for this model were based upon seventeen community characteristics which were separated into five microaccessibility indicators. These included: services, housing, access to social networks, education and employment, and culture. A score was created for each respondent by aggregating their responses for the community characteristics present in each of the five indicators using a

Likert Summated-Scale approach (J. Kolodinsky, Hogarth, J., and Shue, J., 2000; Likert, 1967). Each indicator included a summated-scale of between two and five Likert-type variables each measuring how well your community offered a community characteristic on a scale from zero to ten with zero being not at all offered, ten being very well offered, and five being the point in the middle. Variables included in the each of these indicators can be seen below in Table 6.

Table 6. Likert Summated Scales

Micro-accessibility Indicator	Variables Included	Min.	Max.
Services	Grocery Stores, Restaurants, Clothing Stores, Healthcare Provider, Childcare	0	50
Housing	Affordable Housing and Adequate Housing	0	20
Access to Social Network	Access to family, friends, and neighbors you consider friends	0	30
Education and Employment	Education & training and employment opportunities	0	20
Culture	Recreation, Arts and Entertainment, Place of Worship, and Natural Surroundings	0	40

A frequency analysis of each of the Likert Summated-Scales was conducted to identify three tertiles of respondents: those who responded that their community offered a low-, middle-, and high-level of the groupings of community characteristics. Of these three groups, those individuals who responded that their community offered the groups of characteristics at a middle- or high-level (as compared to a low-level) were included in the model.

3.3.2. Preferred Mode

In assessing a respondent's preferred mode of travel, the first step was to determine how an individual usually gets to the grocery store and to visit their friends, whether they preferred another mode, and if so, what mode. If a respondent stated that they traveled to these locations in a certain mode and did not prefer another mode, their current mode was coded as their preference. If, however, a respondent stated that they did prefer another mode, this alternative mode was coded as their preference. If an individual did not know or refused to answer whether they preferred another mode, their current practice was regarded as their preference. If an individual responded that they preferred to get to either of these locations in "Another Way", but the individual respondent did not state clearly their alternative preference, their current practice was regarded as their preference. In order to establish a single nominal variable for preferred mode, if a respondent preferred a zero- or low-carbon mode of travel to both the grocery store and to visit their friends they were coded as a 1. All others were coded as a 0.

This preferred mode variable functioned as an intermediary dependent variable. All previous independent variables were used along with the predicted probability variable (PREDICT CONSIDER) corresponding to whether the predicted probability of an individual's consideration of climate change was greater than or equal to 0.5 (1) or not (0), the independent variable (BELIEVE) corresponding to the belief that a respondent "should walk and bike more," and the otherwise excluded independent variable, IMP FEELSAFE; this previously excluded variable presented the response of those who ranked the importance of a feeling of safety in your community in the mid- or high-leve tertile range, as compared to those who ranked its importance in the lower-tertile range. Both BLVWALKBIKE and IMPFEELSAFE were coded on a nominal scale.

3.3.3. Low-Carbon Behavior

The final dependent variable within this model was whether or not a respondent engaged, at least once in a low-carbon mode of transportation. This data was established upon creating a single variable based upon information from the survey. A low-carbon mode of transportation included zero-carbon modes (e.g. walking and biking) and low-carbon modes (e.g. public transit and motorcycles). Although buses, for example, may still use gasoline, once bus occupancy is greater than three riders, the CO_2 emissions per rider per kilometer have been shown to be lower for buses than for cars (Stanley and Watkiss 2003 in Chapman, 2007). Similar arguments may be made for other modes of public transit. Motorcycles, meanwhile, often receive superior mileage per gallon and were thus grouped with other low-carbon modes. If a respondent did not specify at least one trip by a zero- or low-carbon mode in the survey, then they were coded as a 0; if they did specify at least one such trip, they were coded as 1.

