




Assessment of Biomass Resources in Afghanistan

Anelia Milbrandt and Ralph Overend

NREL is a national laboratory of the U.S. Department of Energy, Office of Energy Efficiency & Renewable Energy, operated by the Alliance for Sustainable Energy, LLC.

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Executive Summary

Afghanistan is facing many challenges on its path of reconstruction and development. Among all its pressing needs, the country would benefit from the development and implementation of an energy strategy. In addition to conventional energy sources, the Afghan government is considering alternative options such as energy derived from renewable resources (wind, solar, biomass, geothermal). Biomass energy is derived from a variety of sources – plant-based material and residues – and can be used in various conversion processes to yield power, heat, steam, and fuel.

This study provides policymakers and industry developers with information on the biomass resource potential in Afghanistan for power/heat generation and transportation fuels production. To achieve this goal, the study estimates the current biomass resources and evaluates the potential resources that could be used for energy purposes.

This study identified biogas generation from animal manure and waste-to-energy (WTE) from urban discards as the most promising sustainable biomass technologies that use existing resources in Afghanistan. The biogas technology is more applicable to rural regions and it provides many benefits to households including reductions in indoor air pollution, reductions in firewood use and collection time (especially for women), and increases in crop production by using the spent slurry as a fertilizer. WTE is best suited for urban areas and it provides two important benefits: environmentally safe waste management and disposal, as well as the generation of clean electric power. Crop residues in Afghanistan are already in use as animal feed, cooking fuel, for farm applications, and as construction material. Forest resources are limited; yet, they represent a significant component of the solid biomass fuels used for cooking and space heating. Therefore, these conventional biomass resources cannot support electricity generation applications in the country. The solid fuel situation in Afghanistan needs attention for many reasons: indoor use is associated with major health problems and, at this stage of natural resource depletion in the country, the continued collection of firewood and shrubs exacerbates the risk of desertification. As with any case of fuelwood scarcity, the remedies include a series of activities such as reducing energy use by improving efficiency of building and cooking/heating equipment, as well as reforestation and aforestation initiatives. These activities mitigate air pollution and conserves plant resources.

Climate and terrain are major limitations on the potential biomass resources in Afghanistan. Climate prediction models indicate that drought will become the normal season by 2030 and that large parts of the agricultural land are likely to become marginal without investments in water management and irrigation by 2060. Annual oilseed production for both food and fuel applications could be undertaken to offset cooking oil imports and provide local biofuels. In addition, common oilseed plants could be grown in similar areas that have been successful with opium poppy, which would provide alternative crops to farmers in those regions.

The Afghan reality is that both food and energy security are poor. Sustainable biomass technologies such as biogas and WTE could find a place in the country's energy mix by providing clean fuel to rural and urban communities without endangering food supply. These technologies also could provide many other environmental and socioeconomic benefits, such as safe waste disposal, reduced GHG emissions, improved households' lifestyle and job creation.

Abbreviations, Acronyms, and Specialized Terms

Abi – irrigated land
AIMS – Afghanistan Information Management Services
CO_2 – carbon dioxide
CSO – Central Statistics Organization
FAO – Food and Agriculture Organization
GDP – Gross Domestic Product
GHG – greenhouse gas
GIS – Geographic Information Systems
Kareze - a historic Persian system of underground water collection
Kuchi – pastoralists, who practice transhumance between high altitude pasture in the summer and the low lands in the winter
Lalmi – rainfed lands
LPG - Liquefied Petroleum Gas
MSW – municipal solid waste
NGO – Non-governmental organization
UNEP – United Nations Environmental Programme
WTE – waste-to-energy

Units of Measure

Btu – British Thermal Unit
dam^3 – cubic decameter (= 1,000 m^3 = 1 ML)
dm – decimeter (= 10 centimeters)
gal – U.S. gallon
GJ – Gigajoule (10^9 J)
ha – hectare
HHV – High heating value
Jerib (Afghan) – 2,000 m^2 or 0.2 hectare
kcal - kilocalorie (= 4,184 joules)
km – kilometer
km^2 – square kilometer
kt (ktonne) - kilotonne (= 1,000 metric ton)
kWh – kilowatt-hour
L – liter
m – meter
m^2 – square meter
m^3 – cubic meter
MCM – million cubic meter, also hm^3 (cubic hectometer)
MJ – Megajoule
ML – Megaliter (=1,000,000 L)
mm - millimeters
Mt – million tonnes
PJ – Petajoule (10^{15} J)
TJ – Terajoule (10^{12} J)
tonne (t) – metric ton

Introduction

Afghanistan is facing many challenges on its path of reconstruction and development. Among all its pressing needs, the country would benefit from the development and implementation of an energy strategy. In addition to conventional energy sources, the Afghan government is considering alternative options, such as energy derived from renewable resources (wind, solar, biomass, geothermal). Biomass energy is obtained from a variety of sources – plant-based material and residues – and can be used in various conversion processes to yield power, heat, steam, and fuel. Biomass energy resources include agricultural crops and residues (including animal waste); forestry products and residues; dedicated energy crops; residues and byproducts from food, animal feed, fiber, wood, and materials processing plants; and post-consumer residues and wastes, such as municipal solid wastes, wastewater, and landfill gases.

This study provides policymakers and industry developers with information on the biomass resource potential in Afghanistan for power/heat generation and transportation fuels production. To achieve this goal, the authors assessed the biomass resources available in the country and evaluated potential resources that could support the development of bioenergy projects. To accomplish these objectives, agricultural, environmental, and socioeconomic data were analyzed statistically and graphically using geographic information systems (GIS). A GIS is a computer-based information system used to create, manipulate, and analyze geographic information. The results are presented in a tabular and geospatial format (maps) at a national, sub-national, and site-specific level.

The authors estimated the biomass resources based on assumptions and factors that relate agricultural and demographic statistics to the amount of residue and waste generated. A detailed description of the methodology is provided throughout the document. Although these numbers are conservative and somewhat arbitrary, users can adjust assumptions and conversion factors for further evaluation of the biomass resource availability.

The authors recommend detailed on-site analysis before developing any facilities. This analysis, however, is useful in refining the prospecting process of site identification.

The Geography and Climate of Afghanistan

Agricultural and forest resource productivity depends on adequate sun, rainfall, and nutrient conditions. Depending on the climate and crop harvesting schedule, there can be seasonal constraints on this type of resource availability and significant annual variability in resource yields at a local level. Adverse environmental conditions (e.g., drought and floods) can have significant negative impacts on resource availability from year to year.

As illustrated in Figure 1, the country is predominately mountainous. Although it is described as having mainly a dry continental climate, the variance in terrain and elevation results in different climatic types. Areas such as northeastern and central Afghanistan, which are more than 2,400 meters (m) above sea level, have long winters (more than six months). At an altitude of 1,300 – 2,400 m above sea level, the climate is temperate or almost temperate, four seasons are clearly marked, and annual precipitation is up to 400 millimeters (mm). The zone at an altitude between 900 and 1,300 m is characterized by hot summers and annual precipitation below 200 mm. In areas below 900 m, the annual precipitation is less than 100 mm and the climate is dry and hot. Some small portions in the country's east adjacent to the Indus valley are affected by southeastern monsoons and climate is subtropical. Afghanistan's climatic types are shown in Table 1.

The terrain of Afghanistan is very diverse, going from the deserts of the Kandahar region, through the western-southwestern lowlands, to the Turkestan plains in the North, running into the lower central mountains, to the high mountains in the Northeast. The snow-capped peaks of the Hindu Kush are a central feature not just of the topography, but also of the water supply – a major part of which is snow melt in the spring and summer.

