DISSERTATION

USING POPPY OIL FOR ENERGY IN AFGHANISTAN:
A LIFE CYCLE ASSESSMENT AND DIFFUSION OF INNOVATIONS APPROACH
TOWARD SUSTAINABLE LIVELIHOOD DEVELOPMENT

Submitted by

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Graduate Degree Program in Ecology

In partial fulfillment of the requirements

For the Degree of Doctor of Philosophy

Colorado State University

Fort Collins, Colorado

Summer 2014

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ABSTRACT

USING POPPY OIL FOR ENERGY IN AFGHANISTAN: A LIFE CYCLE ASSESSMENT AND DIFFUSION OF INNOVATIONS APPROACH TOWARD SUSTAINABLE LIVELIHOOD DEVELOPMENT

The past 10 years of war in Afghanistan, which was preceded by nearly 40 years of conflict, has brought Afghanistan to an interesting crossroads. Instability and lack of infrastructure have led to challenges in resource governance increase community resilience. Research and development are urgently needed in Afghanistan to create solutions to meet the humanitarian needs of people in developing and post-disaster/conflict areas in order to promote and maintain stability. In the past, many issues facing the country, such as poverty, illiteracy, and food insecurity, were discussed as if they were disconnected and separate challenges. Yet, the cornerstone in discussions of development in Afghanistan almost always focuses on agriculture and the impact of *Papaver somniferum*, poppy, cultivation for the production of opium and heroin while ignoring non-traditional solutions. For example, poppy seeds contain a large fraction of oil, which is practical as a fuel. Oil from poppy can be used to provide rural farmers (approximately 75% of Afghan citizens) with a straight vegetable oil energy source to power slow diesel generators for village electrification.

In this study, I address the need for development in Afghanistan by investigating the potential for using poppy seeds as a mechanism for transitioning farmers to alternative livelihoods. In this approach I address three key issues by showing, first, that the oil extracted from poppy seeds is a viable renewable energy source that can run slow diesel generators and that reduces the environmental and health hazards of diesel emissions. I present a life cycle

assessment of the production and use of straight vegetable oil extracted from poppy seed with the primary goal of comparing on-farm versus regional production in terms of energy output and greenhouse gas emissions.

Second, I then present a means of producing a straight vegetable oil (SVO) fuel from poppy seeds by evaluating the utility of the co-products and describe the methods of using a manually cranked oil expeller that results in recovering approximately 80% of the available oil. Third, I present a theoretical framework with poppy SVO as the product to introduce this new intervention.

A model of the energy system is developed, based on the Argonne National Laboratory life cycle assessment tool, GREET, and includes agricultural production and transport inputs and outputs. Two cases for the production and use of the poppy seed-derived SVO are modeled: (1) an energy system in which individual farmers harvest poppy seeds, extract oil, and use the oil on-farm; and (2) an energy system in which groups of farmers harvest their seeds, then send the product to a regional extraction mill for the oil to be returned to farmers, households, and/or blenders. I model a total of 24 scenarios based on energy production, inputs, emissions and the impacts of fertilization.

The poppy oil was filtered and tested for oxygen stability, speed of sound, density, kinematic viscosity and bulk modulus. Nutritional testing was conducted for protein and energy, and also for use as a soil amendment. Thirdly, I developed a social-ecological system framework to provide a road-map for the implementation of transitioning farmers to alternative livelihoods with the farmers at the center of these changes with non-governmental agencies playing active supporting roles with local and regional governments.

I determined that the on-farm scenario would be GHG-neutral and almost all of the available energy of the poppy seed oil would be available for use, resulting in a maximum energy return on investment (EROI) of 2,800. Other transportation scenarios were calculated to have a GHG content and EROI ranging from 1.5-240 kg GHG's and 0.27-1,300, respectively. The oil had favorable fuel characteristics (cold filter plugging point of 292 K (s_d =0.231); speed of sound 1,470 m/s (s_d = 0.0283); density 0.919 g/cm^3, and kinematic viscosity: 27.9 mm^2/s). The resulting crushed seeds proved acceptable as an animal feed (19.4 MJ/kg; 33.3% protein) and soil nutrients (21.1 ppm N, 340 ppm P and pH: 6.5).

A point in the progress of development in Afghanistan is to recognize and capitalize on the similarities of sustainability and adaptation have in discussions of governance in both innovation diffusion and environment in the development field. Specifically, discussions on increasing access to energy innovations which often involves understanding the environmental trade-offs in terms of emissions and land-use change. The literature describes transportation distance as the major contributor to energy and emissions in energy production distribution, my work showed this to be especially evident. A number of frameworks have been presented to outline the governance/management practices that need to be in place to deal with the major impacts on natural resources and resource adaptation for societies and environments. The literature continues to support the interdisciplinary route of including governance/co-management strategies. Thus, rather than focusing on the economics of exporting the poppy oil in my project, the oil can be used as a peace building and partnership based resource. Access to energy in the rural areas of Afghanistan remains a development challenge. Sustainable production and use of a readily abundant energy source could provide a much needed improvement in energy access for the remote farmers of Afghanistan. The results of this study suggest that on-farm SVO production and use is a sustainable alternative to the regional energy production models from the perspective of GHG emissions and energy efficiency. As the fuel and its co-products are being proposed as resources to be used locally and improve life within the villages, there is a value for the local people/partners in bolstering of self-sufficiency and independence that can truly foster the partnership among stakeholders that is a barrier in other proposals of developmental outreach.

PREFACE

In summer of 2011 I began reaching out to sources I had the most accessible access to who would be able to help us in information gathering on-the-ground in Afghanistan. I made use of contacts with the U.S. Navy, U.S. Marines, U.S. Department of State along with personal contacts, community groups, aid agencies and Rotary Clubs to initiate communication with people in Kabul. By November 2011, I was able to secure a visa for travel and to meet with contacts at the University of Kabul, Rotary Club of Kabul, Afghanistan's Ministry of Agriculture, Horticulture and Livestock Program and rural farmers. Once on-the-ground, these contacts extended to USAID affiliates, area citizens, farmers, store owners and political officials.

In-Country Discussions

Among the citizens I met with, the topic of poppy in Afghanistan at the local level is described as hardly different from the U.S. marijuana debate: Should poppy be legalized because the majority of people already incorporate it in their lives so regularly for both licit and illicit means? From my time in Afghanistan, I learned from citizens, business-people, farmers, as well as non-governmental organizations (NGO) and governmental staff that there are key missing pieces to the functioning of sustainable development in Afghanistan. Topics of our discussions and meetings ranged from daily life, needs for energy, water and food access to personal/professional interactions and observation of opium production, agricultural challenges, ideas and capabilities to address opium and daily life challenges.

In-country Working Conditions and Political Climate

The primary goal of my in-country expedition was to engage in discussions to gain a better understanding of the interest in the creation of a poppy oil fuel. Poppy production in Afghanistan is nearly exclusively linked to the illicit opium market; for safety concerns, my discussions in country were in the form of ‘rapid assessments’ and by which I followed these guidelines:

Never making appointments more than 24 hours in advance;

1. Keeping to an irregular ‘schedule’;
2. Taking different routes to/from apartment in the city among the populations;
3. Conducting discussions in confidence and taking notes as conditions allowed.

I made most useful and insightful observations of a number of local people while commuting, in brief meetings in schools and discussions at night time during excursions at night in the streets of Kabul. The timing of my observation trip came during a time when coalition forces were still heavily relying on the use of regular night raids, drone strikes, and on high alert after the siege by the Haqqanni [terrorist] Network on the U.S. Embassy in Kabul (Sept 2011). I departed just before the Koran burning incident at Bahgram Air Force Base (Feb 2012) and before the spate of riots on the streets of Kabul, followed by the brazen attack on foreigners at a resort just outside of Kabul (June 2012).

Lessons Learned to Motivate the Framework

I found that the connection between the government and resource users fails to provide services the people feel they need. Some of the services the state is providing are not necessarily desired by the people. This not only leads to a waste of resources (financial and otherwise), but also a level of frustration for all parties, increases lack of trust and a feeling of un-fulfillment for both parties. A specific example is the challenge of agricultural fertilizer. The Ministry of Agriculture is not authorized (nor likely capable) of monitoring the quality of fertilizers imported into the country. Additionally, the Ministry is not authorized to ‘advise’ or make recommendations to citizens on soil amendments. Thus, although the Ministry may provide basic soil testing (soil nutrients, texture, pH), the Ministry does not provide farmers who receive these results as much guidance as some believe is needed. Various agencies such as World Bank and USAID are providing resources for the agriculture community, however, not as widespread or robust enough for the demand, resulting in additional 3rd party actors who often sell false-fertilizer to farmers who have no other choice, no recourse and little ability to negotiate, nor a governing body to regulate on their behalf.

Under these conditions, I believe there is an opportunity for poppy to be a transition to alternative livelihoods. The question of the capability of a biofuel to be a catalyst in the transition, I argue, depends primarily on the presentation and motivation. If the fuel is solely presented as an opaque attempt at gagging resistance to new alternatives to poppy farming or an attempt to buy local support to cease opium production then, there is clearly only a minimal chance for this or most any other attempt to transition. However, presenting transition ideas as opportunities for joint relationship building and/or tribal and national sustainability and self-sufficiency would provide an honest acceptance of the on-the-ground realities the people are most concerned with. The recognition of the ubiquity of the opium trade and its likelihood of continuing would allow transition projects to get past the barriers to collaboration thereby providing an opportunity for technological and educational engagement toward an approach that truly is concerned with the health and well-being of the people and nation. As a result, I could widened the selection of people who I can engage in steps toward adoption and transition farmers to other alternatives and to forge understanding and trust, which are the basis of alliances and progress.

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Chapter 1. Introduction

Research and development are urgently needed in Afghanistan to create solutions to meet the humanitarian needs of people in developing and post-disaster/conflict areas in order to promote and maintain stability. In response, the Afghan government has recently begun investigating options such as energy derived from renewable resources (i.e., wind, solar, biomass, geothermal) (Milbrandt and Overend 2011). However, given the turmoil of the last many decades in Afghanistan, the governance system and infrastructure to support projects such as these is likely to be years, if not decades from development and implementation (Milbrant and Overend 2010). Opium poppy cultivation in Afghanistan continues to challenge public health, environmental quality, regional stability and global security. Efforts to reduce the growth and sale of illicit opium and its derivatives have been unsuccessful and in some cases counterproductive. My work considers the feasibility of using Afghan-grown poppies to produce a biofuel that could power slow diesel engines and help provide a peaceful transition to high value crops such as camelina while increasing regional public health, environmental quality, security, and economic growth in Afghanistan.

In this research, I provide evidence that synthesizing biofuel from poppy oil is feasible from an emissions and energy return on investment perspective by developing a suite of life-cycle assessment models (Chapter 2). In chapter 3, I describe the fuel characteristics of opium poppy oil and the properties of the co-products after extraction. I then develop a theoretical framework for the implementation of this innovation which, while specific to poppy production in Afghanistan, could easily be modified for other products in other countries facing disparities in resource management and innovation between national policies and local resource users (Chapter 4). My work here presents a unique approach for addressing a number of the issues involved in the looming policy, leadership, energy and implementation challenges Afghanistan continues to face.

There is an emerging viewpoint that it is unrealistic to attempt to stop Afghan farmers from growing poppies (*Papaver somniferum*) without an alternative that is at least as profitable as selling opium. Growers in Central Asia and, to a lesser extent, Latin America, South America, and Southeast Asia, supply the global illegal opium market (UNODC 2009). At the height of Afghan opium output following the overthrow of the Taliban, Afghanistan provided 92% of the world's illegal opium supply (UNODC 2009). After a poppy blight and various counternarcotic measures, production decreased, but the United Nations (UN) estimated that the Afghan contribution in 2011 was about two-thirds of the global supply (UNODC 2011). The illicit trade of opium and its derivatives is complex due to the geo-political and social instability in the region and the underground nature of the business.

In Afghanistan, there is a strong negative correlation between the security of each province and the amount of poppy cultivated within. The least secure and highest poppy producing areas are in Helmand province (UNODC 2011), the traditional Pashtun homeland in Afghanistan, which borders the highly unstable Pashtun homeland territories in Pakistan.

Opium comes from the dried sap (also called opium tar or latex) of poppy seed pods and can either be smoked in its raw form or chemically refined into morphine, codeine, heroin, and various semi-synthetic opioids (UNODC 2009; U.S. Dept. Justice 1992). Farmers make vertical slits in the poppy seed pod and subsequently collect the opium tar until the seed pod has been completely tapped (U.S. Dept. Justice 1992). This process requires a considerable amount of manual labor, and migrant workers within Afghanistan travel around the country to earn meager wages as day laborers doing this. Migrant workers are often students, soldiers, farmers from other areas and, increasingly, internally displaced persons (IDPs) who use the poppy harvest season (from late spring to early fall, depending on the altitude at which the poppies are grown) to earn money (U.S. Dept. Justice 1992).

The illegal opiate trade threatens security, governance, public health, development, and millions of human lives worldwide. Furthermore, Afghanistan can never become a sustainably functioning state if the opium trade continues to support insurgent networks while keeping the Afghan farming majority in a state of poverty (Van Ham and Kamminga 2007). Past policies have shown, however, that attempting to stop poppy farming at the source will *not* increase stability in Afghanistan (UNODC 2011).

Instability has prevented much needed development in Afghanistan. It is widely accepted that access to electricity, a primary requirement for communication, lighting, and small-scale industries, is a major driver of economic development and social prosperity. Rural electrification, thus, directly addresses poverty reduction and overall quality of life (Rive and Rübbelke 2010; Zheng, Li et al. 2010; Malla, Bruce et al. 2011; Karekezi, Lata et al. 2012). In lieu of electricity, many of Afghanistan's citizens use biomass for their daily energy needs. In Kabul, aid workers have reported acute firewood shortages in and around the city and ordinary households in rural areas often lack sufficient fuel for heating, cooking and other agricultural energy needs. Outside of the cities, biomass solid fuels are likely to remain the fuel of choice until other options are made available (Milbrandt and Overend 2011). Across the country, the use of biomass resources is almost complete at 90% (Milbrandt and Overend 2011) providing evidence that a decentralized, village-level introduction to a new energy source would be perhaps the one successful route toward village electrification. The U.S. Department of Energy's (DOE's) National Renewable Energy Laboratory's (NREL) researchers reported that the Afghan government is investigating options such as energy derived from renewable resources (wind, solar, geothermal) (Milbrandt and Overend 2011).

It is important to understand that Afghanistan's large contribution to global drug markets is not a recent phenomenon. Opium has been grown in Afghanistan and the surrounding region since roughly 3400 B.C. and has always provided great wealth and power to those who could control its trade (Ray and Kattimani et al. 2007). Large crop yields of opium poppies were a valuable asset to any rising empire and the small clans of people living in what is now Afghanistan became accustomed to regularly defending their land against neighboring empires. The large global demand for opium has often been a major contributor to Afghanistan's long, turbulent history of violent conquest, tribal uprisings, foreign occupation, and austere military rule.

Tragically, opium has not benefited the Afghan farmers who grow it. While the growers earn, on average, $8.90 (USD) per day per household from growing opium, the opium they produce supplies nearly two-thirds of the $68 (USD) billion global illicit opiate industry (UNODC 2011). Despite the vast profits enabled by Afghan-grown opium, Afghanistan remains one of the poorest countries in the world, and is heavily dependent on foreign aid. Nearly 85% of Afghans work in agriculture (OUNCA 1999) with opium poppies as one of the most abundant crops (UNODC 2011). While the Taliban used cruel and violent means to successfully ban poppy cultivation in the 1990s, the international community now associates a growth in Afghan poppy production with an increase in insurgency. The U.S. government and other aid-providers are closely monitoring Afghanistan with concern that the illicit sale of Afghan opium is helping to fund terrorist networks (Glaze 2007).

One of the most fundamental economic concepts is the inelastic demand curve, which describes how the demand for a certain commodity stays relatively stable regardless of price changes. Addictive drugs like heroin and other opiates fall under this category, which sheds some light on why certain aspects of eradication attempts have failed. Cuts in supply increase prices with next to no change in demand. The market becomes more profitable and thus more attractive for prospective suppliers. Thus, attempts at poppy eradication have resulted in *more* poppy cultivation.