Additional independent variables added in, at this stage of the regression, included rurality and inclement weather. Rurality was coded nominally as either rural or not rural while inclement weather was coded from open-ended responses to the question, "how would you describe the weather yesterday." For cases in which the individual responded with descriptions of rainy, stormy, wet, windy, or conditions, the respondent was coded as 1. All others were coded as 0. The predicted probability for low-carbon mode-preference (PREDICT PREFER) corresponding to whether the predicted probability of individual's consideration of climate change was greater than or equal to 0.5 (1) or not (0) was also included.

3.4. Identification and Multicollinearity

To ensure that the system of equations used was identified, it was necessary to satisfy rank and order conditions. The rank condition was satisfied as each subsequent regression equation for consideration of climate change, preferred mode, and low-carbon travel behavior contained at least one exogenous (independent) variable that is excluded from the previous equation. The order condition was satisfied by ensuring that the number of excluded exogenous variables from any of the three regression equations in this system was at least as large as the number of right hand side endogenous (dependent) variables in the same equation (Wooldridge, 2003).

In testing for multicollinearity, or the presence of "general interrelationships" amongst the independent variables, the only variables with a Pearson Correlation Coefficient value of greater than 0.6 that were included were neighbors you consider friends (related to friends), adequate housing (related to affordable housing), and restaurants (related to grocery stores and clothing stores). However, a relatively low Cox and Snell R^2 value of 0.059 has shown that despite these relatively few high Pearson Correlation coefficient values, that there is a lack of collinearity within this model (Judge, 1980).

4. RESULTS AND DISCUSSION

Results including frequencies and summary statistics are presented in Table 7. While the majority of individuals surveyed thought about climate change when they traveled, only about ten percent of respondents preferred a low-carbon mode of travel or engaged in low-carbon travel behavior. While 70.9% if respondents lived in a rural area, 43.8% of respondents stated that they had access to public transportation. On average, people own more motor vehicles than bicycles and 75.8% of people believe they should walk or bike more. The majority of respondents to this survey (52.8%) were women.

Table 7. Variable Descriptions and Survey Summary Statistics

Variable	Variable Description	Frequency	Observation %
Dependent Variables			
CONSIDER	Think about climate Δ when they travel (given in % agree)	511	52.7%
PREFER	Prefer low-carbon modes	102	10.5%
BEHAVIOR	Engaged in low-carbon travel	101	10.4%
Demographics, Beliefs, and Constraints			
GENDER	Gender (given in % male)	458	47.2%
EDUCATION	Education of at least a bachelor's degree	498	51.3%
RURALITY	Do you live in a rural area?	688	70.9%
BELIEVE	Believe you should walk or bike more (given in % agree)	735	75.8%
PUBLICTRANS	Access to public transportation (given in % yes)	425	43.8%
		Mean	S.D.
AGE	Age	51.29	14.14
INCOME	Income (in U.S. dollars)	77445.22	56415.06
MOTORS	# of motor vehicles	2.27	1.26
BIKES	# of functional bicycles	1.99	1.94
Micro-accessibility Indicators		Median	
SOCIALSCALE	Access to family, friends, and neighbors you consider friends (0-30)	20.00	
SERVICESCALE	Grocery Stores, Restaurants, Clothing Stores, Healthcare Provider, Childcare (0-50)	28.00	
EDUEMPSCALE	Education & training and employment opportunities (0-20)	10.00	
HOUSESCALE	Affordable Housing and Adequate Housing (0-20)	10.00	
CULTURESCALE	Recreation, Arts and Entertainment, Place of Worship, and Natural Surroundings (0-40)	28.00	
PLACESWALK	Places you can walk to (0-10)	6.50	
Importance of Community Characteristics			
IMP NATURAL	Natural surroundings	9.00	
IMP PLACESWALK	Places you can walk to	7.00	

Note. N=970

Results of the binary logistic regression models are presented in Table 8. The model predicting climate change consideration performed best, predicting 68.9% of the respondents who think about climate change when they travel. The model predicting an individual's preferred mode of travel only successfully predicted 3.9% of those of preferred low-carbon modes of transportation. The performance of the final model performed between the first two models, successfully predicting 5.9% of the individuals who traveled at least once by a low-carbon mode during the day for which they completed their survey.