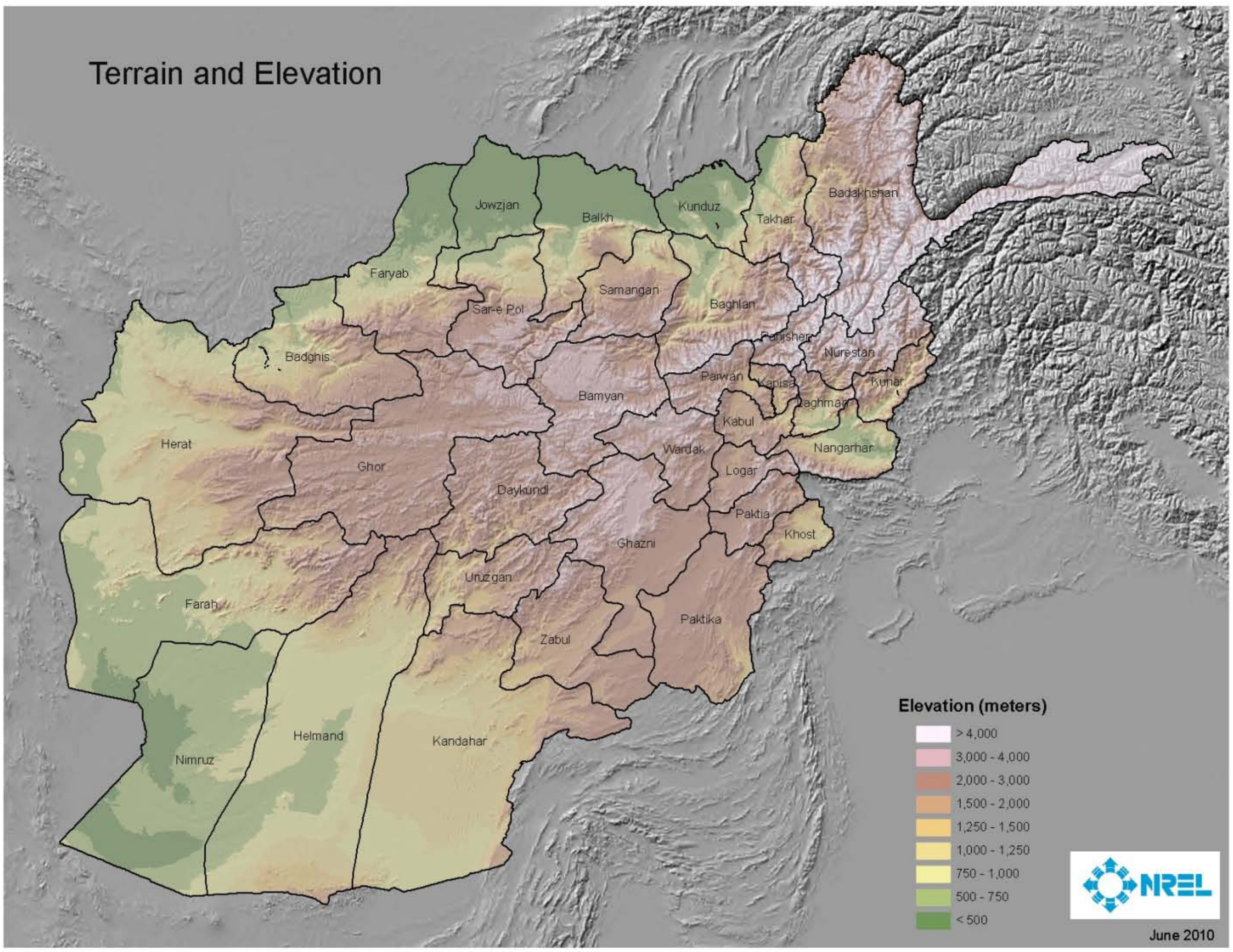


Figure 1. Terrain and elevation map of Afghanistan

Table 1. Climatic Types of Afghanistan

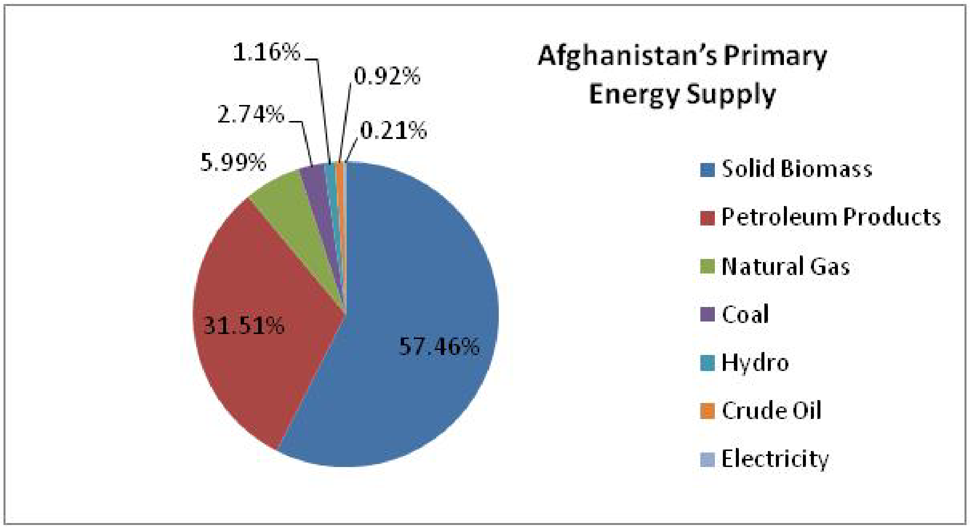
REGION	CLIMATIC TYPE
Extreme North	Continental desert climate
South	Sub-tropical desert climate
Northwest	Continental semi-arid Mediterranean climate
Lower central & Southeast	Warm semi-arid Mediterranean climate
Northeast central	Continental semi-arid to moist Mediterranean with
Lower Kabul Valley	Dry Steppe climate
High mountains, central and Northeast	Alpine

Source: Thieme 2006

The Afghan Energy Situation

Energy production and supply in Afghanistan is very unstable due to the country's damaged and fragmented power generation and distribution infrastructure, as well as the high dependency on imported petroleum products. Several domestic agencies, such as the Ministry of Energy and Water; the Ministry of Mines; the Ministry of Rural Rehabilitation and Development; the Ministry of Commerce and Industries; and the Ministries of Urban Development, Finance, and Economy are involved in rebuilding the country's energy sector. Additionally, donor agencies such as the United States Agency for International Development (USAID) and the Asian Development Bank (ADB), as well as and several nongovernment organizations (NGOs) are supporting the rehabilitation and development efforts.

Although Afghanistan is using domestic oil and natural gas, the potential reserves in the north remain untapped due to the country's long period of political instability. Afghanistan also uses indigenous coal, most of which is in the north between Herat and Badashkan provinces. However, as shown in Figure 2, these sources of energy comprise a small portion of the country's energy portfolio compared to the two largest suppliers – solid biomass and petroleum products. Biomass resources are domestic, while petroleum products such as diesel, gasoline, and jet fuel are imported from neighboring countries (mainly Pakistan and Uzbekistan, with limited volumes from Turkmenistan and Iran). Electricity, which is also imported from neighboring countries, provides the smallest portion of the country's energy mix. As of September 2009, about 15% of households in urban centers had access to electric power, but only 6% of rural households had access to electricity (SIGAR 2010).



Source: ADB 2006; figure illustrates percentage of total energy supply

Figure 2. Afghanistan's primary energy supply, 2002

At a household level, the use of solid biomass resources – firewood, charcoal, animal dung, and crop residues – is very high, about 90% of total (Table 2); firewood provides 65% of the domestic fuel. Anecdotal evidence and historical sources show that rural population is almost totally dependent on biomass fuels for cooking and heating, while lighting is provided by kerosene. In urban areas, there is a push to use liquefied petroleum gas (LPG) to offset fuelwood consumption and its resulting air pollution.

Table 2. Usage of Domestic Fuels for Cooking, Space, and Water Heating, 2002

Household Fuel	ktonne/yr	Overall Share of Household Use (%)
Fuelwood	6,145	65
Charcoal/other	1,013	25
Coal	122	3
Kerosene	55	2
LPG	135	5

Source: ADB 2006; LPG - liquefied petroleum gas

The high altitude and severe winter conditions for much of the population result in a very high per capita consumption of fuelwood and charcoal, which increases to more than 10 t/yr for households in some circumstances. Aid workers have witnessed acute firewood shortages in and around Kabul, and there is a general concern that the ordinary households in rural areas often lack sufficient fuel for cooking. Outside of the cities, biomass solid fuels will most likely remain the fuel of choice until other options are made available. However, wealthier families often have fossil fuel options as part of their energy portfolio. If the solid biomass is calculated on the basis of dry fuelwood equivalence (i.e., 18 GJ/t) it corresponds to 5.95 million tonnes (Mt). The actual tonnage is larger than this, because field residues such as wheat straw, dung, and shrubs have a lower heating value. For comparison, the amount of biomass used to fuel Afghanistan is almost 150% of the tonnage of wheat harvested in 2007.