The cost and uncertain supply of energy also drive the illicit opium market. The price of imported diesel in Afghanistan changes frequently, but it is usually much more than most Afghans villages can afford. The diesel supply is also susceptible to shortages and price shocks, which prevent economic growth and stability (Paterson 2005). High costs of fuel continue to limit transportation and contribute to the lack of mobility, education, and access to information that Afghans have experienced since the Taliban destroyed and blocked off most of the country's infrastructure. Difficulties and dangers of transportation within Afghanistan are also why the Taliban has been so successful in controlling the illegal opium supply. The farmers sell their poppies at the farm-gate because they cannot afford the expenses and safety risks of traveling to market. As such, it is imperative that Afghanistan locates stable energy alternatives with a lower price and a more consistent supply.

These interlinked challenges are especially marked in Afghanistan, which is home to the largest international supply of illicit opium and where illicit narcotics play a major role in the economy and culture. Illicit opium production has been estimated at nearly 50% of the country's gross domestic product (GDP). Moreover, in a 2010 report by the United Nations Office of

Drugs and Crime (UNODC), it was estimated that from 2005 to 2010, the number of opium users in Afghanistan grew by 53% (UNODC 2010).

Opium is inextricably linked with Afghan history and tradition. Efforts to institute reform in Afghanistan by going directly against established traditions have failed, just as they failed for numerous ancient and recent empires. Afghanistan's population is multiethnic, culturally diverse and, often, factionalized. However, most Afghans have religion in common as 80% of Afghans are Sunni Muslims (OUNCA 1999). Nearly 75% of Afghans work in agriculture, and poppies are one of the most common crops produced (UNODC 2011, OUNCA 1999). In short, opium poppy farming may be inevitable but the way the seed pods are traded and utilized can move towards a system that benefits Afghan farmers *and* increases state capacity.

Forms of legal opium include morphine, codeine, and thebaine-based prescription pain medications, along with other semi-synthetic drugs (molecularly altered derivatives of natural opium components). The vast majority of the world's legal opium supply comes from Australia, Turkey, and India. U.S. laws stipulate that 80% of imported opium must come from India and Turkey while European countries typically import medicinal opium from Australia (UNODC 2011). Every opium-importing country must submit annual reports to the United Nations for transaction audits and opiate industry regulation. The limited supply of licensed opium growers and pharmaceutical companies that can legally purchase opium results in consistently high medicinal opiate prices, and a supply that cannot meet the demand.

Based on research conducted by the Afghanistan Research and Evaluation Unit (Pain 2006), a group of researchers at the Los Alamos National Laboratory's Intelligence Division created a simulation modeling the supply chain of the Afghan/Pakistani opium trade, starting in

Helmand province in southern Afghanistan—the largest opium contributor of all the Afghan provinces—and following the trade routes and synthesis of opium into heroin (Watkins and MacKerrow et a. 2010). Over 59% of Afghanistan's opium is produced in Helmand province (UNODC 2011), and in 2007 Helmand farmers planted the largest recorded provincial opium crop in Afghanistan thus far—an astounding 102,000 hectares (UNODC 2011). While fewer hectares are farmed now than in 2007, Helmand province is still the epicenter of opium cultivation in Afghanistan.

Ultimately, involvement in the illegal opium trade is more profitable than other available income sources, but not by much, especially for those involved in the first few steps of the supply chain (Watkins and MacKerrow et a. 2010). There are also many risks, financial and otherwise, at each step of the process. This is good news as it would not be difficult to steer most of the farmers, traders, and processors away from the illegal opium trade if one could devise an alternative that is even slightly more profitable. The real challenges would be keeping up with the rise in opium prices after the sharp decrease in supply and managing the Taliban's response to major cuts in their income.

Poppy crop elimination is a complex issue, as both insurgent groups and impoverished farmers have become increasingly reliant on income from the illegal opium market. The Afghan drug economy generates about 50% of Afghanistan's GDP, or $2.8 billion (USD), and almost three million Afghans depend on poppy cultivation as their sole source of income (Van Ham and Kamminga 2007). These staggering estimates suggest that eliminating such practices would be extremely difficult and doing so would destroy the livelihood of many Afghans (UNODC 2011, OUNCA 1999). Thus far, approaches to limiting the drug trade in Afghanistan seems to have been as ineffective as they have been misguided.

Although international and Afghan counternarcotic policies have changed in the last few years, past eradication efforts by the U.S. and the Afghan governments have further complicated and exacerbated the illegal opium situation. In 2005, the U.S. Drug Enforcement Agency's Central Poppy Eradication Force only managed to destroy 250 hectares of poppy crop representing less than one percent of the land used for poppy cultivation (Van Ham and Kamminga 2007). During the same year the Afghan government destroyed 5,000 hectares representing about five percent of the total poppy cultivation land. An analysis of the first stage of internationally-driven poppy eradication efforts in 2005 stated that "the first real, nationwide, massive eradication campaign has been counteracted by a bumper harvest of more than 6,100 tons of opium, an increase of 49 percent from 2005 and an all-time high" (Van Ham and Kamminga 2007). The same report noted that although 15,300 hectares were eradicated in 2006, cultivation nonetheless increased to 165,000 hectares.   Poppy eradication is not only ineffective, but also counterproductive.

UNODC now reports that increasing security and aid are much more effective than attempts to eradicate poppy fields and the U.S. government has also adopted this view (UNODC 2011). According to a 2010 U.S. Senate counternarcotic report for Afghanistan, efforts have shifted from simply eradicating poppies and poppy fields to fostering "sustainable alternative licit economic opportunities" and developing "increasingly self-reliant and effective counternarcotic law enforcement entities (US Senate)." The strategy focuses on programs "1) breaking the narcotics-insurgency-corruption nexus and 2) helping to connect the people of Afghanistan to their government (US Senate)."

While my plan to use poppy oil as a biofuel and incorporate its co-products in this manner in Afghanistan is unprecedented, using locally produced straight vegetable oil (SVO) as a fuel source is not a novel idea. Numerous research and international development groups have successfully established biofuel programs in rural areas of developing countries. These projects, like ours, aim to reduce the costs of fuel and provide a consistently renewable source of energy which, in turn, results in increased economic stability and political/social partnerships.

The rush to generate renewable forms of energy often neglects developing areas of the world. I propose using the oil extracted from poppy seeds grown in Afghanistan to produce biofuel. This endeavor would allow farmers in rural and developing areas to provide their own fuel while simultaneously improving public health, transportation, security, and the local economy.

The chemical composition and physical properties of the oil extracted from the opium poppy makes it a viable option for use as a biofuel. Changes in political stability and the market price of diesel may affect the response to such an initiative as well as its expected outcomes. While political stability is critical, it should not be the determining feature or characteristic of scientific research. In fact, politically and economically unstable regions are precisely where scientific contributions to public health and the environment are most needed. Similar research has shown that creating and using straight vegetable oil biofuels in rural areas is realistic and sustainable.

The advantages of implementing a project such as this are numerous. Afghan famers already know how to cultivate and harvest opium poppies, and poppy oil is easy to extract and filter into a biofuel. The initial expenses of installing dual fueling engine systems and providing seed crushers will be offset by permanently reduced fuel costs. Reduced use of expensive, imported diesel will reduce health risks to the local population by improving air and soil quality and allow for greater agricultural yields. Increasing the net incomes of the farmers will expand the Afghan economy and if the farmers can sell excess biofuel to others in the area, Afghanistan can reduce its dependence on foreign aid and increase opportunities for foreign direct investment.

The need to undertake alternative routes to developmental and socio-politically sensitive approaches to governance and natural resource use in Afghanistan continues to be a major failure in the international community. Controversies surrounding the incorrect handling of Qur'an burning fueled a new wave of violent interactions between U.S. soldiers, and Afghan civilians and insurgents. Insurgent groups are continuing to capitalize on anti-American/anti-Western sentiments. Diplomatic relations between the United States and Afghanistan are extremely tense. With the drawdown of NATO and allied troops slated for late-2014 with Afghan President Karsi refusing to sign a NATO security agreement, my project has the potential of winning the hearts and minds of the people who matter the most by leaving the agricultural sector of Afghanistan something other than promises and bomb/bullet ridden fields to remember the international community.

In the chapters that follow I provide evidence that synthesizing biofuel from poppy oil is feasible from an emissions and energy return on investment perspective by developing a suite of life-cycle assessment models (Chapter 2). In chapter 3, I describe the fuel characteristics of opium poppy oil and the properties of the co-products after extraction and discuss issues of using poppy oil in slow diesel engines for energy production. I then develop a theoretical framework for the implementation of this innovation which is specific to poppy production in Afghanistan to address resource management and innovation challenges between national policies and local resource users (Chapter 4).

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Chapter 2. Life-Cycle Assessment of Poppy Straight Vegetable Oil Fuel Production: A Case for Small-Scale, Local Use, and Production

1.0 Introduction

Access to energy is a global challenge that has been a special difficulty in Afghanistan.). A recent report highlighted the benefits to Afghanistan of the development and implementation of a comprehensive energy strategy as the country seeks to overcome its many challenges in reconstruction and development (Milbrandt and Overend 2011). The instability of the country has resulted in a fragmented energy distribution system that relies on imported petroleum to power generators for limited electricity supply. This incomplete and often damaged distribution system has meant that thousands of remote villages are economically out of reach of connection to the electrical grid, or experience severe and unpredictable shortages of electricity.

In lieu of electricity, many of Afghanistan's citizens use biomass for their daily energy needs. In Kabul, aid workers have reported acute firewood shortages in and around the city, and ordinary households in rural areas often lack sufficient fuel for heating, cooking and other agricultural energy needs. Outside of the cities, biomass solid fuels are likely to remain the fuel of choice until other options are made available (Milbrandt and Overend 2011). Across the country, the use of biomass resources is almost complete at 90% (Milbrandt and Overend 2011). The Afghan government is investigating options such as energy derived from renewable resources (wind, solar, geothermal), but clearly these options would take years to bring to an operational status (Milbrandt and Overend 2011).

Given the role that electricity can play in the socio-economic status of the rural population, decentralized power generation with renewable energy sources could play a key role in electrifying remote villages. Unmodified vegetable oils ("straight vegetable oil", SVO) have been shown to have fuel properties (Misra and Murthy 2010; Fore et al. 2011; Sidibe et al. 2010; Altin et al. 2000) that enable them to be used in slow diesel engines for stationary applications (Milbrandt and Overend 2011). The slow diesel engines that would be most suitable are simple, closed crankcase designs. The engines operate on four-stroke principle and at relatively low speeds of 1000 rpm and are easy to maintain, economical to operate, and need minimal replacement of spare parts. The engines are widely used for pumps for irrigation purposes, flour mills, and rice hullers.

Poppy seeds contain high-quality oil, which is well suited for combustion (Tiwari and Ghosal 2005; Aksoy 2011; Aksoy 2011), having a higher heating value of 39.6 MJ/kg, density of 893 g/L, and viscosity of 42.4 mm^2/s. In comparison, petroleum diesel has a higher heating value of 44.6 MJ/kg, density of 854 g/L, and viscosity of 1.9-4.1 mm^2/s. Although poppy is not a perfect replacement for diesel, poppy oil has fuel characteristics that compare well to well-known oil seed crops such as camelina (higher heating value of 39.1 MJ/kg, density of 925 g/L and viscosity of 28.9 mm^2/s) and soybean oil (higher heating value of 39.6 MJ/kg, density of 914 g/L and viscosity of 65.4 mm^2/s). In addition to use as an SVO fuel, poppy seed oil can be blended with diesel or converted to biodiesel and is thus a useful, fuel source (Tiwari and Ghosal 2005; Aksoy 2011; Aksoy 2011).

While unorthodox as a fuel source, poppy is a crop known to farmers in this region and presents a stable production opportunity. Energy production from poppy seed SVO may be more energy-efficient and less carbon-intensive than from other biofuels, since the production of SVO does not require the resources and energy inputs of conversion processes such as transestrification (the use of ethanol or methanol in the deprotonation of vegetable oil triglycerides to make biodiesel). However, only a few studies exist about the environmental impacts of poppy production chains, and the energetic benefits and production system comparisons have not been investigated. Reliable information on the impact of production, in terms of basic net energetic and environmental impacts of poppy seed-based oil production, is needed.

Life-cycle assessment (LCA) has been established as an important tool in assessing the impacts of biofuel production (Consoli 1993; Lindfors 1995). Whereas many LCAs take an 'absolute' approach, I developed a *relative* LCA to address the goal of this study, which was to compare on-farm versus regional production in terms of energy output and greenhouse gas emissions by examining a set of scenarios (combinations of low/high harvest area and low/high yield intensity) for SVO production from poppy seed oil crops as a potential local energy resource. Outcomes of emissions and net/gross energy output were obtained using "Well-to-Pump" (Field-to-Pump) LCA modeling. The distribution of production plants and physical location, and comparison of the environmental burdens associated with small- or large-scale production, are aspects that "have hardly been considered for biodiesel production from a LCA perspective" (Iglesias, Laca et al. 2012); this statement is even more applicable for SVO.

2.0 Methods

2.1. Site Description

To develop my relative LCA, I modeled a theoretical site in Afghanistan, which is mostly mountainous and has a dry continental climate. The variance in terrain and elevation results in different climate types, allowing for the growth of poppy plants across the country; however, the majority of the poppy farming is done in the southern provinces. Some portions in the country's eastern Indus valley experience southeastern monsoons and subtropical climate. At 900 m, the annual precipitation is under 100 mm and the climate is hot and dry, while at elevations between 900 and 1,300 m above sea level exhibit hot summers and annual precipitation under 200 mm.

From 1,300 to 2,400 m above sea level, the climate is almost temperate with annual precipitation of up to 400 mm. The northeastern, central and high-altitude (2,400 m above sea level) regions of Afghanistan tend to have very long winters (Milbrandt and Overend 2011).

The terrain in most rural parts of Afghanistan is rugged and mountainous, and it is challenging to cover long distances without a reliable truck. Approximately 70-80% of the 31 million population are farmers or herders who live in villages outside of the major cities (UNEP 2009) working 12% of the 652,225 km^2 land that is arable, of which 6% is actually cultivated (UNEP 2009). These farmers typically use a mixed crop and livestock cropping system (Milbrandt and Overend 2011). The average farm size is 2.8 ha in non-irrigated areas, and 1.4 ha for areas farmed in pockets of irrigable land. Land ownership and tenure is communal grassland and urban land tenures (Watkins, Mac Kerrow et al. 2010) and only one crop is grown per year, due to the short growing season in higher elevations (> 2000 m) (SEI 2009).

2.2. LCA Model and Analyses

2.2.1. LCA Model

Our life-cycle analysis was based on the Greenhouse gases, Regulated Emissions, and Energy use in Transportation (GREET) model developed by Argonne National Laboratory (ANL 2012). This model was used to calculate the energy use and greenhouse gas (GHG) emissions generated during the entire process, from harvesting poppy seeds to producing the SVO for combustion in an engine. The GREET (Beta) version 1.0.0.8376 was used for all calculations. For simulations estimating the Well-to-Pump (Field-to-Pump) component, inputs were managed in two stages: (1) GREET (Beta) parameters (fuel properties, environmental farming inputs and transportation requirements) and (2) production regime scenarios (Farming: fertilizers, irrigation, farming equipment; System: harvest area, harvest (yield/hectare); Transportation: field-to-plant, plant-to-distribution). For overall comparison, GREET calculates greenhouse gas equivalents.

Next, I calculated energy return on investment (EROI = energy available ÷ energy input) with energy input equal to 1 for the on-farm scenarios to avoid division by zero.

2.2.2. LCA System Boundary

The relative LCA system consisted of the relevant processes necessary for fuel production, and included only production and transport to simplify the model (Fig. 1). The cultivation of poppy, the transportation of the poppy seeds and use of power in farming were the same for each scenario with the exception of the on-farm model (since there is no transportation for the on-farm model), which does not require intermediate transportation, and therefore were neglected (Fig. 2). Since the production of the biofuel feedstock does not introduce crop-based land-use changes, my comparative analysis begins at harvest, the point at which the scenarios diverge. The LCA model includes the transportation of the seed from field to extraction plant ("well-to-plant"), and of the oil to the villages ("plant-to-pump"), in the total "Well-to-Pump" model. The farmer-transport phase includes all round trips involved in accomplishing the delivery to site for the regional (centralized) model. The SVO production phase includes the extraction of the oil from the seed as well as filtration that yields the final product. The calculations were normalized to the production of 1 GJ of energy (64.4 kg of poppy seeds).