Table 3 presents the B coefficients, the exp (B) values and the significance levels associated with the independent variables. The B coefficient predicts the change in the log-odds of the dependent variable for every one-unit increase in the independent variable, holding all other independent variables constant. Because the B coefficients are expressed in log-odds units, interpreting them can be challenging (UCLA Academic Technology Services). The exp (B) value represents the probability or odds of achieving the dependent variable given a change in the independent variable. Regression coefficients are considered significant if the value is less than or equal to 0.100.

4.1. Climate Change Consideration

The categories of community characteristics offered that were significant and had a positive effect on the probability that an individual would consider climate change when they traveled were a high-level of education, training and employment opportunities as well as a high-level of cultural characteristics. A high-level of education, training and employment opportunities and cultural characteristics made the probability of climate change consideration 165.7% and 142.2% as likely respectively.

Similarly, those individuals with at least a bachelor's degree were 150.8% as likely to consider climate change as those who did not have at least this level of education.

Surprisingly, the presence of the community characteristic of housing (mid-level and high-level) resulted in a significantly reduced probability of achieving the dependent variable of climate change consideration. A respondent was only 66.3% and 74.2% as likely to consider climate change when they travel if their community offered mid- and high-levels, respectively, of affordable and adequate housing.

The probability of a respondent who stated that the community characteristic of places to walk to was highly important (in the 66th percentile or greater) were 184.7% as likely to consider climate change as one who ranked places to walk at a low-level of importance.

Both number of bicycles and number of motor vehicles owned proved to be significant in changing the odds of climate change consideration, but in opposite directions. A respondent was 90.9% as likely to consider climate change for each unit increase in the number of motor vehicles in the household but 112.9% as likely for each additional functional bicycle owned.

4.2. Preferred Mode

The presence of certain community characteristics, including a high-level of social networks and a medium level of education, training and employment opportunities, tended to decrease the probability of an individual preferring a low-carbon mode of transportation. In these cases, a respondent was 53.3% and 49.3% as likely to prefer a low-carbon mode if a community offered each of these characteristics, respectively. If an individual responded that they held a high level of importance for places you could walk to, the respondent was 340% as likely to prefer a low-carbon mode. Finally, a respondent was 162.8% as likely to prefer a low-carbon mode if they held at least a bachelor's degree. Preferred mode, itself was not a significant variable in predicting low-carbon travel behavior.

4.3. Low-Carbon Behavior

The only community characteristic that had a significant effect on the odds that a respondent would engage in low-carbon travel behavior was access to public transportation. In the presence of access to public transportation a respondent was 189.9% as likely to engage in low-carbon travel behavior. Surprisingly, when a community offered a high-level of access to family, friends, and neighbors, a respondent was 59.4% as likely to engage in low-carbon travel behavior.

Values and beliefs had contradictory effects. A respondent who held a medium/high level of importance for places to walk proved, as expected, to increase the odds that an individual would engage in low-carbon travel behavior; such a respondent was shown to be 204.9% as likely to engage in low-carbon travel behavior. Meanwhile, a respondent who believed that they should walk or bike more was 47.2% as likely to engage in low-carbon travel behavior.

The number of motor vehicles available and number of functioning bicycles owned by a household has opposite effects, as was the case with climate change consideration. An increase in the number of motor vehicles (of one unit) resulted in a individual being 73.3% as likely to engage in low-carbon travel. Given a one-unit increase in the number of functioning bicycles in a household, the probability that an individual would engage in low-carbon travel was 117.7% as likely. The only other significant demographic that affected the probability of low-carbon travel was gender; if a respondent was male the odds of engagement in low-carbon travel was 151.7% as likely.

Consideration of climate change had no significant impact on the probability of engaging in low-carbon travel behavior. This conclusion is consistent with findings in the literature that showed that even support for climate change mitigation was not enough to impact low-carbon travel behavior (Ladd 1990 in Bord, 1998; Bord 1998). Similarly, preferred mode had no significant impact on the probability of low-carbon behavior. Though the literature suggested that preferences, along with opportunity and obligation, might impact behavior (Stradling et al. 2000 in Anable, 2005), preferences alone proved insignificant.