The solid fuel situation needs attention for many reasons. The use of solid fuel is associated with major health problems; and, at this stage of natural resource depletion in Afghanistan, the continued collection of firewood and shrubs, as well as the use of dried dung, exacerbates the risk of desertification. One recent example is the destruction of pistachio forests in Badghis province for fuel wood (IWPR 2010). This analysis shows that the use of dung as a solid fuel could be replaced by anaerobic digestion with a concomitant improvement in efficiency, and the conservation of nutrient values. However, the provision of fuelwood is a major concern.

A threefold approach can be applied to resolve the fuelwood scarcity issues. First and foremost, Afghanistan needs to reduce energy demand while still providing the same service for cooking and space heating. NGOs' efforts have identified that insulation of buildings in northern or high-altitude areas would positively impact fuelwood consumption directly, while improved cookstoves, including ovens, will also help reduce consumption (Nienhuys 2009). There is also a need for increased fuelwood supplies, which could be ensured by planting trees and shrubs.

Agricultural Resources

Overview of Agricultural Sector

The agricultural sector of Afghanistan is the most important component of the country's economic development – it accounts for more than half of the gross domestic product (GDP), with more than 80% of the population engaged in farming or herding, or both (UNEP 2009). Tragically, several decades of war, lack of governance, and drought have depressed the agricultural activities in Afghanistan and contributed to the degradation of natural resources. Agricultural productivity is hampered by water shortages (due to poor irrigation systems and lack of rain water), lack of credit, little mechanization, insufficient outreach of agricultural and veterinary extension services, and poor accessibility of markets and communities (ICON Institute 2009).

Because of the mountainous terrain and dry climate, agricultural development in Afghanistan is very challenging. Of the total land area (652,225 km^2), only about 12% is arable (of which 6% is actually cultivated), permanent pasture covers 47%, forest land is 2%, and the remaining 39% is barren land/mountains (Figure 3). The amount of agricultural land under cultivation and pasture has dropped in the past two or three decades either through abandonment (due to lack of water availability and damage to irrigation systems), degradation (due to soil erosion, salinization, and reduced soil fertility), or urban expansion (NEPA-UNEP 2009).

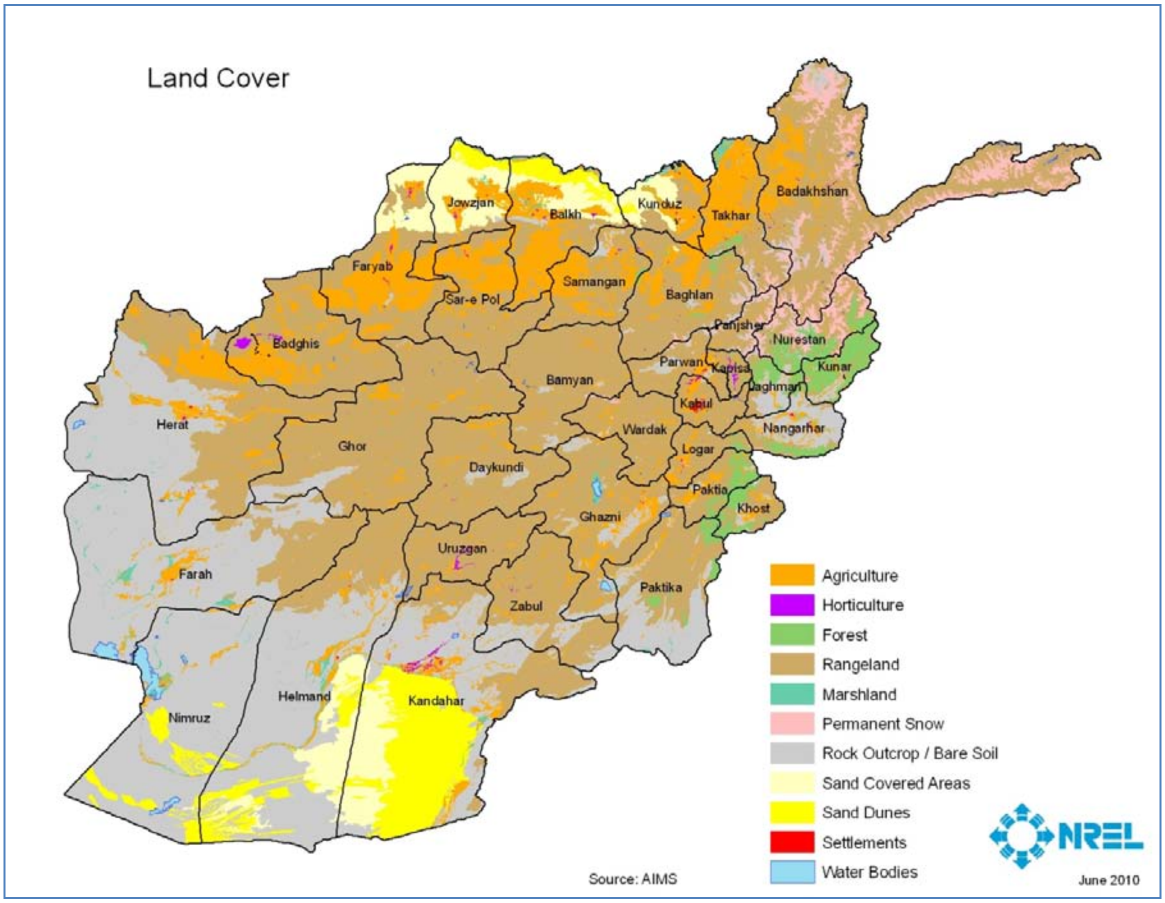


Figure 3. Land cover

There are two basic farming patterns in Afghanistan: 1) a mixed crop and livestock system; and 2) the Kuchi pastoral system, which is based on a nomadic existence, named after the Kuchi communities who migrate seasonally and transfer grazing animals to different pastures (UNEP 2003). Land-holding size and type vary between and within provinces. In general, farmland size in Afghanistan is small, about 7 Jerib (1.4 ha) for irrigated land and about 14 Jerib (2.8 ha) for rainfed land. Land ownership and tenure is communal grassland, urban land tenures, or arable land – however, land ownership is not well understood. The cadastral records are mostly incomplete and out of date. Nevertheless, each farmer knows the boundaries of his farm, so private land rights are clearly established at the micro and local levels.

Crop Residues

Most crop production in Afghanistan is concentrated in pockets of irrigable land (in the north and along rivers), along with some rainfed areas in the northern foothills and plains (Figure 4). The irrigated areas are known as "Abi" and the dry-farmed areas are called "Lalmi" (USDA 2002). Although estimates vary, it is thought that about 3.3 million ha (about 5% of the total land area) is irrigated and regularly planted, while 4.5 million hectare (ha) (about 7%) is rainfed and is planted opportunistically, depending on precipitation (SEI 2009). In areas at high elevation (above 2,000 meters),only one crop is grown per year, due to the short growing season; whereas at lower elevation, two crops a year are grown depending on water availability. As shown in Figure 4, most of the rainfed crops are produced on sloping terrain, which has led to severe soil erosion over the years. The United Nations Environmental Program (UNEP), in a post-conflict environmental assessment, points out that “increasing rural population pressure on available land over the last two to three generations has led to more traditional grazing land being cultivated for rainfed wheat crops, even on very steep slopes and in the highest mountains. Yields have proved to be uncertain and crop failures common. The environmental degradation resulting from the destruction of the original ground cover and consequent erosion is widespread and very serious” (UNEP 2003).