2.2.3. Poppy Seed Production and Harvesting

In Afghanistan, the seeds of the majority of poppy fields are rarely collected as they are generally considered a waste by-product and remain the field. Based on descriptions of farming practices by farmers and hosts from the Afghanistan Ministry of Agriculture, Irrigation and Livestock, farming practices typically leave residual poppy biomass, including seed, in the field (Mourning-Star 2014). The seeds are thus available for SVO production. Agricultural cultivation and harvesting is done primarily by manual labor, with livestock used when possible. Only rarely are tractors or machines available, and thus any fertilization and irrigation is normally accomplished by hand.

2.2.4. Extraction and Refining

The extraction and refining of the poppy oil is described in depth elsewhere (Mourning-Star and Reardon 2014). Briefly, the extraction process involves crushing poppy seeds using a manually cranked Piteba ™ oil expeller that separates the seeds into oil and a crushed seed mash referred to as presscake. Refining is the process of filtering the oil to remove large pieces of poppy seed that may have passed through the expeller. The manual nature of these processes effectively means that they require no energy input and produce no emissions. For this analysis, oil is the product and the presscake (animal feed) is the co-product. However, the final use of SVO (electricity production in a generator) and presscake were not included in this comparative LCA. Based on expeller experiments (Mourning-Star and Reardon 2014), I estimated that 40% of the dry seed weight could be extracted as oil with an estimated 2% loss during transportation from crop harvest to extraction and a 3% loss during the oil extraction process.

2.2.5. Scenario Descriptions

For the purposes of this study, it was presumed that poor rural farmers do not add fertilizers and that production is targeted toward farming land that already has access to livestock labor. Thus, the base case is no fertilization and no herbicides. I used four parameters to describe 24 different scenarios (Table 1): transportation distance, farm size, yield, and fertilizer usage.

The effect of on-farm vs. regional production was evaluated using four transportation parameter values: 0 (on-farm), 5, 10, and 25 km (regional). These were created to compare the impacts of the different production strategies because transportation can play a large role in energy and emissions in production and distribution. The regional distances were modeled as five farm sites situated equidistant from an extraction plant. The three options place the extraction plant 5, 10, or 25 km from the farms, thus requiring a transportation plan for the distribution of the harvested seeds and extracted oil. Transport of seeds to the extraction plant, SVO extraction, processing, and SVO transport from the extraction plant back to farms are included in the transportation stages considered here. The transport subsystem does not include the manufacturing of vehicles and SVO transport to a “commercial” point. The impact related to the roads is also excluded, as these would not be explicitly constructed for the transport of the product of the system analyzed.

Farm sizes of 0.4 and 20 ha were used based upon my research of the size that individual farmers may access and have decision-making power to exercise. Tenant farmers may have around 1 ha, while midlevel land-owning farmers may be willing to consider 20-ha plots.

The estimation of yields was calculated on a per-hectare basis. Since poppy production is primarily an illegal venture in Afghanistan, accurate harvest yields are nearly impossible to verify. For this study, I used two realistic harvest estimates of 1,750 and 3,750 kg/ha in harvested poppy seed. These numbers were based on suggestions by Duke (1983).

In addition, I compared two fertilization schemes. For the low-hectare, high-yield scenario on-farm (0 km transportation distance) and the high-hectare, low-yield scenario at the 10 km transportation distance, a basic soil amendment of 11.3 kg/ha nitrogen, 40.0 kg/ha phosphoric acid, and 45.5 kg/ha potassium oxide was evaluated (Table 1, scenarios Q and R, respectively). Finally, four additional scenarios (Table 1, scenarios U,V, W, and X) in which 2,270 kg (2,706 L) of petroleum diesel was transported by truck from a storage depot 100 km away for each of the distance scenarios (0, 5, 10, and 25 km).

3.0 Results and Discussion

3.1. Poppy Seed SVO Energy Production

The GREET (Beta) model was used to simulate a total of 24 scenarios (Table 1). In all cases, the model outputs discussed here only take into account activities from harvest to the point at which the poppy SVO would be used and thus do not represent the complete energy consumption and emissions amounts. Scenarios A, E, I and M (low-harvest area/low yield) were found to yield approximately 26.4 GJ of energy (745 L poppy seed SV0), while the scenarios C, G, K and O (high-yield area/low-harvest) would be expected to produce 1,320 GJ (37,100 liters poppy seed SV0 Table 2). One estimate for yearly household energy demands for rural homes in Southeast Asia is 9.5 GJ (Daioglou, Van Ruijven et al. 2012). Thus in my conservative model, each hectare of harvested poppy seed could power nearly 3 homes or operate a 6.6 kW slow diesel generator at three-quarter load for 486 hours. The organization of farmers into co-operatives traditionally has the benefit of economy of scale. However, in my study, the primary benefit comes in the form of 'regional system stability' because the majority of the energy inputs are non-mechanical. This means that if a farmer in one area were to have a low yield, the system is protected by level productivity on the other farms so that no one farm is left completely without poppy seed SVO, and excess poppy seed SVO could be sold at a profit to the farm in need. I note, though, that the system-wide energy efficiency and emissions are best served when the SVO is used on-farm.

3.2. LCA Comparison of On-Farm vs. Regional

Since the scenarios A, E, I and M (low-harvest area/low yield) and scenarios C, G, K and O (high-yield area/low-harvest) presented the same transportation demands, they had the same emissions profile and energy inputs. As is the case in most life-cycle analyses, I estimated that the further the transportation distance, the lower the EROI (Fig. 3). I calculated that the transportation scenarios of 5, 10, and 25 km would require 19.2, 38.4 and 96.0 GJ, respectively for my system boundaries (see Supplementary Materials Table 1). In addition, the simplicity of the poppy SVO production system is such that economics of scale are minimal and would not offset the energy inputs of increased transportation distances in any of the scenarios.

I then calculated GHG emissions and EROI for each scenario. Furthermore, I developed a scenario based on a different oil crop, camelina (a close relative to canola). Since canola (rapeseed) and poppy have very similar agronomical traits (Duke 1983), I modeled camelina production based on the fertilized 10 km transportation distance, with the same input and yield assumptions as for the poppy seed model. The agro-economic off-set for switching to camelina is the improved engine performance and better blend characteristics of camelina oil.

The analysis illustrated that on-farm poppy seed oil production was far superior to the other scenarios (Fig. 3). On-farm SVO production was calculated to have the lowest emissions and highest EROI in the high hectare/high yield scenarios with no fertilization. Scenario Q (high hectare/low yield scenario using fertilizer and a 10 km transportation scheme) was calculated to have 13.7 kg of GHG emissions and an EROI of 386 (Fig. 3).

The transportation of diesel to the villages was the most unfavorable of all the scenarios, with GHG emissions ranging from 29.9 to 53.4 kg and EROI from 38.5 to 68.7 for the chosen LCA system boundaries (Fig. 3).

Calculations for the 5 km transportation distance case (Table 4) showed that 247 mg volatile organic carbon species (VOCs), 677 mg of carbon monoxide (CO), 2.18 g of nitrogen oxides (NO_x), and 536 mg of sulfur oxides (SO_x) would be emitted per year per 5 km traveled. In addition, particulate matter emissions for this distance were projected to be 162 mg of 10 µm diameter (PM_{10}) and 105 mg at 2.5 µm diameter ($PM_{2.5}$). Finally, 2.18 g of methane (CH_4), 33.7 mg of nitrous oxide (N_2O), and 1.43 kg of carbon dioxide (CO_2) would be produced during the 5 km transportation distance (Table 4). The 5 km model used 19.2 MJ in energy inputs (per farm). Energy requirements for the 10 km and 25 km models were proportionally higher requiring 38.4 MJ and 96.0 MJ, respectively. The resulting emissions were similarly proportional to the 5 km model.

VOCs are known to be a major health concern in terms of respiratory and allergic reactions in humans, and are key constituents of smog – a real concern for mountain valleys. SO_x harm crops, livestock and people; they decrease the growth rate of crops and are an irritant to the throat and lungs in animals and people. SO_x are also a major contributor to acid deposition (acid rain), another special concern for mountain valley areas. PM_{10} and $PM_{2.5}$ are heterogeneous mixtures of many components from various sources (Cherrie 2002). Fine PM ($PM_{2.5}$) is of greater concern that the larger size fractions because of its ability to penetrate deep into the respiratory and the circulatory systems (Seaton, Soutar et al. 1999).

3.3 Impact of Fertilization

Since information about fertilization schemes for the illicit drug trade is difficult to ascertain, and reliable fertilizers can generally be difficult to obtain in Afghanistan, I evaluated only two fertilization schemes (Table 3 and Fig. 4). It is typically accepted that fertilization will increase yields, an aspect I captured in my scenarios by having high and low yields.

The addition of fertilizer in scenario R (low-harvest area/high-yield) resulted in an increase in required energy input to 127 MJ (see LCA in Supplementary Materials Table 10). The addition of fertilizer to scenario Q (high-harvest area/low-yield at 10 km) resulted in an increase in energy requirements to 147 MJ in the fertilizer model (see LCA in Supplementary Materials Table 10).

I calculated, as expected, no emissions or energy inputs for the on-farm transportation scenarios (Table 3). Emissions calculations per 64.4 kg of poppy seeds for the 0 km transportation distance case with fertilizer were that 8.17 mg VOC, 10.7 g of CO, 51.0 g of NO_x, 253 g of SO_x, 37.4 g of CH_4, 14.3 g of N_2O, and 7.07 kg of CO_2 would be produced. In addition, the calculated particulate matter emissions for this distance were projected to be 10.8 g of PM_{10}, 6.44 g of $PM_{2.5}$. Emissions for the 10km fertilizer model produced 8.42 g VOC, 11.4 g of CO, 53.2 g of NO_x, 10.9 g of PM_{10}, 6.55 g of $PM_{2.5}$, 253 g of SO_x, 39.6 g of CH_4, 14.3 g of N_2O, and 8.50 kg of CO_2.

3.4 Poppy Seed SVO for Rural Electrification

It is difficult to compare these poppy seed SVO relative LCA results with other SVO LCAs reported due to the variability of regions, cropping paradigms, feedstock inputs and characteristics. These comparisons are especially difficult in unstable, rural, under-developed countries like Afghanistan. In the case of Afghanistan, these regions are in states of war and hostile toward indigenous people as well as outsiders. In addition, these regions do not typically have access to an equivalent energy production system for baseline comparison. The present study is unique in that it proposes the use of an agricultural waste product for use in electrifying these remote rural villages.

In the global context, the emissions and energy use for regional production are minimal in the scenarios considered here; at the maximum transportation distance of 25 km, the use of fertilizers has a larger impact on GHGs than transportation. This is supported by research on rapeseed by Baquero et al. (2011), who found their LCA to be most environmentally and economically efficient when implemented on agricultural systems in on-farm production and use scenarios (Baquero, Esteban et al. 2011). In that study, rapeseed SVO was shown to have positive contribution to a farm’s value chain in Spain that extended to the community level, and GHGs were predicted to decrease through a reduction in use of fossil fuels. Their economic evaluation models showed clear economic benefits of introducing rapeseed to the traditional crop rotation of wheat and barley. The key factors analyzed in their model were diesel fuel price, diesel fuel grants and crop aids. Their scenarios results showed a profit increase in diesel seed and SVO seed scenarios comparing to their baseline scenario (18% and 10% profit increase, respectively). In further research, Grau et al. (2013) showed their SVO LCA model to be maximized in terms of environmental impacts and energy efficiency when production and use were designed for agricultural self-consumption (Grau, Bernat et al. 2013).

While biodiesel receives more attention than SVO, emissions and energy requirements of transestrification would greatly increase emissions and decrease the overall available energy for use. However, on the practical side, the on-the-ground realities cannot be over-emphasized. The use and maintenance of vehicles in terms of skilled labor, costs, and accessibility to rural farmers is at worst unrealistic and at best cost prohibitive.

4.0 Conclusions

The goal of this study was to assess the net/gross energetic and emissions feasibility of producing poppy seed SVO as a transition strategy for poppy farmers to alternative crops. This SVO would be used to electrify remote villages through power generation. I investigated two specific issues: the impacts of fertilization, and whether there were energy or emissions advantages to on-farm production compared to regional production. I found that a decentralized/on-farm scenario was more efficient energetically and produced lower levels of emissions. In the low-harvest area/high-yield, energy and emissions for the 10 km and 25 km scenarios were increased by a factor of two and five in comparison to the 5 km models, respectively. I also observed that the energy and emissions then increased by a factor of three for the high-harvest area/high-yield models. In terms of the energy input and emissions created, the on-farm model clearly makes the most efficient use of resources. In the low harvest area/high yield scenarios, energy and emissions for the 10 km and 25 km scenarios were increased by a factor of two and five in comparison to the 5 km models, respectively. I also observed that the energy and emissions then increased by a factor of three for the high-harvest area/high-yield models.

Few LCA studies have been completed addressing rural electrification of remote villages in conflicted/post-conflict areas of the world. Rural electrification studies, such as those reported by the FAO on Jatropha oil production and use in Nepal, Mali, India, Thailand, and Guatemala, and palm oil in Tanzania (Hunt and Dubois 2009), provide a solid foundation for the implementation of rural electrification in developing countries. My LCA provides a platform for supporting the energetic inputs and GHG and emissions outputs of such projects. Given the similarities between poppy seed and other oil seed crops, such as camelina and canola (rapeseed), in terms of the soil and farming inputs needed (Duke 1983), transitioning from poppy once the electrification has taken hold could be a more realistic expectation that is at the present time feasible (Milbrandt and Overend 2011). However, additional research is needed to expand on this proposal to monitor the transition and measure the rates of adoption and uses of this innovation.

5.0 Tables

Table 2.1. Scenarios by fuel/crop, yield, area, fertilizer use and transportation distance.

Scenario	Fuel/Crop	Yield (kg/ha)	Farm size	Fertilizer use	Transportation: On-farm (0 km) or Regional (5, 10, 25 km)
A	Poppy	1,750	Low	N	OF
B	Poppy	1,750	High	N	OF
C	Poppy	3,750	Low	N	OF
D	Poppy	3,750	High	N	OF
E	Poppy	1,750	Low	N	5
F	Poppy	1,750	High	N	5
G	Poppy	3,750	Low	N	5
H	Poppy	3,750	High	N	5
I	Poppy	1,750	Low	N	10
J	Poppy	1,750	High	N	10
K	Poppy	3,750	Low	N	10
L	Poppy	3,750	High	N	10
M	Poppy	1,750	Low	N	25
N	Poppy	1,750	High	N	25
O	Poppy	3,750	Low	N	25
P	Poppy	3,750	High	N	25
Q	Poppy	1,750	High	Y	10
R	Poppy	3,750	Low	Y	OF
S	Camelina	1,750	Low	Y	OF
T	Camelina	3,750	Low	Y	10
U	Diesel	N/A	N/A	N/A	200
V	Diesel	N/A	N/A	N/A	231
W	Diesel	N/A	N/A	N/A	263
X	Diesel	N/A	N/A	N/A	357

Table 2.2. Poppy seed and SVO production by farming scenario.

Scenario*	***Farmed area (ha)***	***Total seed production (kg)***	***Total SVO production (GJ)***	***Total SVO production (L)***
A,E,I,M	1	1750	26.4	997
B,F,J,N	50	3750	56.5	2140
C,G,K,O	1	87500	1320	49900
D,H,L,P	50	188000	2820	107000

*See Table 1.

Table 2.3. Emissions comparisons for fertilizer scenario for low harvest area/high yield on-farm production (scenario R) and high harvest area/low yield at 10 km transportation distance (scenario Q) and diesel delivery scenarios (U, V, W and X), in which a diesel depot is located 100 km away).