Table 8. Logit Regression Output

	Climate Change Consideration			Mode Preference			Transportation Modal Choice		
Variable Name	B	Exp(B)	Sig.	B	Exp(B)	Sig.	B	Exp(B)	Sig.
SOCIAL MID	.216	1.242	.219	-.253	.776	.354	-.196	.822	.498
	(0.176)			(0.273)			(0.289)		
SOCIAL HIGH	-.046	.955	.796	-.630	.533	.040*	-.521	.594	.082*
	(0.178)			(0.307)			(0.300)		
EDU MID	.167	1.182	.376	-.707	.493	.030*	.108	1.114	.743
	(0.189)			(0.327)			(0.330)		
EDU HIGH	.505	1.657	.009*	-.419	.658	.192	.100	1.105	.762
	(0.193)			(0.321)			(0.329)		
HOUSE MID	-.411	.663	.029*	.569	1.767	.058	-.055	.947	.868
	(0.188)			(0.300)			(0.330)		
HOUSE HIGH	-.299	.742	.074*	.158	1.172	.573	.092	1.096	.745
	(0.167)			(0.281)			(0.283)		
CULTURE MID	.098	1.103	.510	.054	1.055	.823	-.073	.930	.785
	(0.148)			(0.240)			(0.267)		
CULTURE HIGH	.352	1.422	.040*	-.381	.683	.188	-.146	.864	.631
	(0.172)			(0.290)			(0.305)		
SERVICE MID	-.160	.852	.373	-.100	.905	.731	-.110	.896	.744
	(0.180)			(0.289)			(0.335)		
SERVICE HIGH	-.311	.733	.138	.120	1.127	.723	.177	1.194	.625
	(0.210)			(0.338)			(0.362)		
IMPNS MID	.168	1.183	.395	-.211	.810	.524	-.568	.567	.142
	(0.197)			(0.331)			(0.387)		
IMPNS HIGH	.177	1.193	.274	.069	1.072	.802	.262	1.300	.332
	(0.161)			(0.277)			(0.270)		
IMPWALK MID	.509	1.664	.025*	.265	1.304	.536	.011	1.011	.981
	(0.227)			(0.429)			(0.465)		
IMPWALK HIGH	.614	1.847	.004**	1.224	3.400	.001***	.718	2.049	.096*
	(0.210)			(0.368)			(0.431)		
INTERACTIO N MID	-.236	.790	.277	-.276	.759	.454	-.059	.943	.896
	(0.217)			(0.369)			(0.448)		
INTERACTIO N HIGH	-.007	.993	.984	-.904	.405	.130	.230	1.259	.728
	(0.354)			(0.598)			(0.661)		
WALK MID	.053	1.055	.825	-.232	.793	.602	.597	1.816	.192
	(0.240)			(0.446)			(0.457)		