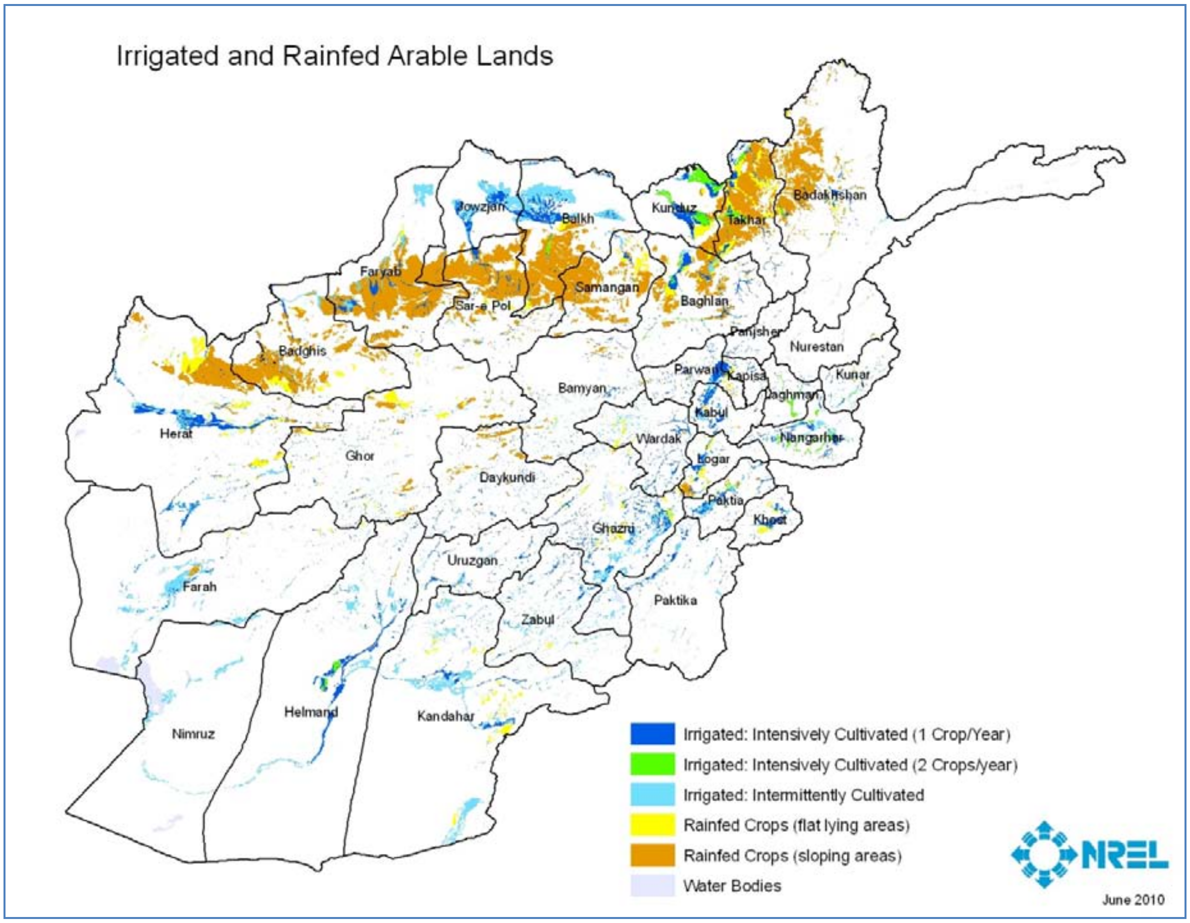
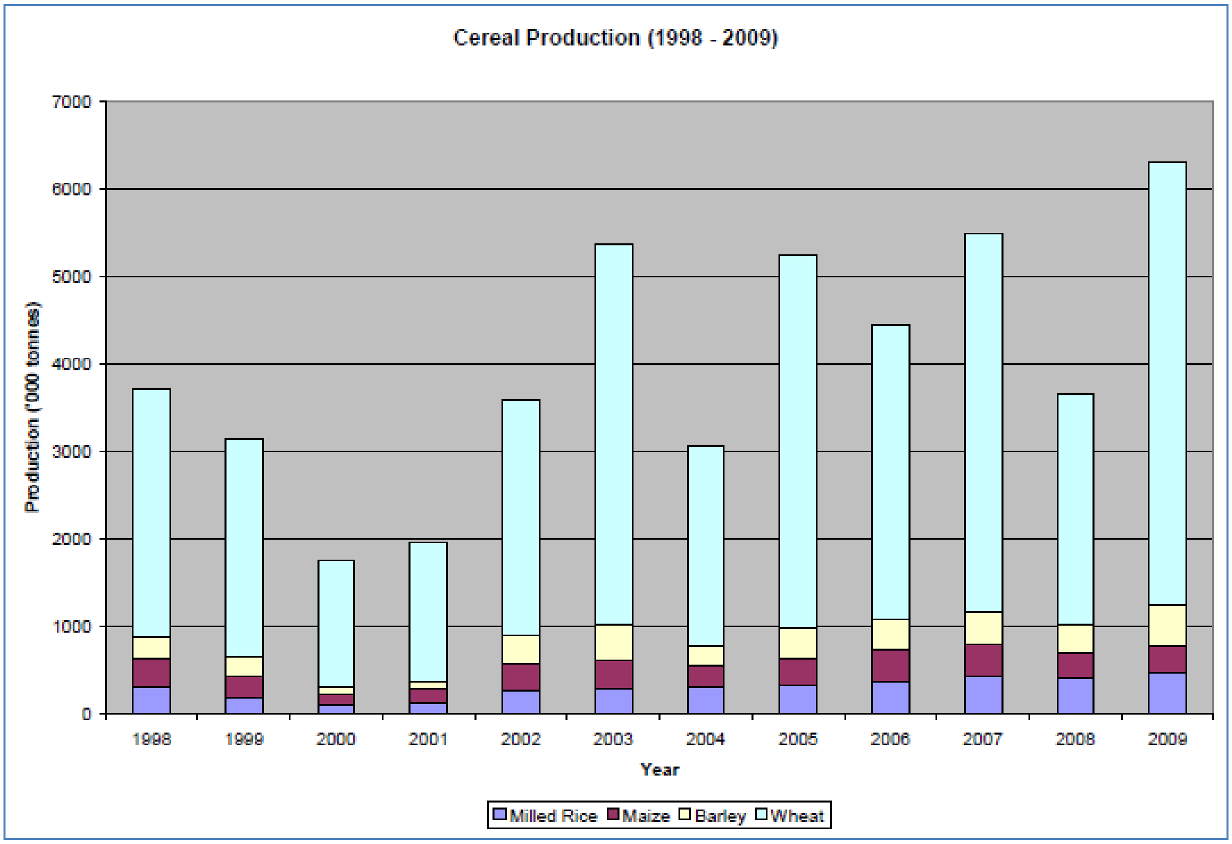


Figure 4. Irrigated and rainfed arable lands

Wheat is the staple crop, accounting for about 80% of total cereal consumption in Afghanistan. The crop is cultivated on both irrigated and rainfed lands, but the yield on irrigated lands is almost three times higher than that on rainfed lands: 2.95 t/ha compared to 1.18 t/ha in years with good rainfall (MAIL 2009b). Winter wheat is the primary crop, while spring wheat is sown in the colder regions. Other grains include rice, maize, and barley. In general, barley is cultivated on rainfed lands for grain (at high altitude) and as green fodder (at lower altitude). The irrigated Abi areas, in addition to wheat, also support the production of rice and maize. Because agricultural production in Afghanistan is very dependent on water from melting snow and rainfall, crop harvests vary dramatically each year depending on the weather. Figure 5 illustrates the changes in cereal production over a 12-year period. Good cereal production was experienced during 2003, 2005, and 2007 mainly due to favorable weather; however, during 2000-2002 and 2004, drought contributed to the low crop output. It must be noted, however, that even in good years, food supply is insufficient and Afghanistan relies on aid from foreign entities.