	Scenarios									
Emissions	**C**	**R**	**Difference**	**J**	**Q**	**Difference**	**U**	**V**	**W**	**X**
VOC (g)	0.0	8.17	8.17	0.49	8.42	7.93	4.95	5.72	6.5	8.83
CO (g)	0.0	10.7	10.7	1.35	11.4	10.1	13.5	15.7	17.8	24.2
NO_x (g)	0.0	51	51	4.37	53.2	48.8	43.7	50.5	57.4	77.9
PM_{10} (g)	0.0	10.8	10.8	0.32	10.9	10.6	3.25	3.76	4.27	5.8
$PM_{2.5}$ (g)	0.0	6.44	6.44	0.21	6.55	6.34	2.1	2.43	2.76	3.75
SO_x (g)	0.0	253	253	1.07	253	252	10.7	12.4	14.1	19.1
CH_4 (g)	0.0	37.4	37.4	0.004	39.6	39.6	43.6	50.4	57.2	77.8
N_2O (g)	0.0	14.3	14.3	0.07	14.3	14.2	0.67	0.78	0.88	1.2
CO_2 (kg)	0.0	7.07	7.07	0.003	8.5	8.5	28.6	33.1	37.6	51.1
GHG: CO_2e(kg)	0.0	12.2	12.2	2.99	13.7	10.7	29.9	34.6	39.3	53.4

Table 2.4. Emissions from low harvest area/low harvest scenarios (A, E, I, and M).

Emission component	**0 km**	**5 km**	**10 km**	**25 km**
VOC (mg)	0	247	495	1240
CO (mg)	0	677	1350	3390
NO_x (g)	0	2.18	4.37	10.9
PM_{10} (mg)	0	162	325	812
$PM_{2.5}$ (mg)	0	105	210	526
SO_x (mg)	0	536	1070	2680
CH_4 (mg)	0	2.18	4.36	10.9
N_2O (mg)	0	33.7	67.3	168
CO_2 (g)	0	1.43	2.86	7.16

6.0 Figures

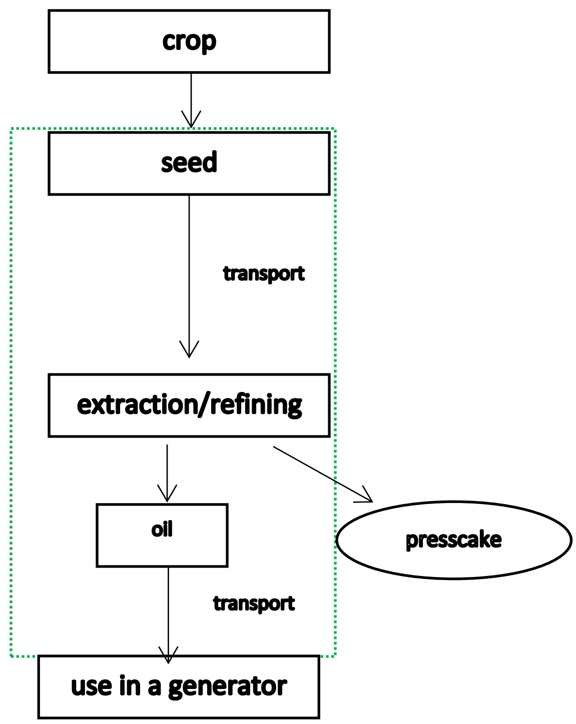


Fig 2.1. Boundaries of centralized (regional) oil production system (dashed line represents the boundary).

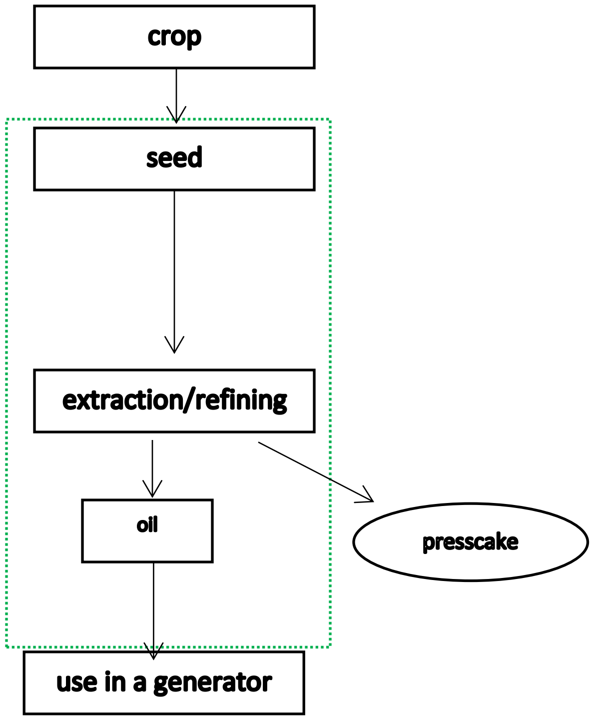
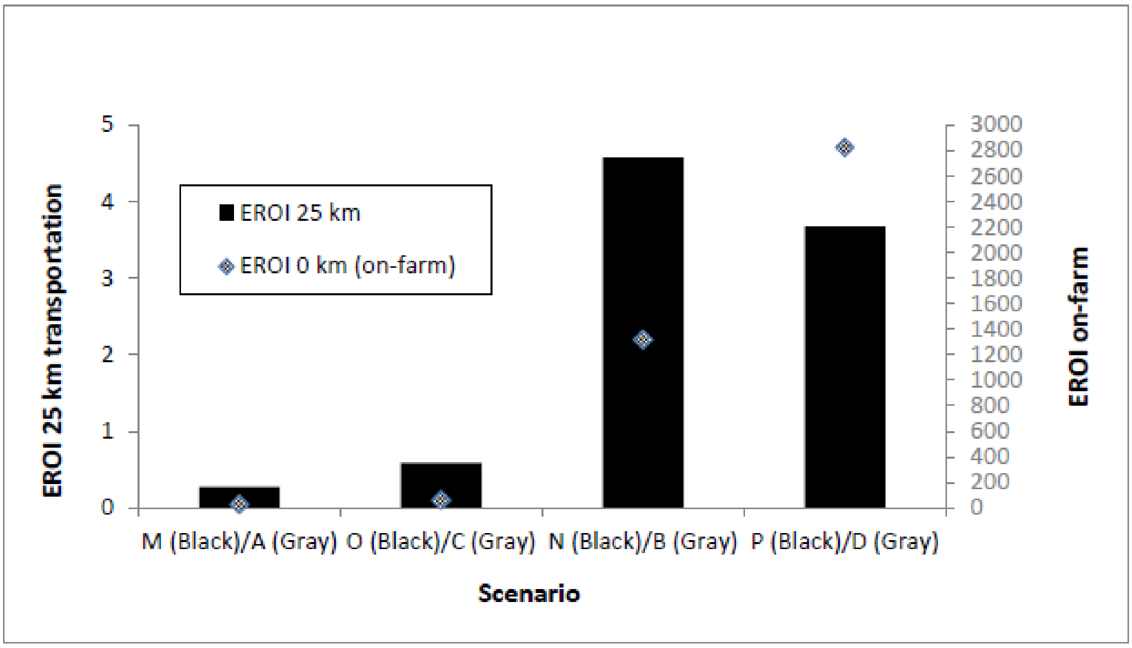


Fig 2.2. Boundaries of on-farm/decentralized oil production system (dashed line represents the boundary).



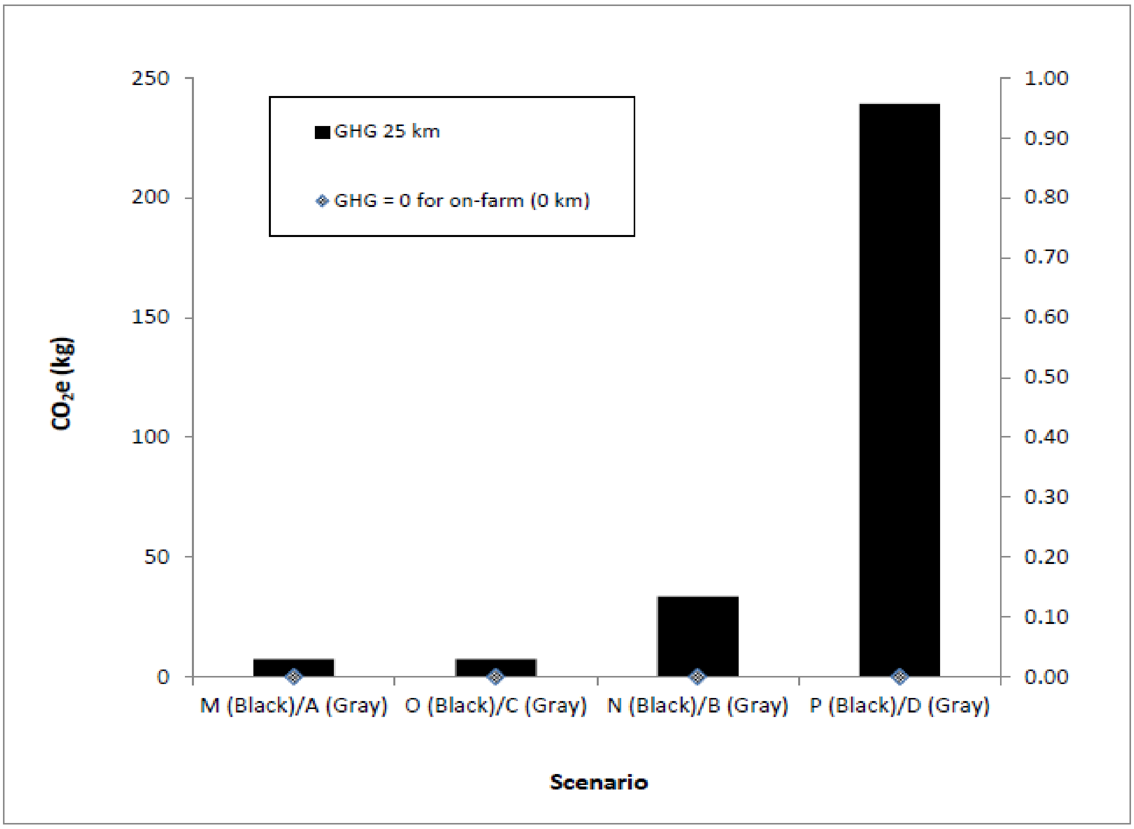


Fig. 2.3. Top: EROI for production and transportation comparing 0 km (on-farm) and 25 km transportation scenarios. Bottom: GHG emissions for production and transportation comparing 0 km (on-farm) and 25 km transportation scenarios. Table 1 provides details of the indicated (lettered) scenarios.

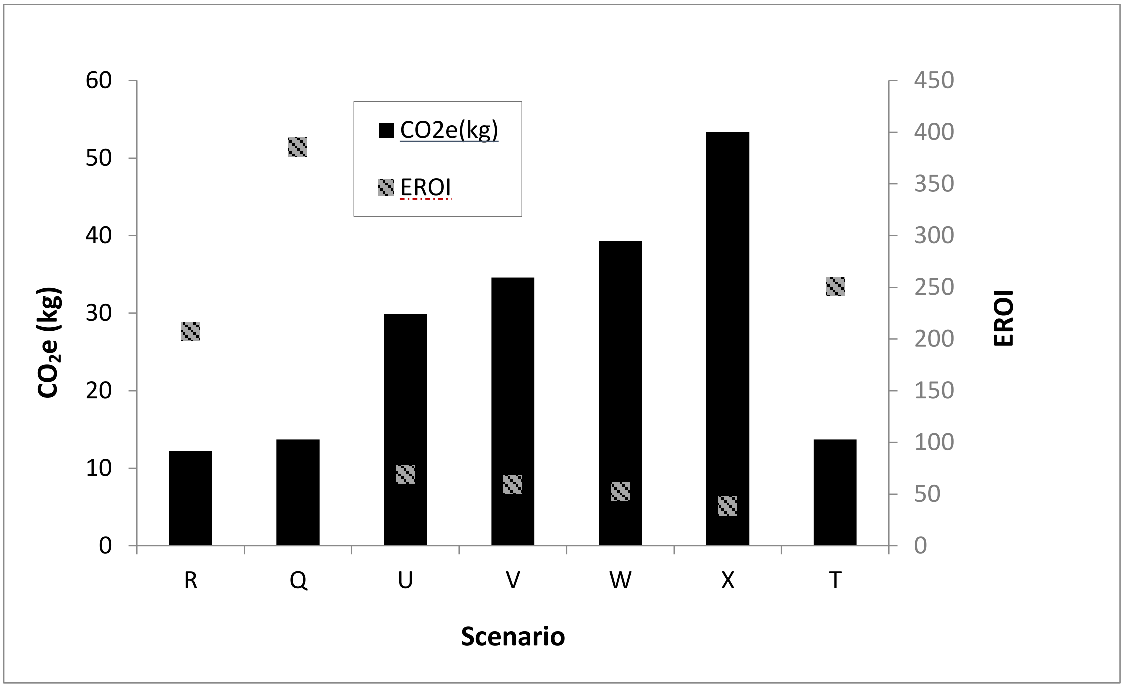


Fig. 2.4. EROI and GHG emissions (CO_2e) for production and transportation comparing the fertilized poppy, diesel, and camelina scenarios. Table 1 provides details of the indicated (lettered) scenarios.

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Chapter 3. Fuel and Co-Products from Poppy-Based Straight Vegetable Oil for Rural Afghanistan

1.0 Introduction

Energy development is an issue receiving increased attention in Afghanistan. Research and development efforts to supply electricity to meet Afghanistan's development and humanitarian needs are growing. The Afghan government is investigating options such as energy derived from renewable resources (e.g., wind, solar, animal waste biomass, geothermal) (Milbrandt and Overend 2011). However, given the turmoil of the last 40+ years in Afghanistan, the infrastructure to support projects is likely to be many years from implementation.

Currently, solid biomass resources such as charcoal, dung, firewood, and crop residues provide about 90% of Afghan energy needs at the household level (primarily cooking and heating), with the rural populations being nearly entirely dependent on biomass for cooking and heating. Unfortunately, combustion of these sources have well documented adverse health effects and their depletion may become a major ecological concern. Given that climate models predict that drought in Afghanistan will become the norm by 2030 and that present agricultural lands are likely to become marginal, Afghanistan and would greatly benefit from an alternative, plentiful energy source (Milbrant and Overend 2011).

Afghanistan currently produces a large amount of oilseeds in the form of poppy seeds. Work by Demirbas (2003, 2009) showed that straight vegetable oil from poppy seeds exhibited good fuel properties showing a higher heating value of 39.6 MJ/kg and a viscosity of 42.4 mm^2/s (at 311 K) (Table 1).

Aksoy showed that a 50/50 blend of poppy oil with petroleum diesel resulted in viscosity of 4.63 mm^2/s, heating value of 42,100 MJ/kg and density of 879 kg/m^3 (Aksoy 2011a; Aksoy 2011b). However, the major challenge with biodiesel production in Afghanistan is the cost of importing the required reagents (methanol or ethanol) and the training required for such processes in rural areas. While biodiesel is now considered viable as compatible for co-use with petroleum fuels, the use of vegetable oil as a fuel in diesel engines has been an interest for more than 100 years (Quick 1980; Knothe, Van Gerpen et al. 2005). SVO fuel offers a strong potential for remote regions to be self-sufficient (Misra and Murthy 2010) and provides energy potential for Afghanistan. Although prior research on poppy SVO has provided estimates on density, heating value, and viscosity, more work is needed to provide a full assessment of the potential use of poppy SVO in Afghanistan (Table 1). Here I provide additional data on cloud point, cold filter plugging point, bulk modulus, speed of sound and oxygen stability of poppy SVO to address the questions: Can poppy SVO be extracted for use by rural Afghan farmers? What are the fuel characteristics of poppy SVO? And, finally, might there exist value in a co-product from the poppy SVO extraction process?

The purpose of this research was to test three hypotheses: (1) the SVO produced is practical for combustion in diesel engines; (2) the waste presscake from oil production has potential as an animal feed; and (3) the presscake has the properties necessary to be an acceptable soil amendment. In particular, the goal of this laboratory work was to investigate the feasibility of poppy oil for use as a fuel and other alternative uses from poppy seed.