	Climate Change Consideration			Mode Preference			Transportation Modal Choice		
Variable Name	B	Exp(B)	Sig.	B	Exp(B)	Sig.	B	Exp(B)	Sig.
WALK HIGH	-.143	.866	.587	.462	1.587	.323	.756	2.130	.128
	(0.264)			(0.467)			(0.497)		
MOTOS	-.096	.909	.100*	-.103	.902	.343	-.310	.733	.010*
	(0.058)			(0.109)			(0.121)		
BIKES	.122	1.129	.004**	.069	1.072	.296	.163	1.177	.013*
	(0.042)			(0.066)			(0.065)		
PUBLIC TRANS	.049	1.050	.748	-.347	.707	.175	.642	1.899	.015*
	(0.152)			(0.256)			(0.264)		
GENDER	-.128	.879	.347	.272	1.313	.227	.417	1.517	.070*
	(0.137)			(0.225)			(0.230)		
INCOME	.000	1.000	.826	.000	1.000	.167	.000	1.000	.722
	(0.000)			(0.000)			(0.000)		
AGE	-.002	.998	.708	-.009	.991	.292	-.008	.992	.329
	(0.005)			(0.009)			(0.009)		
EDU	.410	1.508	.006**	.487	1.628	.072*	.459	1.583	.095*
	(0.148)			(0.271)			(0.275)		
BELIEVE				.229	1.257	.404	-.751	.472	.002**
				(0.274)			(0.242)		
IMP FEELSAFE	-	-	-	-.327	.721	.181	-	-	-
	-			(0.244)			-		
INCLEMENT WEATHER	-	-	-	.258	1.294	.485	-.396	.673	.293
	-			(0.369)			(0.377)		
RURALITY	-	-	-	-	-	-	-.304	.737	.233
	-			-			(0.255)		
PREDICT CONSIDER	-	-	-	-	-	-	.016	1.016	.953
	-			-			(0.264)		
PREDICT PREFER	-	-	-	-	-	-	.466	1.593	.703
	-			-			(1.221)		
Constant	-.430	.650	.269	-1.780	.169	.009**	-2.129	.119	.004**
	(0.389)			(0.681)			(0.739)		
	Consider	Don't Consider		Prefer	Don't Prefer		Low-Carbon	No Low-Carbon	
Predicted Correct %	68.9%	53.4%		3.9%	99.9%		5.9%	99.7%	

Note. * = Sig. < or equal to .100, ** = Sig. < or equal to .010, *** = Sig. < or equal to .001
Note. S.E. in parentheses.

4.4. Research Questions

These results of this paper are significant in their ability to inform communities, policymakers and transportation planners in the designing and planning of low-carbon communities. The remainder of this section examines the two questions initially posed at the beginning of this paper and offers guidance to the aforementioned constituencies for future community design decisions.

(1) Which specific characteristics, when offered by a community, might contribute to an increased probability of low-carbon travel behavior such as walking, biking, or the use of public transportation in northern rural climates?

In designing a low-carbon community in northern rural climates, the primary community characteristic that should be considered is access to public transportation. When a respondent had access to public transportation they were 189.9% as likely to engage in low-carbon travel behavior.

The ability for the provision of public transportation by a community to encourage low-carbon travel behavior is supported in the literature. Articles by Kitamura (1997), Ewing (2001), and Cervero and Kockelman (1997) have all shown that distance to bus stops, rail stations, and transit service intensity can influence public transit mode-share and the likelihood of an individual traveling by walking, biking or transit modes; however, all of these studies have taken place in either urban or metropolitan cities on the west coast of the United States. Another study of the more northern climate of Calgary, Canada demonstrated that distance to a light rail transit (LRT) station or bus stop will both encourage commuters to use transit; however, Calgary is far from rural with a population of 738,200 as of March 1994 (O'Sullivan, 1996). Similarly, the range that Canadians were willing to walk to a LRT station was between 300 and 900 meters, while the walking distance guideline used by the Niagara Frontier Transportation Authority in Buffalo, New York, another populous northern city, was 457 meters (O'Sullivan, 1996). O'Sullivan (1996) also found that commuters will not walk as great a distance to get to a bus stop as they will to get to a LRT station; this should be of particular interest to rural areas where there exists limited public transportation options (Rosenbloom 2002 in J. Kolodinsky, 2008).

The inability of other micro-accessibility indicators to influence the probability of low-carbon travel behavior was not supported in the literature, however, the majority of the literature on community characteristics' impact on modal choice and travel behavior, as previously stated, has taken place in large, urban U.S. cities. Given that over 70% of respondents in this survey characterized their area as rural, implementing the most effective form of public transportation to encourage low-carbon modal use in northern rural climates is crucial.

(2) Which community characteristics have the greatest impact on the probability of an individual's pro-environmental travel behavior when compared to their consideration of climate change and mode preference?