Source: MAIL 2009b

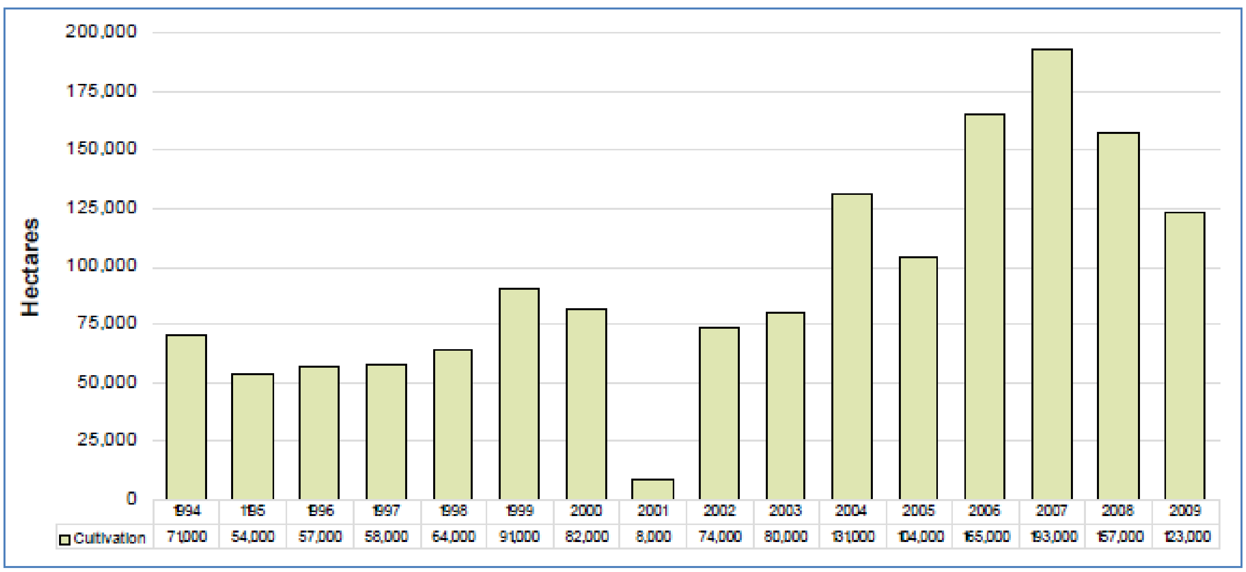
Figure 5. Cereal production (1998-2009)

Pulses and fodder are also grown as part of farmers' crop rotations. Pulses include chickpea and lentil; some fodder plants are annual clover and perennial alfalfa. A wide variety of vegetables and fruits including potatoes, onions, tomatoes, okra, cauliflower, melons, watermelons, apricots, peaches, pomegranates, apples, and grapes are produced for domestic consumption, local markets, and export. Sugar beet and sugar cane are also cultivated where appropriate. Afghanistan has also long been noted for its production of nuts, including almond, walnut, and pistachio. Dried fruits and nuts make up a large portion of the Afghan export - these high-value food products are in great demand in international markets, but they are nowhere near the levels of the 1980s when Afghan dried fruits accounted for almost 60% of the world market (CSO 2008-09).

Oilseed crops are also produced – mainly cotton, mustard, some sesame seeds, and flax (linseeds). Cotton is grown in some northern provinces (Baghlan and Kunduz) and Nangarhar.

Cotton cultivation has been declining during the past 5-6 years, but efforts by foreign aid agencies, such as USAID and the World Bank, aim to improve this trend. They are providing technical and financial assistance to cotton growers to increase cotton production and yield, as well as upgrade the capacity for ginning cotton and producing cottonseed oil.

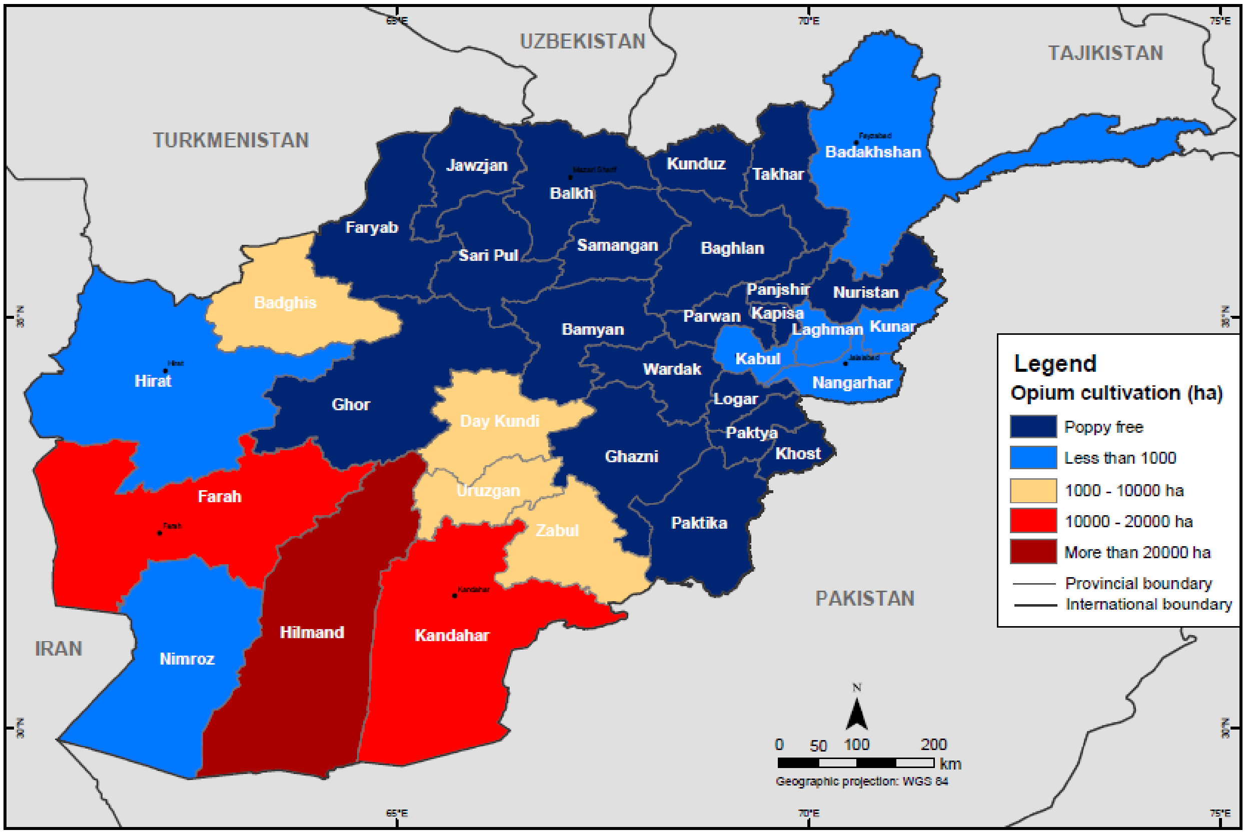
According to the International Monetary Fund, however, the “informal” agricultural sector – devoted to opium production – earns about 40-50% of GDP; although, as an illegal activity, it does not register in official economic calculations (UNEP 2009). The United Nations Office on Drugs and Crime (UNODC) has been monitoring the opium poppy cultivation in Afghanistan since 1994 (Figure 6). The “dip” in poppies cultivation during 2001 was largely due to a strictly enforced ban imposed by the Taliban government. However, with the departure of the Taliban, followed by a period of instability, the cultivation increased again in 2002 and continued to increase until 2007 when it reached record levels, and the country became practically the world’s exclusive supplier – about 93% of the global market (UNODC 2007). Poppy cultivation, which provides many Afghan farmers with significantly greater income than other crops, drives the rural economy. The gross income from opium per hectare is US$ 3,562 vs. US$ 1,101 from wheat (UNODC 2009).



Source: UNODC 2009

Figure 6. Opium poppy cultivation in Afghanistan, 1994-2009

Since 2007, Afghanistan officials and aid agencies have led a massive program to destroy poppies and offer help to farmers to grow alternative crops, such as wheat or cotton. As a result, the cultivation of poppies was reduced by about 35% - from 193,000 ha in 2007 to 123,000 ha in 2009 - although drought in 2008 also contributed to the lower level of production. Another achievement of the program is that 20 of the 34 provinces were “poppy free” in 2009 compared to13 in 2007. Current cultivation is concentrated in seven provinces of the South and West: Hilmand, Kandahar, Uruzgan, Daykundi, Zabul, Farah, and Badghis (Figure 7). According to the UNODC Survey in 2009, these are the most insecure provinces in the country, which further substantiates the link between insecurity and opium cultivation observed since 2007.