2.0 Methods

2.1 Oil Extraction

In a set of four trials, a Piteba Oil Expeller™ (Piteba. The Netherlands) manual expeller was used to demonstrate the potential use of a simple, low-tech extraction process that could easily be scaled up to be livestock-driven for use in rural regions of Afghanistan in which energetic inputs and technological repairs are rare or non-existent. In four oil extraction trials I used 113 g, 128 g, 180 g, and 300 g of poppy seeds, respectively, which were put into a Piteba Oil Expeller™. The oil was then filtered through three felt-polyester gravity drip-filters of increasingly fine mesh (25 µm, 10 µm and 0.5 µm) made by the Utah

Biodiesel Supply (Syracuse, UT). The oil was stored and refrigerated at approximately 280 K until tested. The residual, or presscake, was stored at room temperature in sealed plastic sandwich bags until being analyzed.

2.2 Fuel Properties

After filtration, the poppy oil from the trials was combined and was tested for cloud point test, oxidation stability and cold filter plugging point test. Cold filter plugging point (CFPP) and cold point (CP) tests were performed using a Lawler Manufacturing Corp DR4-14L (Edison, NJ) on 50 mL of poppy oil. The oxidation stability test was accomplished on 3 g of poppy oil using Metrohm's 743 Rancimat (Herisau, Switzerland). Speed of sound, density, kinematic viscosity and bulk modulus were measured using an Anton-Paar (Ashland, VA) viscometer.

2.3 Animal Nutrition

For the nutritional testing I tested for energy and protein in the presscake. Protein content was measured using procedures presented by Martin et al. (2013). For energy content, the heat of combustion was determined using a Parr oxygen bomb adiabatic calorimeter (Model 1261, Parr Instrument, Moline, IL).

2.4 Soil Nutrition

Samples of the presscake were tested for texture, pH, elemental carbon, NO_3-N, phosphorus, potassium, nitrogen, carbon and C:N ratio by the Colorado State University Soil, Water and Plant testing laboratory.

3.0 Results and Discussion

3.1 Poppy Seed SVO

Since diesel is the primary fuel for powering generators in Afghanistan, I highlight here that some key fuel characteristics of diesel are higher heating value of 44.6 MJ/kg, density of 854 g/L and viscosity of 1.9-4.1 mm^2/s. Although poppy is not a perfect replacement for diesel, poppy higher heating value of 39.6 MJ/kg, density of 893 g/L and viscosity of 42.4 mm^2/s has comparable fuel characteristics to some other well-known oil seed crops such as camelina (higher heating value of 39.1 MJ/kg, density of 925 g/L and viscosity of 28.9 mm^2/s) and soy bean oil (higher heating value of 39.6 MJ/kg, density of 914 g/L and viscosity of 33.1 mm^2/s).

For CFPP and CP the oil tested at 292 K (s_d =0.231) and 290 K (s_d =0.351), respectively. This means that the oil can be expected to function in adverse climates, but may have a viscosity that prevents it from flowing well in very cold climates found in Afghanistan – thus requiring some pre-heating. The poppy oil oxidized in an average of 225 minutes (s_d =2.96) (3.75 hours), which is in between the American Society for Testing and Materials (ASTM) limit of 3 hours and the European Standards (EN) limit of 6 hours. The poppy oil had a speed of sound of 1,470 m/s (s_d = 0.0283) a density of 0.919 g/cm^3, bulk modulus of 1.94 GPa and kinematic viscosity of 27.9 mm^2/s values, which are similar to those observed by Aksoy and others (Table 1 and 2) (Eklund and Ågren 1975; Duke 1983; Tiwari and Ghosal 2005; Aksoy 2011; Aksoy 2011). Askoy et al.'s work is of great interest because they showed that poppy oil blended with diesel produced promising results which support the assertion of the viability of poppy oil as a viable fuel source beyond SVO (Aksoy 2011; Aksoy 2011).

3.2 Poppy Presscake Properties for Animal Nutrition

The protein content was assessed and compared to beef and chicken feed standards as described in procedures presented by Martin et al. (2013). This analysis showed that the poppy presscake contained 33.3% protein (by weight); this is 173% and 169% greater than the beef or chicken feed standards, respectively. The energy content was observed and compared to corn and alfalfa. In the comparisons I made between the poppy presscake to the corn and alfalfa, the poppy presscake contained 24.56%, and 18.70% more energy in MJ/kg, respectively.

Feed for cattle and other livestock can often be one of the largest requirements for a farm. For small villages, grazing fodder for cattle and other livestock can be especially challenging in hard economic or climate conditions. As presented in research separately by Hunt and Dubuois (2009), the availability for a feed source that allows farmers in rural – often remote mountain regions – to have the flexibility to both provide electrification and feed for livestock is a great economic, environmental and energetic advantage (Hunt and Dubuios 2009; Gaul 2013; Grau, Bernat et al. 2013).

In work investigating the use of poppy presscake as far back as 1851 it was shown that it was successful for fattening cattle and sheep (Payen and Richard 1851; Cornevin 1892). It was also shown that using the presscake in other livestock was also viable (Payen and Richard 1851; Statham 1984). Separate research presented observed positive results in using the presscake for broiler and laying hen feed (Küçükersan, Yeşilbağ et al. 2009).

3.3 Poppy Presscake Properties for Soil Nutrition

The results of the testing showed the presscake had a loam-like texture with a pH of 6.5, electrical conductivity of 3.0 (mS/cm), carbon of 44.8 mg, a C:N ratio of 7.56 and NO_3-N, P, K of 21.1, 340 and 27.9 ppb, respectively (Table 3).

These results show that the presscake may be a helpful soil amendment in some regions of Afghanistan depending upon the soil health. The texture was estimated by the hand-feel method and resulted in a loam classification that is typically considered an ideal texture for gardening and agricultural uses because it retains nutrients and water. The pH of 6.5 is a slightly acidic, near neutral level. The soluble salts were measured by the electrical conductivity of a soil extract from a 1:1 soil:water ratio and resulted in 3.0 mS/cm, meaning the utility of conductivity must be viewed in relation to the specific crop being planted, but should be acceptable for most non-sensitive crops.

The nitrate nitrogen, reported in ppm NO_3-N, is soluble and readily available for plant uptake and is therefore considered equally available as fertilizer N. Thus, at 21.1 ppm, the presscake contains 34.5 kg NO_3-N/acre to a depth of 30.5 cm. Similarly, the phosphorus and potassium content were extremely high, especially for dryland production, at 340 and 27.9 ppb, respectively however within the same ranges as prior analysis by Ozcan et al. (Musa Özcan and Atalay 2006). Both phosphorous and potassium may require measured use to avoid over saturation of the soil, depending upon the condition of the soil and the crop being produced.

With estimates of 1,750-3,750 kg/ha of seeds capable of being harvested, it is estimated that a potential production of 250-535 kg/ha of presscake could be available for use, depending on each farmers' livestock and planting situation. The results in Table 3 include NPK comparisons to a generic soil amendment from a typical home garden variety fertilizer and recommendations for tomato nutrient levels presented by Rorabauch (2013). The table shows that although the presscake has some promising nutrients, additional work may be needed to properly allocate NPK levels for application to soils, such that it may be more advantageous to use the presscake for livestock feed than for a soil amendment.

While additional work is needed in Afghanistan to assess farm-by-farm soil conditions, the soil in Afghanistan is generally lacking in macro and micro nutrients (Srinivas, Bishaw et al. 2010) a number of these nutrients are readily available in poppy seed presscake. Very few studies have presented this novel idea; however, it was found in that this practice increased the soil pH in Tasmania when applied to spinach crops (Hardie and Cotching 2009). As reported by Srinivas et al. (2010), soil in Afghanistan is typically much higher than that of the poppy presscake, and therefore should not present a similar problem.

3.4 Poppy SVO in Afghanistan

The chemical composition and physical properties of the oil extracted from the opium poppy makes it a viable option for use as a fuel in slow diesel generators. In considering the 'best' fuel for a purpose, judgment is context dependent. In rural Afghanistan where access to energy sources is limited, fuel produced from poppy oil may be a promising option. The initiative studied here involves extracting SVO from poppy seeds using a simple seed crusher. Once the SVO is isolated, the poppy oil can be filtered and burned as fuel, while the leftover seed casings can be mixed with livestock feed or used as agricultural fertilizer. Perhaps the most promising aspect of this project is the possibility to transfer this model to other livelihoods in Afghanistan and to be able to support farmers' efficiency via fertilization or using the oil to power irrigation pumps.

The production of 1,750 and 3,750 kilograms of poppy seed per hectare converts to approximately 746 and 1,600 liters of SVO per hectare, respectively. Thus a one hectare field with a 1,750 kg yield scenario was found to yield approximately 26.4 GJ of energy. Since some estimates for yearly household energy demands for rural homes in Southeast Asia estimate approximately 9.5 GJ (Daioglou, Van Ruijven et al. 2012), such that each hectare of harvested poppy seed could power nearly 3 homes or operate a 6.6 kW slow diesel generator at three-quarter load for 486 hours. This endeavor would allow farmers in rural and developing areas to provide their own fuel while simultaneously improving public health by implementing electrification and increasing security by supplementing self-sufficiency and the local economy.

The idea to use poppy oil as a biofuel and incorporate its co-products in this manner in Afghanistan is unprecedented, but using locally produced straight vegetable oil (SVO) as a fuel source is also not a novel idea. Numerous research and international development groups have successfully established biofuel programs in rural areas of developing countries and I can see the fuel property comparison of some of these fuels sources to poppy oil (Table 2). These projects aim to reduce the costs of fuel and provide a consistently renewable source of energy that, in turn, results in increased economic stability and political/social partnerships. For example, Tiwari and Jagadish's 2009 article described a project designed to make irrigation affordable to rural Nepalese families by producing and using SVO from native Jatropha plants (Hust and Dubois 2009). Irrigation, which is necessary for high-yield agriculture, is prohibitively expensive to many farmers in the Siraha region of Nepal due to the cost of the diesel fuel required to operate the irrigation pumps. The project was established in the interest of helping the farmers power their irrigation pumps at a fraction of the cost. The seeds were collected from native Jatropha plants, and the researchers provided three oil expellers to produce fuel for thirty irrigation pumps modified to operate on SVO. In addition to providing various community groups with the means to produce Jatropha oil, the project design also included community awareness workshops to provide information about how to gather, store, and use Jatropha seeds and the resultant presscake (biomass leftover from oil production). The Jatropha fuel research is, in many ways, an encouraging parallel to this proposed project. Even if implementation would not be possible in every area of Afghanistan right away, this idea could be feasible even on a fairly small scale.

4.0 Conclusions

My research showed that oil extracted from poppy seeds can be accomplished and poppy SVO is a viable renewable energy source. The fuel properties of poppy SVO are favorable for use in slow diesel generators. I also found that the waste from extracting oil from the poppy seeds, presscake, could be used as soil amendment and animal feedstock.

5.0 Tables

Table 3.1. Fuel properties of some vegetable oils versus No. 2 Diesel ASTM D975 standards).

	Higher heating Value (MJ/kg)	**Density (g/L)**	**Kinematic Viscosity**
No. 2 Diesel	44.6	854	1.3-4.1 (mm^2/s at 313 K)[**]
Corn	37.8[#]	721[*]	35.1 (mm^2/s at 311 K)[**]
Soybean Oil	39.6 [#]	914 [#]	65.4 (mm^2/s at 300 K)[#]
Rapeseed (Canola)	38.9[#]	914[**]	37.3 (mm^2/s at 311 K)[**]
Camelina	39.1[#]	925[***]	28.9 (mm^2/s at 311 K)[***]
Poppy	39.6[**]	893[*****]	42.4 (mm^2/s at 311 K)[**]

[*] ANL (2012); [**] Demirbaş(2003); [***] Kruczyński (2013); [****] Shah, Joshi et al.(2013); [*****] Aksoy (2011); [#] Demirbaş(2009); [##]Dobreet al. (2011).

Table 3.2. Poppy oil property tests.

Characteristic	Poppy Oil
CP (K)	256 (0.351)
CFPP (K)	294 (0.231)
OS (minutes)	3.76 (2.96)
Speed of Sound (m/s)	1470 (0.0283)
Bulk Modulus (GPa)	1.94

*CP – Cloud Point; CFPP – Cold Filter Plugging Point; OS – Oxidative Stability.

Table 3.3. Poppy press-cake soil nutrition/mineral content versus a generic soil amendment and recommended tomato nutrient levels.

Characteristic	**Amendment**		
	Poppy presscake	Generic soil amendment*	Tomato recommended nutrient levels**
Texture Estimate	Loam	--	--
pH	6.5	--	--
EC (mS/cm)	3	--	--
Total C (%)	44.8	--	--
C:N Ratio	7.56	--	--
NO_3-N (ppm)	21.1	200	264
P (ppm)	340	80	116
K (ppm)	27,900	360	219

* Soil amendment based on 20-20-20 (NPK) diluted in 5mL/3.79 L of a typical generic home garden variety fertilizer.** Rorabauch (2013)

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Chapter 4. Empowering Rural Communities in Afghanistan: A Diffusion of Innovation Framework for Narcotic Crop Use Replacement using Renewable Energy Biofuel and Co-Products

1.0 Introduction

This chapter presents a framework based on the diffusion of innovation perspective for ecological policy, management, and health for Afghanistan based on a renewable energy project using poppy oil. Past researchers, policy-makers, ecologists, and others have proposed aspects of this framework; however, the tools needed to address Afghanistan's social and environmental challenges are complex and no single discipline or approach can successfully tackle all of the needed aspects. Therefore, the framework I propose combines the important social and political issues in the region with a strategy for the diffusion of a poppy-based fuel source. The ultimate goal of diffusing this innovation through rural Afghanistan is to help promote health, education, and well-being among marginalized populations as a mechanism to increase self-sufficiency in a manner that will allow for more productive partnerships to be built; in some ways, this is a direct way of 'winning hearts and minds' by actually providing people with what they want and need: greater health and access to improved living conditions.

In order to implement a renewable energy project based on poppy oil, it is important to develop a framework that takes into consideration the social context of the region. Moreover, a framework is needed that is flexible and respectful of the history, complexities, and needs of Afghanistan. It also must be capable of incorporating the needs of individual citizens, diverse villages, and the governance system. The past 10 years of war, which was preceded by nearly 40 years of internal and external conflict, has brought Afghanistan to an interesting crossroads.

Previous discussions of development in Afghanistan have almost always focused on agriculture and the impact of poppy cultivation for production of opium and heroin. Other issues—like the fact that the country has some of the world's highest rates of maternal-child-infant mortality, extremely low literacy rates, lack of access to water, and widespread food insecurity—were discussed as if they are disconnected and separate challenges. A successful framework must see that all of these challenges are interconnected.

Poppies have not always been used solely to produce illicit narcotics in Afghanistan. A long history of using poppies for food and medicinal products exists. Oil from poppies can also be used to provide rural farmers (approximately 75% of Afghan citizens) (U.S. Agency for International Aid 2014) with a straight vegetable oil energy source to power slow diesel generators for village electrification. The oil extracted from poppy seeds is a viable renewable energy source that reduces the environmental and health hazards of diesel emissions, and can operate in slow diesel generators (Aksoy 2011; Martinot and Sawin 2011). Additionally, the remaining presscake can be used as a fertilizer and animal feed. Prior research has shown that synthesizing a biofuel from poppy oil is indeed possible (Mourning-Star and Reardon 2014 - unpublished). However, an alternative framework for a first-step transition toward introducing village electrification in rural Afghanistan as a mechanism towards energy self-sufficiency needs to be explored.

The innovation diffusion (ID) perspective provides a useful way to develop specific steps to implementing a strategy centered on introducing an environmental/agricultural technological innovation to the country's remote rural social systems. This perspective seeks to provide insight into how, why, and at what rate new ideas spread though a social system (Rogers 2010). Furthermore, In Afghanistan, the ID model must address the history of farming poppy and create a framework to inspire farmers to fully complete the five-step process of innovation diffusion. The five steps of the process the user goes through are: (1) knowledge of the innovation (exposure), (2) persuasion of the utility of the innovation, (3) decision on the advantages/disadvantages, (4) the implementation of the innovation in some way, and (5) the confirmation of the innovation (Rogers 2010). These descriptions were initially laid out by Everett Rogers in 1962 and later expanded on by numerous others (Dearing 2009; Lundvall, Joseph et al. 2009; Di Benedetto 2010; Rogers 2010; Buchanan, Cole et al. 2011; Jacobsson and Bergek 2011; Srholec 2011; Khavul and Bruton 2012). Rogers (2010), goes further by categorizing potential users by their innovation adoption rates: the innovator; the early adopters; the late adopters; the early minority; the late majority, and the laggard.