In examining the effects of these community characteristics on both the probability of climate change consideration and low-carbon travel behavior, there were no community characteristics that impacted all three dependent variables, nor was there a characteristic that impacted both consideration of climate change and low-carbon travel behavior. This makes a comparison of the odds-impact of any of the dependent variables impossible; however, what *can* be said about the community characteristics examined in this paper are that different characteristics impact different stages of the decision-making process in different ways, with regards to low-carbon travel behavior.

Though a consideration-behavior gap is evidenced through a greater percentage of individuals who responded that they considered climate change when they travel (52.7%) as compared to those who engaged in low-carbon behavior (10.4%), this gap will not likely be lessened through changing individuals' consideration patterns or through changes or even improvements to the community characteristics that only significantly and positively impacted the probability of such consideration.

While the high-level presence of both community characteristics of education, training, employment opportunities and cultural characteristics contributed to an increased probability of climate change consideration, these variables did not have any significant impact on the probability of low-carbon travel behavior. Concentrating on providing community characteristics such as housing or services will likely negatively impact the probability of climate change consideration but, again, not impact the probability of low-carbon travel behavior. Because climate change consideration proved not to significantly change the probability of low-carbon travel behavior, even if the probability of such consideration was increased in other ways, this would not increase the probability of low-carbon travel behavior.

The independent variable of a high level of ‘importance of places you can walk to’ was the one variable which impacted all three stages of the decision-making process. A high level of importance for places you can walk resulted in a respondents’ being 184.7% as likely to consider climate change, 340.0% as likely to prefer a low-carbon mode of transportation, and 204.9% as likely to engage in low-carbon travel.

5. CONCLUSION

Southworth (2005) noted that achieving low-carbon travel behavior will likely vary by culture, place, and city size, and this was supported by our research. Though access to public transportation nearly doubled the likelihood of a respondent engaging in low-carbon travel behavior, neither improving access to public transportation nor increasing the quantity of public transportation available would be the best solution for northern rural climates due to the high costs and geographical restrictions discussed earlier.

To successfully plan, design, or re-design a low-carbon community in a northern rural climate, with regards to travel behavior, it appears necessary to instill in our community members, the importance of places one can walk to. When respondents placed a high level of importance on places you can walk to, this resulted in an individual being over twice as likely to engage in low-carbon transportation behavior. This variable also served to encourage consideration of climate change and a preference for low-carbon modes of travel. Instilling such importance in communities around the U.S. is being accomplished in different ways.

One way this is currently being done is through Michelle Obama's Let's Move campaign which aims to increase opportunities for children to safely walk and ride to school, parks, playgrounds, and community centers among other locations. Such a program would both increase physical activity levels for children and adults, and could contribute to the dependent variables discussed in this paper (Let's Move!, 2010).

Another way the 'importance of places you can walk to is' being conveyed to communities is through Department of Transportation policies (DOT). In June 2009 the DOT, along with the Department of Housing and Urban Development and the Environmental Protection Agency, revealed the Interagency Partnership for Sustainable Communities which aims to expand transportation options while protecting the environment. This partnership places the needs pedestrians and cyclists alongside the needs of motorists and proclaims walking and bicycling as "an important component for livable communities" (Kambitsis, 2010).

A strong emphasis on the importance of places one can walk to will move northern rural communities in a direction in which they might be better prepared to address the constraints of a low-carbon future. More programs such as those stated here are necessary to further instill these values into communities in northern rural climates.

Future research is required to better understand other possible combinations of community characteristics, micro-accessibility indicators, and optimal land-use patterns that a northern rural community might implement in order to increase the probability of low-carbon travel behavior and why certain community characteristics did not encourage low-carbon travel behavior in this study, as they did in other regions. Additionally, though inclement weather was not a significant contributor to predicting low-carbon travel behavior in this survey, these results reflect the first stage (spring) of a four-season panel survey and thus, future research should examine how weather patterns may change low-carbon travel behavior over the course of different seasons.

Acknowledgements – I thank Jane Kolodinsky, Chip Sawyer, Erin Roche, and Thomas DiSisto for their help, guidance, and support throughout this research.

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