Source: UNODC 2009

Figure 7. Opium poppy cultivation in Afghanistan by province, 2009

After crops are harvested and processed, various residues and byproducts remain on the field, such as straw, husks, stalks, and leaves. Based on crop production statistics and use of appropriate crop-to-residue ratios, this study estimates that about 6.8 Mt of crop residues were produced in Afghanistan during 2008-09 (Table 3). The energy content of agricultural residues varies between 10-17 GJ/t due to moisture content. Therefore, the corresponding energy content of the crop residues in the country is between 68 petajoules (PJ) and 115 PJ, equivalent to 64 and 110 trillion British thermal units (Btu), respectively. The analysis includes field crops (cereal crops, potatoes, sugar cane, sugar beet, and cotton) and not the additional residues that are available from growing other crops such as vegetables. Pruning of orchards and grapevines provides residues as well, but because of lack of data on the trees/vines' condition, spacing, and pruning practices, it is difficult to estimate the quantity of material that is collected annually, so it was not included in this analysis. However, given the area planted to orchards[1] and vineyards in 2008-09 (about 105,000 ha) and applying some general assumptions, it is estimated that about 285,000 tonnes (t) of biomass may have been generated from pruning during the year, which represents about 5.7 PJ of energy.[2] Additionally, processing residues such as almond and walnut shells, as well as olive pits, can be used to produce charcoal through pyrolysis of biomass, which could be used for cooking and as a soil amendment. Processing residues provide an additional

[1] The orchards include apples, peaches, apricots, plums, figs, pomegranate, almonds, walnuts, and olives.
[2] Assuming an HHV of 20 GJ/t (dry basis) for orchard, vineyard, and processing residues.

338 TJ of energy. The analysis methodology and results for orchards, vineyards, and processing residues are presented in the Appendix.

Table 3. Crop Residues

Crop	Production (tonnes)	Residue Type	Crop to Residue Ratio	Residues (tonnes)
Wheat	2,623,000	husk	0.3	786,900
		straw	1.5	3,934,500
Barley	333,200	straw	1.3	433,160
Rice	409,700	husk	0.2	81,940
		straw	1.5	614,550
Maize	279,900	cobs	0.3	83,970
		stover	2.0	559,800
Potato	280,000	leaves	0.4	112,000
Sugar cane	62,960	baggase	0.33	20,777
		tops/leaves	0.05	3,148
Sugar beet	13,316	tops/leaves	0.02	266
Cotton	35,000	husk	1.1	38,500
		stalks	3.8	133,000
Total	4,037,076			6,802,511

Production in 2008-09 from CSO's Afghanistan Statistical Yearbook 2008-09; Crop to Residue Ratios adopted from Singh and Gu 2010

The leading provinces for residue production from cereal crops[3] include Balkh, Helmand, Heart, Kunduz, and Nangarhar (Figure 8). To generate the map on Figure 8, data on crop residues from cereal production was allocated to the cropland in each province. The goal is to illustrate the spatial distribution of these resources at the province level. The tabular results of this analysis are presented in the Appendix.

[3] No data on other crops by province was available at the time of this study.

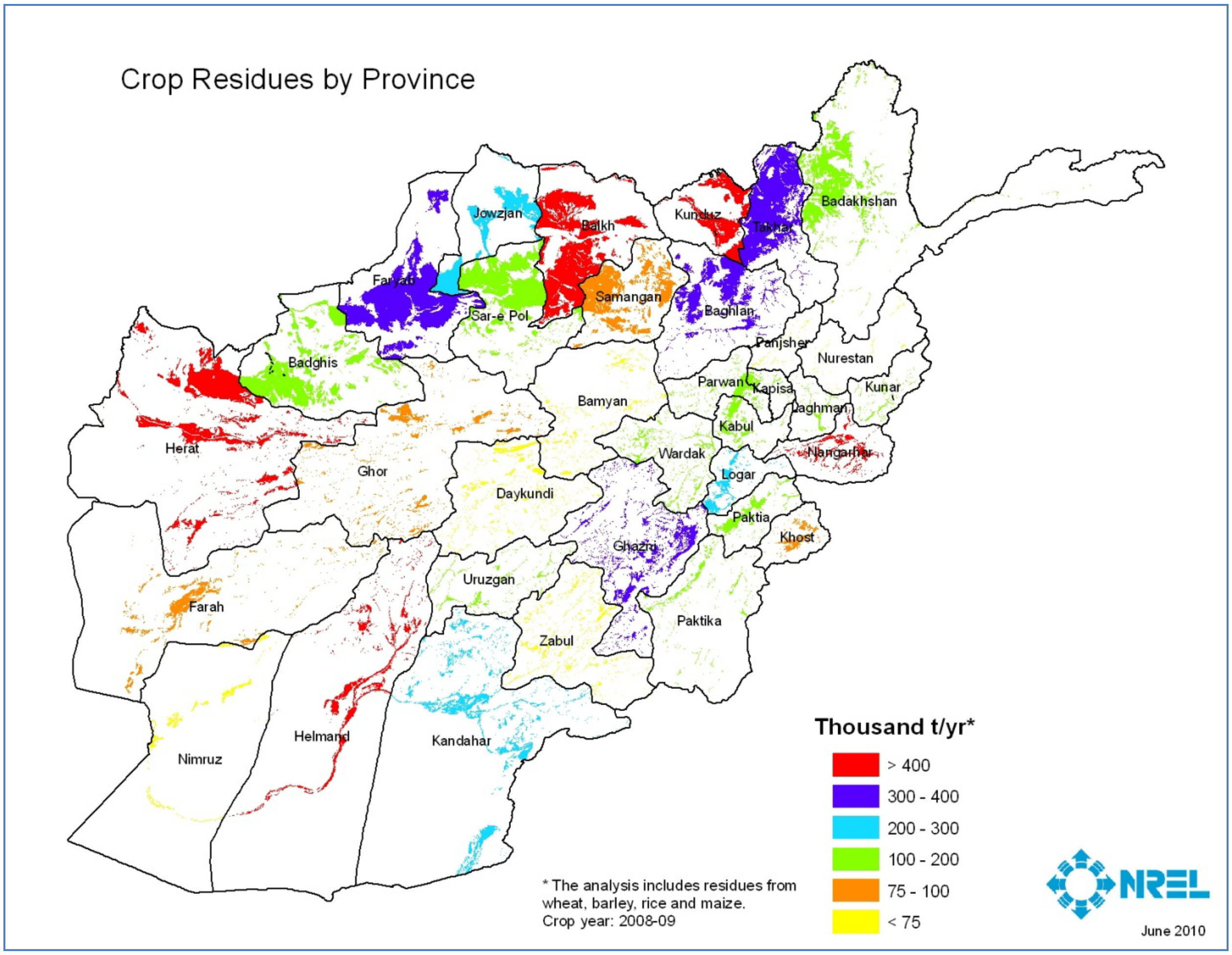


Figure 8. Crop residues by province

Unlike other regions in the world, where field crops are produced commercially and generate large concentrations of residues, much of Afghanistan's production is run by households for self-consumption or local markets – about 80% of the country's population is subsistence farmers living in small villages. The lack of large-scale crop production, and their dispersion, increases collection and transportation costs, which would restrain the use of these residues for centralized electricity generation or transportation fuels production (such as cellulosic ethanol). Regardless of this constraint, however, the crop residues in Afghanistan are not available for this type of application. These resources are already used as animal feed, on farm applications, and as construction material. Moreover, crop residues are a significant component of the solid biomass fuels used for cooking. Due to demands made by other sectors (animal feed, in particular), however, these resources can't contribute to their full potential estimated above. Furthermore, improved cookstoves would be required to use the estimated potential more efficiently.

Animal Waste

Animal husbandry is a major feature of the Afghan agriculture – about 79% of rural households and 94% of Kuchi population own some kind of livestock (IOCN Institute 2009). Animals kept by farmers include cattle, ox, horses, donkeys, camels, goats, sheep, and poultry (mainly chickens, some ducks and turkey). For most Afghan farmers, the animals are the only source of power for cultivation and transport, often shared among them in these activities. In addition to providing families' subsistence requirements for meat, dairy products, and eggs, the animals also provide manure used as an energy source, organic fertilizer, and building material.