Therefore, this chapter presents a framework centered on ID for how to approach the farmer and governance issues of implementing a village electrification program using the novel fuel source of poppy straight vegetable oil (SVO). The framework overlays the methods of ID with the theories of ecological governance by using a combination of first-hand knowledge and experiences of Afghanistan's agricultural, political, and outreach staff interactions and on-the-ground observations. It also explores the political, social and economic considerations that are necessary to implement such transitions in Afghanistan through the lens of ID.

2.0 Background

As a crossway of the Silk Road, trade has always been a major component of Afghanistan's relationship with the rest of the world, as well as internally among the tribes of the state. The tribal mix of nomadic and pastoral communities in which these important trade relationships overlay is important in understanding both the history of trade and conflict. Traditionally, the main items of commercial trade in Afghanistan were various fruits, nuts, and handicrafts (CIA 2011). After nearly 30 years of war, Afghanistan trade now relies on cotton, coal and has a growing industry in copper and natural gas. These contracts for the mining of oil and some rare minerals are slowly opening prospects for growth. However, opium is Afghanistan's most well-known export (CIA 2011).

Afghanistan's central role in the international narcotic trade of heroin and opium has placed the issue of alternative livelihoods to poppy growing in Afghanistan at the center of numerous conversations and much political maneuvering. In my correspondences with members of the U.S. Navy, Marines, U.S. State Department, Senate staffers, and on-the-ground contacts, attempts to provide alternative livelihoods to poppy growth are of key interest to diplomatic and military strategy. From the perspective of these agents and agencies, Afghanistan is divided into two primary categories: stable and unstable. Stability, usually measured in terms of military confrontations with insurgents, is directly correlated with levels of poppy cultivation: high poppy production is correlated with high instability. Figure 1 from the United Nations Department of Safety and Security illustrates the correlation between insecurity and opium poppy cultivation, which is used to fund insurgent activity.

Given time, the eradication of poppy production and alternative livelihood strategies could help improve security in Afghanistan. But in the near term, officials expect much of the illegal opium activity to move to neighboring regions in Pakistan. Many experts believe that insurgent groups in northern Pakistan are waiting until U.S. forces withdraw from Afghanistan so that they can increase terrorist activity in Afghanistan (Kux 2011), which likely includes ramping up illegal opium production in both Afghanistan and Pakistan for funding purposes.

Though investments have been made in up-rooting poppy production, this has led to both an increase in money to be made from growing poppy and a resistance to turn against the status quo in Afghanistan. Attempts to move farms away from illicit opium production to non-narcotic crops such as wheat, cotton, saffron and various nuts have been attempted throughout most of the coalition occupancy. However, it is my belief that any viable plan to convince farmers to grow alternative crops must resolve the reasons for the failure of the poppy eradication efforts. Failures are often blamed on a combination of a lack of security, splits in loyalty of the farmers between local insurgents and coalition forces, and

Livelihood transitions involving the eradication of poppy in Afghanistan have a number of challenges. The linked challenge of instability and poor governance/unstable government has led to inconsistent policies and enforcement. Prior to the Taliban rule, the cultivation of poppy crops for illicit opium production was fairly open and unrestricted. When the Taliban came to power, they implemented an extremely strict rule of law which has been the only mechanism successful in deterring opium production. When the U.S. intervened in 2001, opium production returned to pre-Taliban levels and eradication efforts of farm destruction were initiated through crop burning and other methods of plowing the crop. Attempts at introducing alternative livelihoods during the coalition occupation have continued to be fruitless (Glaze 2007, UNODC 2011). In addition, the inconsistencies and inability for the insurgents or the U.S. allies to reliably deliver on promises of security, education, and infrastructure to the people and farmers understandably breeds an environment of decreased trust internally and externally. High rates of poverty in the population continue to leave a developed illicit narcotics economy as one of the sole sources of reliable income for the farmers. Whereas before the war the Taliban tried to eradicate production, they have since exploited eradication efforts to their own benefit by providing protection to Afghan farmers and drug traffickers in exchange for their loyalty (Glaze 2007).

These issues may be similar to the issues Turkey faced when it transitioned from illegal poppy production and trade to pharmaceutical production, which was previously mentioned. However, Turkey's transition away from illicit opium production corresponds to the rise in Afghan opium profiteering, feeding the black market for opium products that have taken haven under Afghanistan's porous policy and governance system (Kamminga, 2006). However, by recognizing the needs of the people to be self-sufficient and including opium farmers in the transition process, I propose, this is a key component to successfully transitioning opium farmers to more positive and internationally acceptable production.

The current governance system in Afghanistan limits the majority of rural farmers to minimal acreage to make crop decisions over. The implementation of a poppy oil based straight vegetable oil can produce a significant amount of oil for energy use. Additionally, carefully calculated implementation and planning may be able to prevent the subsequent shift of the black market to Pakistan, Thailand or Burma/Myanmar.

3.0 A Hybrid Theory – A Hybrid Framework

A framework that links factors that interact across social, organizational, and biophysical domains and undertakes a resilient and sustainable approach would be desirable in Afghanistan. Some adaptable examples of processes that link these components with policy-making, regulation and communication across and between governance systems have been proposed (Folke, Carpenter et al. 2002; Adger, Brown et al. 2003; Olsson, Folke et al. 2004; Lebel, Anderies et al. 2006). Sustainability has come to encompass the interplay of the components of ecology, society, government and economy (Folke, Carpenter et al. 2002; Folke 2006; Berkes 2007). Resilience is an important aspect of sustainability because it is a measurement of how robust a system is to change and disruptions and the ability of that system to return to its prior state. In this way, the resilience component of sustainability is the governance or institutions that link the ecological system to the social system.

The key elements of diffusion theory are innovation, communication, time, and the social system (Rogers 2010). The success of the introduced innovation is assessed during the five step process of the adoption process. As mentioned in the chapter introduction, the five steps of the process the user goes through are: (1) knowledge of the innovation (exposure), (2) persuasion of the utility of the innovation, (3) decision on the advantages/disadvantages, (4) the implementation of the innovation in some way, and (5) the confirmation of the innovation (Rogers 2010). These steps were initially laid out by Everett Rogers in 1962 and later expanded on by numerous others (Dearing 2009; Lundvall, Joseph et al. 2009; Di Benedetto 2010; Rogers 2010; Buchanan, Cole et al. 2011; Jacobsson and Bergek 2011; Srholec 2011; Khavul and Bruton 2012). Rogers (2010), went further by categorizing potential users by their innovation adoption rates: the innovator; the early adopters; the late adopters; the early minority; the late majority, and the laggard.

Early adopters tend to be in tune with the social system and have a high level of sway in their village or neighborhoods such that others tend to seek out their advice (Di Benedetto 2010; Rogers 2010; Buchanan, Cole et al. 2011). Typically, they are the ones who are willing to be among the first to try a new product, technology, and/or innovation. This also means that they are often more willing to take risks and are of a higher socio-economic status. Early adopters play a central role in driving and diffusing innovations because of their willingness to try new things. They model the possibilities of transformation for others and help build support for change (Rogers 2010). These factors, among others, make early adopters more open to new science and technological innovations. In Afghanistan, small farm owners living near larger cities are the most likely early adopters for these kinds of agricultural innovations. Although not typically the first group that would come to mind, these farmers have been exposed to many of the more recent political and technological changes than their counterparts further away from larger cities. Often in developing countries, farmers are not considered ‘innovators’. This perspective of thinking may result in some to question how I expect that farmers would be an acceptable selection as the early adopters. However, it has been my experience in life, both as a farmer and in numerious interections that, in fact, farmers are extremely innovative. Specifically in developing countries in which they regularly face obstacles of low technology, minimal financial support and variable environmental conditions. Farmers in many developing regions truly are flexible and adaptable due in part to their intimate knowledge of the land and environmental conditions.

4.0 Resulting Framework

An idea intervention can be thought of as moving from conflict to cooperation. A common technique for guiding progression toward cooperation in international affairs is to partner development efforts with diplomatic efforts (Figure 2 a). However, often, the path from conflict to cooperation is not a straight line, but a complex path with various ups and downs (Figure 2 b).

Here, I present a promising theoretical framework that complements the strengths and utility of the interdisciplinary aspects of narco-agriculture, governance and alternative livelihoods. I use an interdisciplinary approach to build the framework to address the multi-faceted challenges of political ecology, enviro-agriculture, socio-cultural interactions in Afghanistan through a hybrid of the models presented by Berkes (2004), Patz and Daszak et al. (2004), Rosenstein (2004), Adger and Brown et al. (2005), Folke and Hahn et al. (2005), Wood

(2006), Folke and Pritchard et al. (2007), Johnston and Slyomovics (2009), and Myers (2009). The proposed framework (Figure 2a-c) shows the progression of rural adaptation to co-management of the narcotic trade, while keeping in mind the corruption in the governmental realm, the past regional/local policies on poppy growth, local citizen needs, and challenges in services.

In this work, I look to these small farm owners because while they may not be as open to risk-taking as diffusion of innovation theory would suggest would be ideal, they are more likely to have some decision-making control over their farms. Moreover, by choosing farmers relatively close to large cities, they have been exposed to the benefits of increased energy access and likely already have ideas of where they would use and benefit from increased access to the energy and its co-products on their farms. Success for these early adopters will be key, as in this case, these small farm owners in Afghanistan will bridge a two-category purpose in both demonstrating the utility of the product and building the community influence toward adoption by later adopters in the use of poppies for energy (Di Benedetto 2010; Rogers 2010).

Implementation progresses from a user driven 'non-management' strategy, to a strategy of engaging a joint user or non-governmental organizations (NGO) management paradigm (Figure 2 c). The presented governance structure combined with the introduction of the new fuel innovation will result in an environment of adopter adaptation as described by Rogers (2010). I expect this will lead to an increased emphasis on the co-products (soil amendment, animal feed, industrial paint additive, and boutique food products).

Figure series 4.2 depicts a transition to a stronger governance relationship in which alternatives have been further incorporated into the local economy and farming habits. In the model, I envision the village moving from conflict-to-reconciliation using diplomacy and development along with a progressive support mechanism that integrates the appropriate disciplinary approach to compliment the growth of a sustainable framework. In this framework, resource management and allocation avoids the waste and potential corruption at high levels of government by giving relatively small levels of control directly to the resource users until a social or economic demand has built up sufficiently to call upon the NGO community to assist in lobbying governmental outlets at the local/regional level. Additionally, this allows outside actors such as the international community and NGO's to continue to support the local/village government structure, which tends to be more stable than the national governmental influence, to ensure the infrastructure development needed by the users.

As a result of the transition phases between co-management, governance with sustainability and adaptation, I explain in Figures 2 c and d where innovation diffusion gains to fill in to better solidify these transitions. I start with the poppy crop being both illegal and primarily un-managed, detrimentally affecting the social ecological system. The resource users are the key constituents of support as the direct target of intervention efforts. The NGO's/societal groups and the government can partner to act as the co-supporters. This stage allows for the early adopters (small farm owners near big cities) to begin using the oil production and usage to show its viability.

In the next phase, a management approach in which the poppy crop is non-illegal (not legal/not promoted), but slightly managed allowing for an environment in which the resource users and the NGO's/societal groups are the direct target of intervention efforts. The government acts as an observing manager along with other international governments with a stake in the country, such as the United States, the U.K. and regional partners like Saudia Arabia. At this phase, the farmers begin making alternative innovations to fit fuel production and usage into their specific needs, while at the same time increasing buy-in to the innovation and allowing for improvement to the design for better diffusion will become observable.

In the final stage to reach cooperation, an interdisciplinary approach in which the poppy crop is “less illegal/non-legal” but since it is more managed, allows for greater flexibility in alternative livelihoods in which the resource users begin developing deeper trust and partnership with the multilateral partnerships. The government will have a more direct relationship with the resource users. The NGO’s/societal groups will act as support agents along with other international governments, which can passively engage/disengage as needed to further facilitate self-sufficiency. The increased self-sufficiency is represented in Figure 2 d, where the depictions of the progress from poppy seeds to the fuel oil are inserted along with co-products (animal feed and/or soil amendment, discussed in Chapter 3) are put to use. The access to the new fuel source will provide the capacity to operate generators that can be used for lighting homes or schools supporting increased education by extending the reading day. The fuel could also be used for heating and thus promoting health through warmth. Possibly the biggest benefit of village electrification of small remote villages would be the ability to access refrigeration technologies for the storage of medications which could greatly reduce the burden of diseases. Alternatively, using the fuel in irrigation pumps could increase food crop production and in tandem with using the seedcake for animal feed or a soil amendment, could promote health and further self-sufficiency.

5.0 Discussion and Conclusions

Opium poppy cultivation in Afghanistan continues to challenge public health, environmental quality, regional stability and global security. Efforts to reduce the growth and sale of illicit opium and its derivatives have been unsuccessful and in some cases counterproductive. In this chapter, I presented a framework for using Afghan-grown poppies to produce a biofuel that could power diesel generators. This framework provides a potential map for the innovation diffusion and agricultural management that needs to happen as coalition forces withdraw from Afghanistan in 2014. Specifically, this framework is designed to begin a sustainable and peaceful transition to high value crops such as camelina and its derivatives, which can propagate increased regional public health, environmental quality, security, and economic growth in Afghanistan. Past policies have shown, however, that merely attempting to stop poppy farming at the source will not increase stability in Afghanistan (UNODC 2011). However, international efforts in India and Turkey have proven to be successful in the near eradication of the illegal opium trade through changes in policies (Kamminga, 2006). I hypothesize in this chapter that similar changes in governance and policy structures, adjusted for the realities in Afghanistan, could do the same.

In other work, I showed the viability of poppy oil and its co-products for use as an emissions and energetically efficient on-farm produced, locally sustainable heating/cooking source, combustion fuel, animal feed and soil amendment (Mourning-Star and Reardon 2014 unpublished). Here, I have presented a framework by which Afghanistan can take an alternative approach toward transitioning farmers away from poppy production by taking smaller steps through a joint (farmer/user, NGO, government) strategy. Redirection of the cultivated opium poppies towards the production of a biofuel could be used. The oil extracted from poppy seeds is a viable renewable energy source that reduces the environmental and health hazards of diesel emissions, can operate in regular diesel engines and generators (with inexpensive modifications) (Martinot and Sawin 2011), and can be used as a soil amendment and animal feedstock. This framework has the potential to reduce the dependence of rural Afghan farmers on the global illicit opium trade and decrease their victimization at the hands of false producers of fertilizers.

Progress of development in Afghanistan must recognize and capitalize on the similarities of sustainability and adaptation in both environmental and innovation-diffusion in the development field. The literature supports the interdisciplinary route of including a governance/co-management strategy for sustainable ecological resource development. Folke (2007) provides analysis that suggests the governance system itself needs to be adaptable and that on-going ecosystem management will incorporate a balance between management and leadership along with balance between conventional resource management and the implementation (Folke, Pritchard et al. 2007). This strategy includes:

- Mechanisms for communication and trust between the governing body and the resource users (vertical) that is not simply top-down, but allows for effective bottom-up communication.
- Mechanisms for communication and trust between the resource users and other civil and non-governmental groups (horizontal and vertical).
- Mechanisms that allow for transparent communication between (i) science/media; (ii) civil groups; (iii) resource users; and (iv) government/regulation via policies that promote management.

One concept Adger et. al (2003) uses to describe the governance/management paradigm is the relationship between decision making and economic factors underlying those decisions on local, regional and global planes. The fact that the poppy crop is one that is well known for thousands of years within the region means that successful introductions to new innovations should be designed such that farmers need not make changes in growth, planting, production, and seasonal activities of poppy production. This is huge factor in production, environment and social habits which make the usage of poppy seeds for rural agriculture and domestic uses especially powerful. Poppy production lends itself to being a transition to other products that may require only slight changes in habits and techniques. Similarly, for the environment the changes would mean less impact since this framework does not promote any land-use change (only putting to use parts of the poppy seed waste product); and would allow researchers and analysts to be able to watch the potential for transition impacts on the environment in different ways prior to mass up-scaling and implementation of alternatives. Economically this means both an opportunity to increase the uses of current crops but also increase education technological advances that would otherwise not occur.