In Afghanistan, as in other developing countries, animal manure is one of the main energy sources along with crop residues and wood. In some parts of the country, it is the only source of energy for rural households. The manure is dried in the sun, collected into big stacks, and used for cooking and heating (Figure 9). However, direct burning of animal manure is not the most efficient use of this material. Instead, it could be used to produce biogas, which is a better fuel than animal dung cakes as described below. Biogas is generated by the anaerobic digestion (decomposition without oxygen) of organic matter, such as animal manure, human excreta, and crop residues. The composition of biogas varies depending on the feedstock, but typical composition includes methane (50% to 70%), carbon dioxide (30% to 50%), and traces of gases such as hydrogen and nitrogen. Biogas is a better fuel than animal dung cakes, because burning these cakes in open fires and stoves indoors results in exposure to air pollutants associated with the development of respiratory infections, lung disease, and cancer; in contrast, biogas is a much cleaner, odorless, and smokeless fuel. The calorific value of animal dung cakes is much lower than that of biogas – 8.8 MJ/m^3 vs. 19-20 MJ/m^3. Biogas can be used not only for cooking and heating, but also for lighting and refrigeration. Additionally, animal dung cakes leave residue after burning - biogas leaves no residue. The process of biogas production creates a valuable byproduct, the spent slurry, which is a highly nutrient organic fertilizer.

Source: Michael Yon 2010

Figure 9. Dung piles in Karbasha Qalat, Ghor Province

There are four levels of biogas application: domestic, community (village), intensive animal feedlots, and industrial. In developing countries, the main use of biogas has been domestic with some community-level applications. The "Renewables 2010 Global Status Report" states that more than 30 million households get cooking, heating, and lighting from family-scale digesters (REN21 2010). Most of them are in China (some 25 million biogas systems) and India (about 4 million). Nepal is third in domestic biogas installations with close to 200,000 digesters, and Vietnam is fourth with more than 150,000 systems. In comparison, there are about 75 family-size biogas plants in Afghanistan (AEIC 2010).

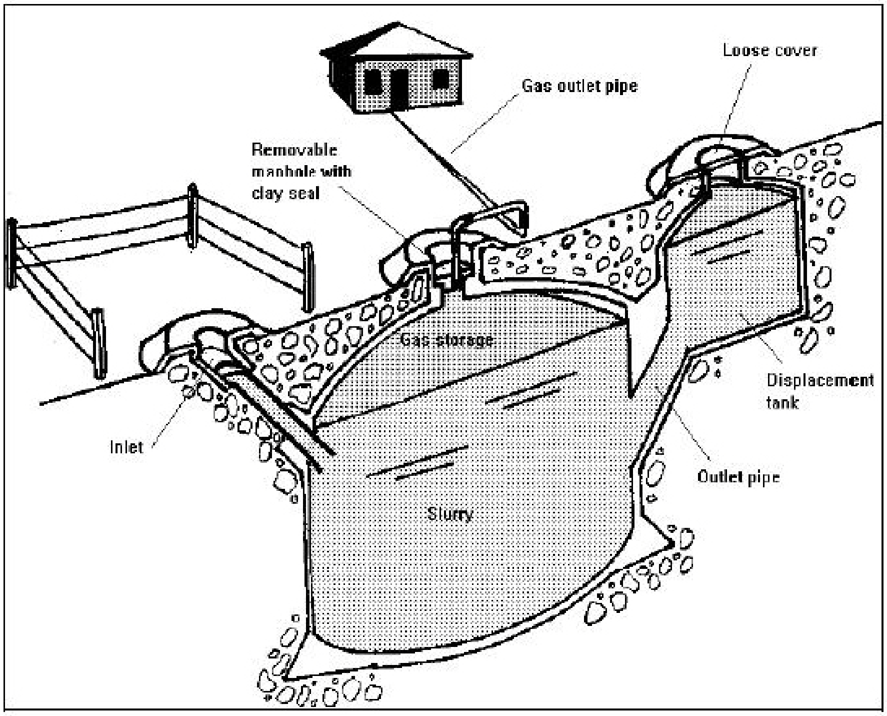
Domestic biogas plants vary in size, depending on the household's needs and quantity of feedstock – mainly animal manure; however, it could be supplemented by other organic material such as kitchen waste, crop residues, and night soil (human excreta). Water availability is also important because the collected manure must be mixed with water in the biodigester (typically at a ratio of 1:1). In general, the smallest size biogas plant (1 m^3 capacity) requires about 25 kg of manure per day (supplied by about two-three cows) and 25 liters of water respectively, which can meet the cooking and lighting needs[4] of a three- to four-member family (Table 4). The largest family-size plant (6 m^3 capacity) can cover the needs of a relatively large joint family of 18-24 members. There are many designs of biogas digesters for household use, including the floating drum and the heat-sealed plastic or rubber bag (balloon) type. However, the fixed-dome design is perhaps the most applied given its relatively low construction and maintenance cost, reliability, simplicity, durability, and long lifetime. Also, the plant is constructed underground, protecting it from physical damage and saving space (Figure 10).

Table 4. Domestic Biogas Plant Size and Daily Feedstock Requirements

Plant Capacity (m^3)	Average Daily Manure Required (kg)	Approximate No. of Cattle	No. of Family Members that Could be Served*
1	25	2-3	3-4
2	50	4-6	6-8
3	75	6-9	9-12
4	100	8-12	12-16
5	125	10-15	15-20
6	150	12-18	18-24

* Cooking and lighting requirements. Source: INFORSE 2008

[4] Biogas generation is low in cold weather, thus it is not a sufficient fuel for space heating during winter months. Additional resources would be required to meet the households' demand for space heating.