In this framework, I was able to propose solutions to many of the shortcomings of other interventions. Rather than focusing on the economic export of a product, the product is being used as a social and technological partnership based on a different resource management. As the fuel and its co-products are being proposed as resources to be used locally and improve life within the villages, there is a much more value for the local people/partners through the bolstering of self-sufficiency and independence. Finally, it is worth recognizing that in regards to both environment and international relations, if one were to go beyond the barriers of governmental actors in the community level, many of the concerns of the outside world (including researchers, do-gooders, and self-serving government representatives/diplomats) are second place to the populations' needs to feed themselves and address their own concerns addressed in the Maslow's Hierarchy of Needs (Fig. 3). Addressing these needs are the first priority for all societies, people and cultures and is a key factor in my proposal, not only in implementation of poppy as a fuel , but also in how one goes about providing these kinds of changes.

These suggestions are not born from an overly naive desire for world peace; rather from person-to-person and on-the-ground discussions with Afghan citizens, political representatives, and government agents. However, these sentiments have been echoed by various news reports and discussions with current top U.S. Diplomats, proven in work by NGOs and changes in U.S. State Department policies and, unfortunately, evidenced by the resilience and progress made by the Taliban, Al Qaeda, the Haqqani Network and other insurgent groups using similar co-management/control and shared benefits paradigms with the rural farmers.

6.0 Figures

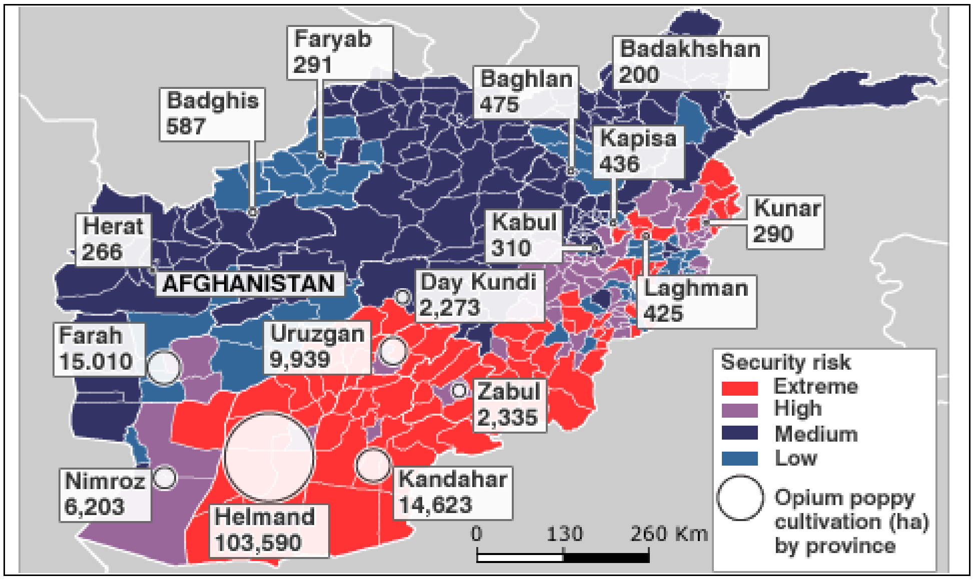

Fig. 4.1 Map of Afghanistan showing the security situation by district and opium cultivation by province in the period 2007 to 2008; United Nations Department of Safety and Security.

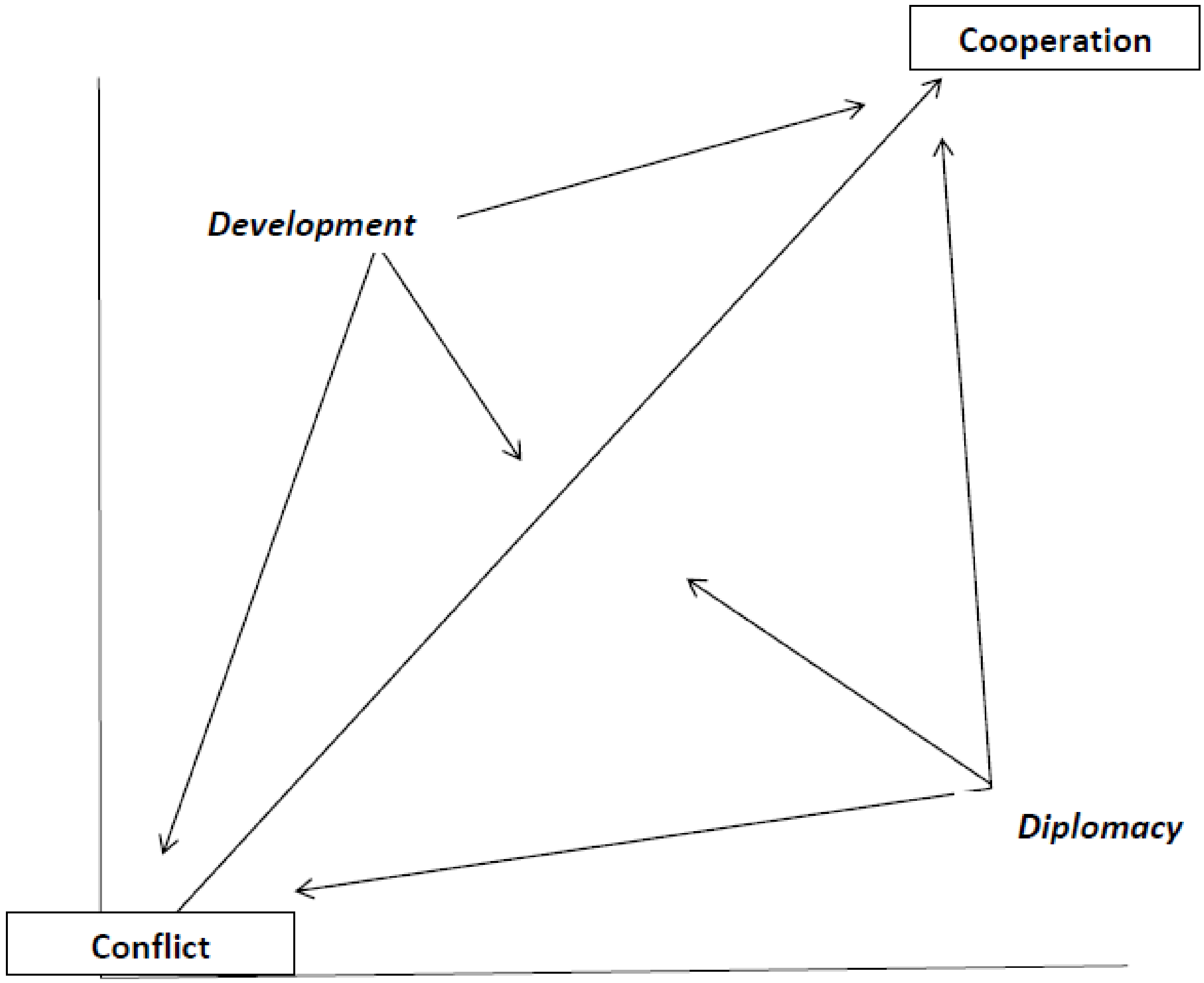

Figure 4.2 a. Framework depicting initial transition toward stability from conflict to cooperation using diplomacy and development, and bolstered by components of diffusion of innovation to implement poppy oil SVO in new livelihood production in Afghanistan.

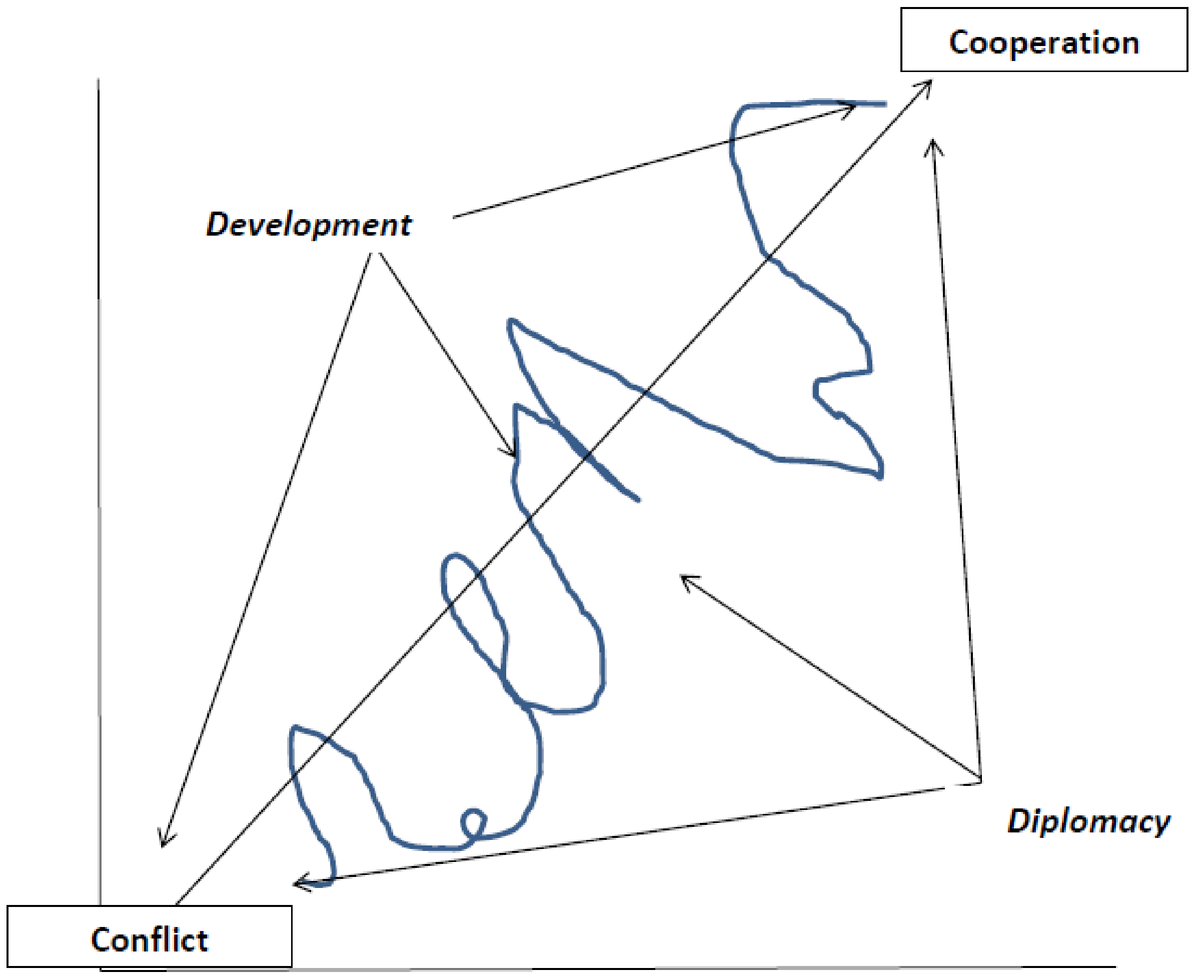

Figure 4.2 b. Framework depicting initial transition toward stability from conflict to cooperation using diplomacy and development, and bolstered by components of diffusion of innovation to implement poppy oil SVO in new livelihood production in Afghanistan.

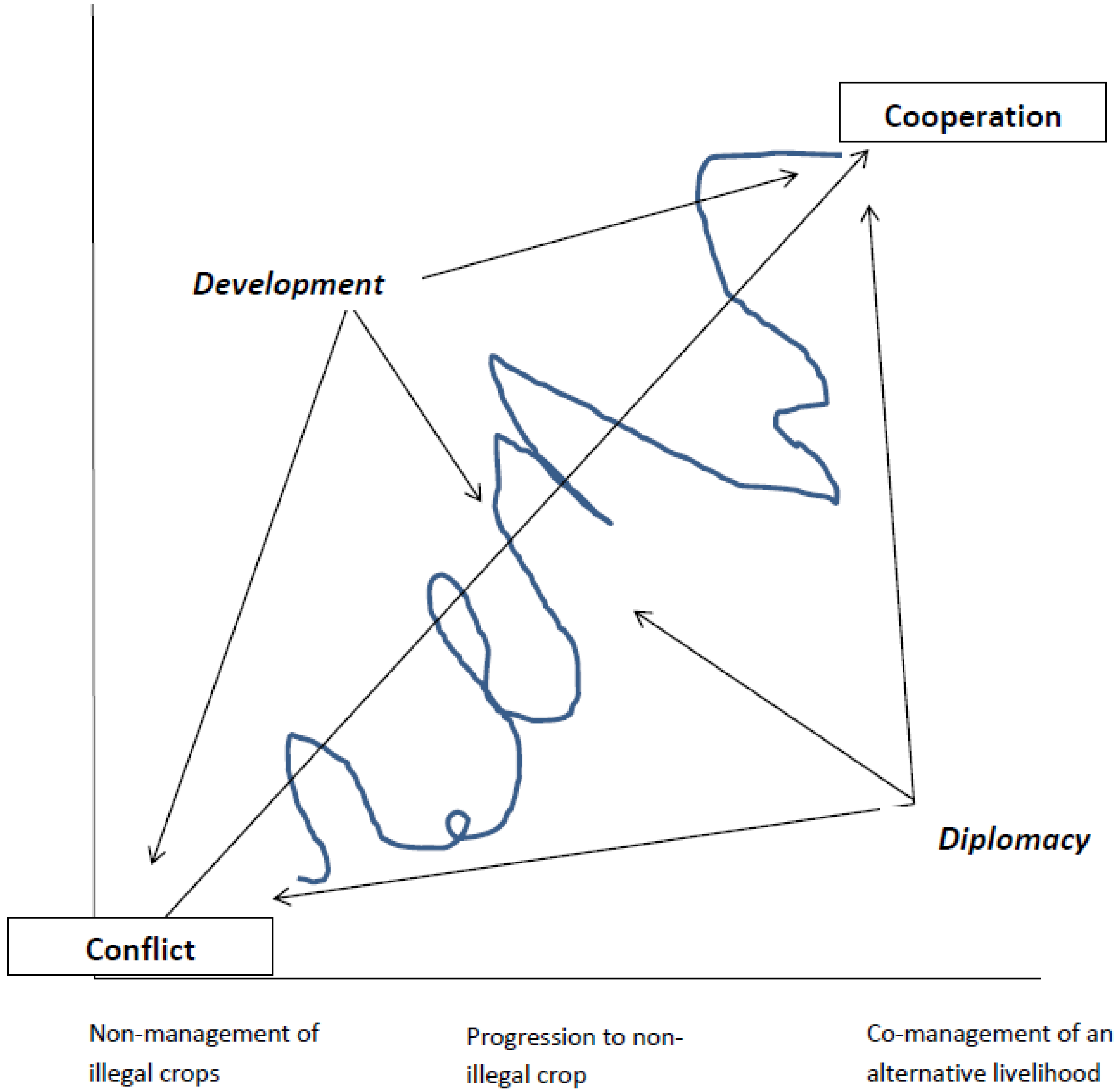

Figure 4.2 c. Framework depicting initial transition toward stability from conflict to cooperation using diplomacy and development, and bolstered by components of diffusion of innovation to implement poppy oil SVO in new livelihood production in Afghanistan.

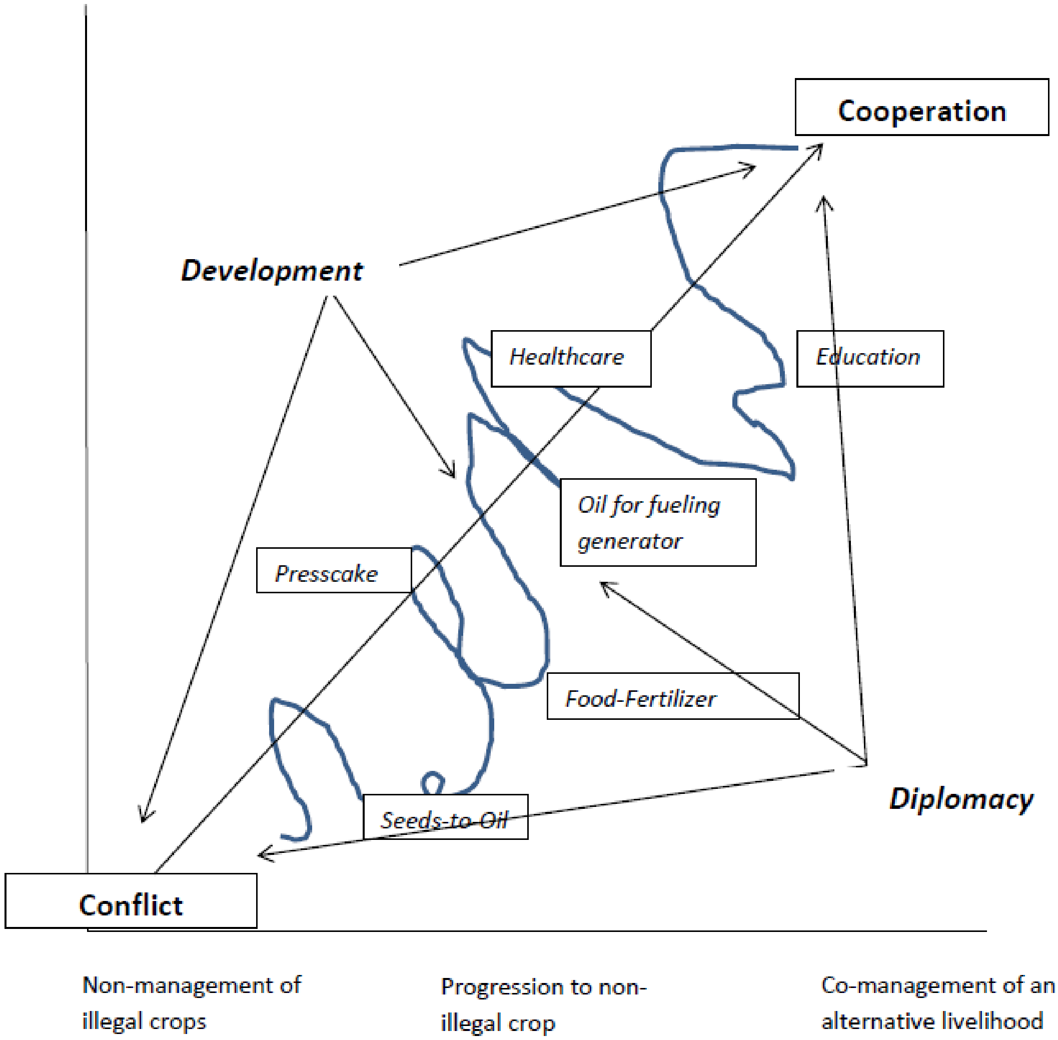

Figure 4.2 d. Framework depicting initial transition toward stability from conflict to cooperation using diplomacy and development, and bolstered by components of diffusion of innovation to implement poppy oil SVO in new livelihood production in Afghanistan.

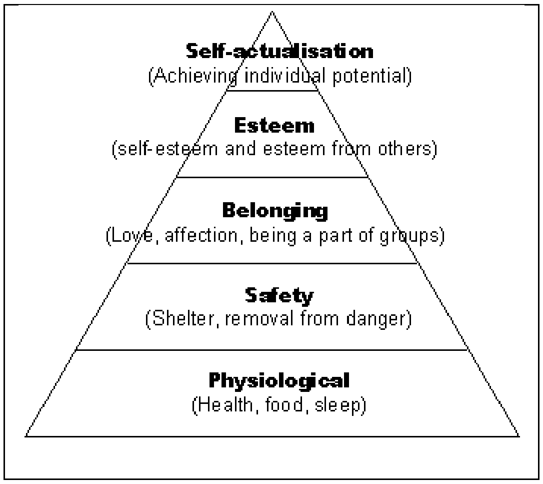

Fig. 4.3 Maslow’s Hierarchy of Needs.

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Chapter 5. Conclusions

In the preceding chapters I used a life cycle assessment model to show that biofuel from poppy oil is feasible from an emissions and energy return on investment perspective. The goal of this section of the study was to assess the net/gross energetic and emissions feasibility of producing poppy seed SVO as a transition strategy for poppy farmers to alternative crops. My LCA provides a platform for supporting the energetic inputs and GHG and emissions outputs of such projects. I found that a decentralized/on-farm scenario was more efficient energetically and produced lower levels of emissions. In terms of the energy input and emissions created, the on-farm model clearly makes the most efficient use of resources.

I then provided analysis demonstrating that the fuel characteristics of opium poppy oil and the properties of the co-products after extraction is viable for use in slow diesel engines to generate electricity. I also establish that the waste from extracting oil from the poppy seeds, presscake, could be used as soil amendment and animal feedstock. Finally, I developed a theoretical framework for the implementation of this innovation specific to poppy production in Afghanistan to address resource management and innovation.

The motivation for this work was driven by my time in Afghanistan. There are a number of needs and issues to be addressed in the interest of providing a safer, stable country for the people of Afghanistan. The challenges are not out of reach if addressed with an open mind and continued passion for finding solutions through research, development, science, technology and innovation. Proposals such as this one, which proposes to put poppy seeds left not used in the heroin trade as a biofuel, have the potential to play a unique role in creating political and social relationships to build a long term foundation for peace and development.

Chapter 6. Supplementary Materials

Detailed GREET Beta output for emissions and Energy inputs. Lifecycle accounts for total energy input into the system measured in MJs. Subcategories are break downs of upstream system inputs.

Table 6.1. Scenario A- Low-Area/Low-

Yield – No Fertilizer

	Transport Distance km				
Emissions	*0*	*5*	*10*	*25*	Units
VOC	0	247	495	1240	mg
CO	0	677	1350	3390	mg
NO_x	0	2.18	4.37	10.9	g
PM_{10}	0	162	325	812	mg
$PM_{2.5}$	0	105	210	526	mg
SO_x	0	536	1070	2680	mg
CH_4	0	2.18	4.36	10.9	mg
N_2O	0	33.7	67.3	168	mg
CO_2	0	1.43	2.86	7.16	g

Table 6.2. Energy input for Scenario A- Low-Area/Low-Yield – No Fertilizer

Energy	Transport Distance km				
	0	*5*	*10*	*25*	Units
Life Cycle	0	19.2	38.4	96	MJ
Resources					
Crude Oil	0	15.80	31.50	78.80	MJ
Natural Gas	0	1.77	3.55	8.87	MJ
Bituminous Oil	0	1.37	2.74	6.85	MJ
Coal	0	0.23	0.46	1.15	MJ
Nuclear Energy	0	0.03	0.06	0.16	MJ
Hydroelectric Power	0	0.01	0.02	0.05	MJ
Wind Power	0	0.00	0.01	0.02	MJ
Forest Residue	0	0.00	0.01	0.02	MJ
Solar	0	0.00	0.00	0.00	MJ
Uranium Ore	0	303	607	1520	µg

Table 6.3. Emissions for Scenario

B- High-Area/Low-Yield – No

	Transport Distance km				
Emissions	*0*	*5*	*10*	*25*	Units
VOC	0	247	495	1240	mg
CO	0	677	1350	3390	mg
NO_x	0	2.18	4.37	10.9	g
PM_{10}	0	162	325	812	mg
$PM_{2.5}$	0	105	210	526	mg
SO_x	0	536	1070	2680	mg
CH_4	0	2.18	4.36	10.9	mg
N_2O	0	33.7	67.3	168	mg
CO_2	0	1.43	2.86	7.16	g

Table 6.4. Emissions for Scenario B- High-Area/Low-Yield – No Fertilizer

Energy	Transport Distance km				
	0	*5*	*10*	*25*	Units
Life Cycle	0	19.2	38.4	96	MJ
Resources					
Crude Oil	0	15.80	31.50	78.80	MJ
Natural Gas	0	1.77	3.55	8.87	MJ
Bituminous Oil	0	1.37	2.74	6.85	MJ
Coal	0	0.23	0.46	1.15	MJ
Nuclear Energy	0	0.03	0.06	0.16	MJ
Hydroelectric Power	0	0.01	0.02	0.05	MJ
Wind Power	0	0.00	0.01	0.02	MJ
Forest Residue	0	0.00	0.01	0.02	MJ
Uranium Ore	0	303	607	1520	µg

Table 6.5. Emissions for Scenario C- Low-Area/High-Yield – No Fertilizer

Emissions	Transport Distance km				
	0	*5*	*10*	*25*	Units
VOC	0	742	1480	3960	mg
CO	0	2030	4060	10800	mg
NO_x	0	6.55	13.1	34.9	g
PM_{10}	0	487	974	2600	mg
$PM_{2.5}$	0	315	631	1680	mg
SO_x	0	1610	3210	8570	mg
CH_4	0	6.53	13.1	34.9	mg
N_2O	0	101	202	538	mg
CO_2	0	4.29	8.59	22.9	g

Table 6.6. Energy input for Scenario C- Low-Area/High-Yield – No Fertilizer

Energy	Transport Distance km				
	0	*5*	*10*	*25*	Units
Life Cycle	0.00	57.6	115	307	MJ
Resources					
Crude Oil	0	47.30	94.50	236.00	MJ
Natural Gas	0	5.32	10.60	26.60	MJ
Bituminous Oil	0	4.11	8.22	20.50	MJ
Coal	0	0.69	1.37	3.44	MJ
Nuclear Energy	0	0.10	0.19	0.48	MJ
Hydroelectric	0	0.03	0.06	0.16	MJ
Wind Power	0	0.01	0.02	0.06	MJ
Renewable	0	0.00	0.00	0.01	MJ
Solar	0	0.00	0.00	0.01	MJ
Uranium Ore	0	910	1820	4850	µg

Table 6.7. Emissions for Scenario D-: High-Area/High-Yield– No

	Transport Distance km				
Emissions	*0*	*5*	*10*	*25*	Units
VOC	0	1980	3960	9890	mg
CO	0	5420	10800	27100	mg
NO_x	0	17.5	34.9	87.3	g
PM_{10}	0	1300	2600	6500	mg
$PM_{2.5}$	0	841	1680	4210	mg
SO_x	0	4290	8570	21400	mg
CH_4	0	17.4	34.9	87.1	mg
N_2O	0	269	538	1350	mg
CO_2	0	11.5	22.9	57.2	g

Energy	Transport Distance km				
	0	*5*	*10*	*25*	Units
Life Cycle	0	154	307	768	MJ
Resources					
Crude Oil	0	126.00	252.00	630.00	MJ
Natural Gas	0	14.20	28.40	71.00	MJ
Bituminous Oil	0	11.00	21.90	54.80	MJ
Coal	0	1.83	3.67	9.16	MJ
Nuclear Energy	0	0.26	0.51	1.28	MJ
Hydroelectric Power	0	0.09	0.17	0.43	MJ
Wind Power	0	0.03	0.07	0.17	MJ
Forest Residue	0	0.03	0.06	0.15	MJ
Geothermal	0	0.00	0.01	0.02	
Renewable (Solar, Hydro,	0	0.00	0.01	0.02	MJ
Solar	0	0.00	0.00	0.00	MJ
Uranium Ore	0	2430	4850	12100	µg

Table 6.9. Emissions for Fertilizer Scenarios: Scenario Q: Low-Area/High-Yield0km; Scenario R: High-Area/Low-Yield10km

Emissions	LHF0	HLF10	units
VOC	8.17	8.42	g
CO	10.7	11.4	g
NO_x	51	53.2	g
PM_{10}	10.8	10.9	g
$PM_{2.5}$	6.44	6.55	g
SO_x	253	253	g
CH_4	37.4	39.6	g
N_2O	14.3	14.3	g
CO_2	7.07	8.5	Kg

Table 6.10. Energy inputs for Fertilizer Scenarios: Scenario Q; Scenario R

	LHF0	HLF10	units
Energy			
Life Cycle	127	146	MJ
Resources			
Crude Oil	26.1	41.9	MJ
Natural Gas	68.4	70.2	MJ
Bituminous Oil	24.7	24.9	MJ
Coal	3.75	3.78	MJ
Nuclear Energy	2.27	3.64	MJ
Hydroelectric Power	1.21	1.23	MJ
Wind Power	0.45	0.45	MJ
Forest Residue	0.27	0.27	MJ
Renewable (Solar, Hydro, Wind, Geothermal)	0.07	0.07	MJ
Solar	0.01	0.01	MJ
Uranium Ore	0.04	0.04	mg
Groups			
Fossil Fuel	0.02	35.1	MJ
Petroleum Fuel	0.01	31.4	MJ
Natural Gas Fuel	0	3.27	MJ
Coal Fuel	0	0.42	MJ
Non Fossil Fuel	0	0.1	MJ
Nuclear	0	0.06	MJ
Renewable	0	0.04	MJ
Biomass	0	0.01	MJ

Table 6.11. Emissions for diesel scenarios

	Transport Distance km				
Emissions	*0*	*5*	*10*	*25*	Units
VOC	4950	5720	6500	8830	mg
CO	13500	15700	17800	24200	mg
NO_x	43.7	50.5	57.4	77.9	g
PM_{10}	3250	3760	4270	5800	mg
$PM_{2.5}$	2100	2430	2760	3750	mg
SO_x	10700	12400	14100	19100	mg
CH_4	43.6	50.4	57.2	77.8	mg
N_2O	673	779	884	1200	mg
CO_2	28.6	33.1	37.6	51.1	g

Table 6.12. Energy inputs for diesel scenarios

	Transport Distance km				
	0	*5*	*10*	*25*	Units
Life Cycle	384	444	504	685	MJ
Resources					
Crude Oil	315	364.50	414	562	MJ
Natural Gas	35.5	41.05	46.6	63.3	MJ
Bituminous Oil	27.4	31.7	36.0	48.9	MJ
Coal	4.58	5.30	6.02	8.18	MJ
Nuclear Energy	0.64	0.74	0.84	1.14	MJ
Hydroelectric Power	0.22	0.25	0.28	0.38	MJ
Wind Power	0.08	0.10	0.11	0.15	MJ
Forest Residue	0.08	0.09	0.10	0.14	MJ
Renewable (Solar, Hydro, Wind, Geothermal)	0.01	0.01	0.02	0.02	MJ
Solar	0.01	0.01	0.02	0.02	MJ
Uranium Ore	6070	7020	7970	10800	µg

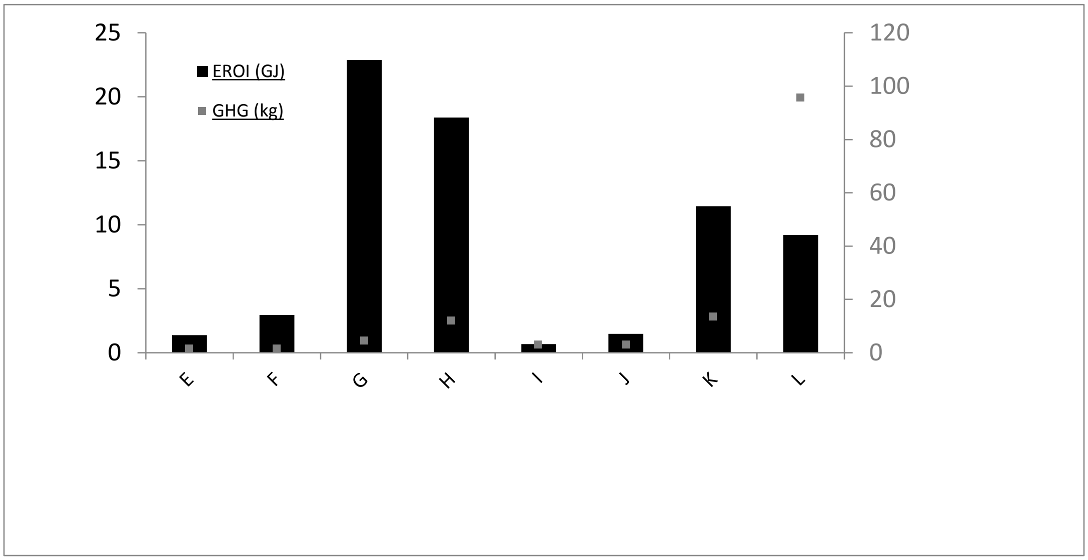

Fig. 6.1 EROI, GHG (kg) for production and transportation comparing 5 km and 10 km transportation scenarios.