Source: Baron, G. 2007

Figure 10. Fixed dome biogas plant design

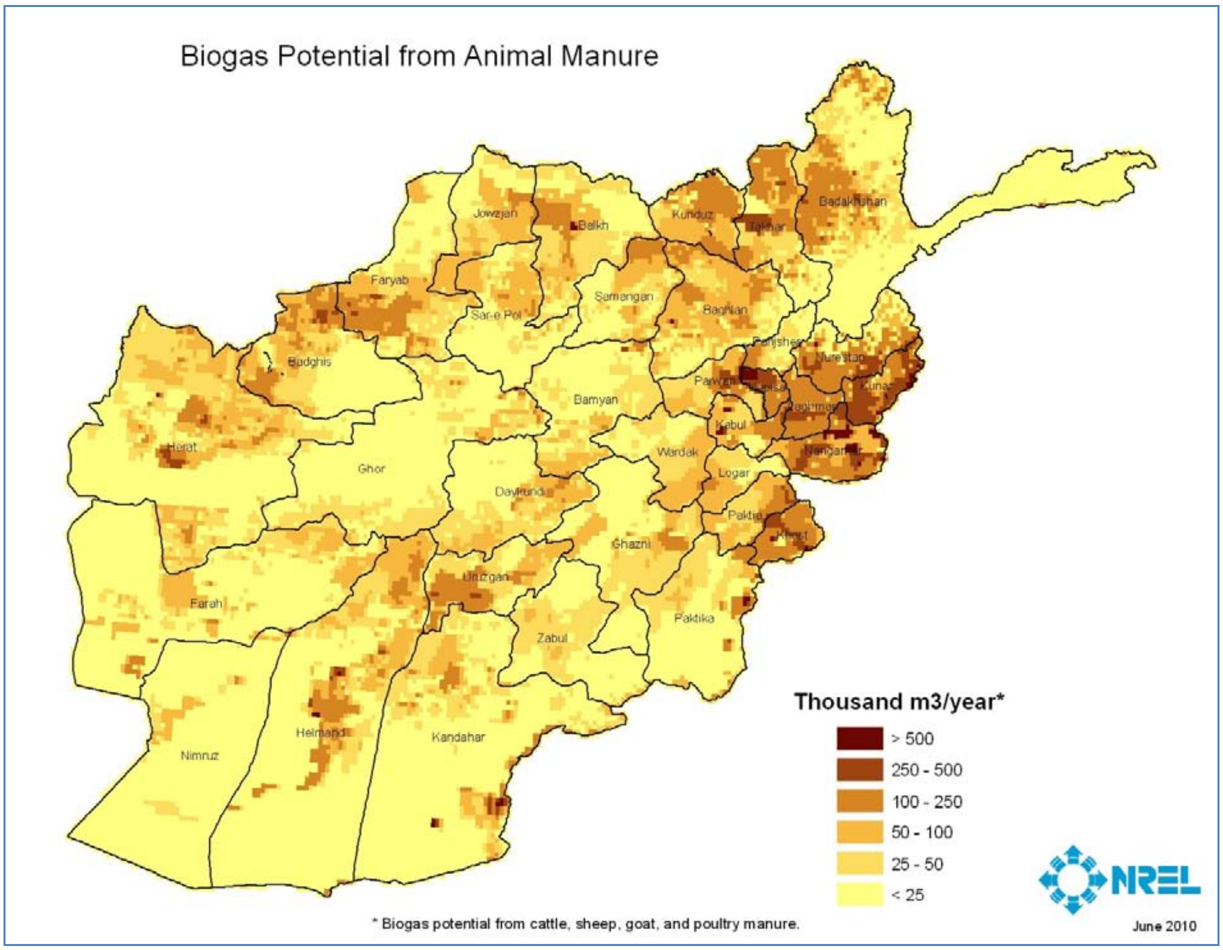
Theoretically, Afghanistan has the potential to produce about 1,408 million cubic meters (MCM) of biogas annually, based on the number of livestock in the country as of 2008-09 (Table 5). This volume is equivalent to about 32 trillion Btu.[5] If only one quarter of this potential is developed, it could fulfill almost half of Afghanistan's current energy consumption of 18 trillion Btu (EIA 2010), or five times the charcoal consumption of 103,000 tonnes (UN 2009), or the entire fuelwood consumption of 1 Mt[6] (UN 2009). Figure 11 illustrates the distribution of biogas potential from the major animal types in Afghanistan: cattle, sheep, goat, and poultry. Locations in the east, north, and some central areas have the highest potential for biogas generation from animal manure. Because of this, the existing 75 family-size biogas plants in the country are constructed in Laghman, Nangarhar, and Herat provinces (AEIC 2010). The distribution of biogas potential from different animal types in Afghanistan is illustrated in the Appendix.

[5] Assuming that the biogas is composed of 65% methane and it yields 650 Btu per cubic foot.
[6] UN reports that fuelwood consumption by households in Afghanistan was 1,531,000 m^3 in 2007. Assuming that 1 tonne of wood = 1.4 m^3, this volume is equal to about 1Mt.

Table 5. Annual Biogas Potential from Animal Manure in Afghanistan and its Equivalents

Livestock	Population* ('000 heads)	Animal Manure ** (kt/yr)	Biogas*** (MCM)	Gas Oil (ML)	Charcoal (kt)	Wood (kt)	Butane (kt)	Dry Cow Manure (kt)	Electricity (GWh)	Diesel Fuel (ML)	Fuel (ML)	Propane (MCM)
Cattle	4,745	17,082	564	349	823	1,956	242	6,934	2,649	372	423	141
Sheep	10,710	7,497	435	270	635	1,509	187	5,348	2,044	287	326	109
Goat	6,386	4,470	259	161	379	900	111	3,189	1,219	171	194	65
Donkey	1,209	3,506	91	57	133	316	39	1,121	428	60	68	23
Camel	183	659	22	13	32	75	9	267	102	14	16	5
Horse	162	583	19	12	28	67	8.3	237	90	13	14	5
Chicken	10,689	235	18	11	27	64	8	226	86	12	14	5
Total	34,084	34,032	1,408	873	2,056	4,887	606	17,322	6,619	929	1,056	352

* Source: CSO 2008-09; MCM - million cubic meter; ML - Megaliter; kt - Kilotonne; GWh - Gigawatt-hour.
** Cattle/horse/camel: 3.6 ton/unit/year; sheep/goat: 0.7 ton/unit/year; poultry: 0.022 ton/unit/year; donkey 2.9 ton/unit/year (adopted from Tatlidil et al. 2009).
*** To convert animal manure to biogas, the coefficients of 33 m^3/year/ton for cattle/horse/camel, 58 m^3/year/ton for sheep/goat, 78 m^3/year/ton for poultry, and 26 m^3/year/ton for donkey were used as conversion coefficients (adopted from Tatlidil et al. 2009).
The following coefficients were used for calculation of biogas equivalents (adopted from Tatlidil et al. 2009) - gas oil: 0.62 L, charcoal: 1.46 kg, wood: 3.47 kg, butane: 0.43 kg, dry cow manure: 12.3 kg, electricity: 4.7 kWh, diesel fuel: 0.66 L, fuel: 0.75 L, and propane: 0.25 m^3.



Livestock data from FAO-ERGO 2007 with a spatial resolution of 3 arc minutes (roughly 5 km)

Figure 11. Biogas potential from animal manure

Technically, however, cattle manure is perhaps the most promising biogas feedstock in Afghanistan (as in India, Nepal, Pakistan, and other countries) given the large amount of material that cattle can provide compared to other, smaller livestock. An Afghanistan household has, on average, between six-eight members, thus a biogas plant with capacity of 2 m^3 per day can meet the energy needs of this size family (Table 4). It would require about 50 kg of manure per day, which could be supplied by four-six cows. It would require the same number of horses, or about eight-nine camels (assuming an average of 6 kg of manure per day), or about 50 sheep/goats (assuming an average of 1 kg of manure per day), or about 277 chickens (assuming an average of 0.18 kg of manure per day) to meet this demand (NIIR Board 2004). As shown in Table 6, most Afghan families don't own that many animals (except perhaps families in Nuristan keeping large herds of goats), so it would be difficult to meet the daily requirements of a biogas plant. There are, however, families in the provinces of Khost, Kunar, and Nuristan that own more than four cattle and would have enough biogas feedstock supply on a daily basis.

Table 6. Livestock Owned per Family in 2002-2003

Agro-Ecological Region	Province	Cattle	Sheep	Goats	Chickens	Donkeys	Horses	Camels	Oxen
Badakhshan		3.05	4.31	4.23	2.93	0.96	0.15	0.00	0.66
East	Khost	4.49	2.71	5.33	16.77	0.90	0.01	0.11	0.07
	Kunar	4.32	2.23	10.65	12.75	0.65	0.01	0.00	0.59
	Laghman	3.76	7.03	4.10	10.20	0.65	0.01	0.08	0.31
	Nangarhar	2.66	3.67	3.31	9.65	0.57	0.02	0.06	0.33
	Nuristan	4.20	4.40	31.04	15.24	0.69	0.17	0.00	0.52
	Paktika	1.34	4.19	6.63	7.83	0.37	0.01	0.15	0.02
	Paktya	2.76	1.95	4.94	15.11	0.49	0.01	0.02	0.03
	Average	**3.06**	**3.47**	**6.78**	**12.06**	**0.60**	**0.02**	**0.08**	**0.20**
Centre-East	Kabul	0.86	2.14	2.24	5.30	0.28	0.01	0.01	0.06
	Kabul City	0.08	0.25	0.07	2.44	0.02	0.00	0.00	0.00
	Kapisa	2.89	2.21	1.82	6.64	0.32	0.02	0.00	0.12
	Logar	1.31	1.30	0.98	4.71	0.31	0.01	0.00	0.09
	Parwan	1.52	2.03	2.33	3.75	0.49	0.03	0.00	0.10
	Wardak	0.87	1.83	0.84	3.32	0.48	0.01	0.00	0.11
	Average	**1.16**	**1.71**	**1.35**	**4.11**	**0.37**	**0.01**	**0.00**	**0.09**
Centre	Bamyan	1.75	6.13	1.55	2.85	0.90	0.07	0.00	0.39
	Ghazni	1.02	3.26	1.00	3.93	0.47	0.01	0.00	0.06
	Ghor	1.94	5.63	1.75	3.36	0.72	0.09	0.00	0.66
	Uruzgan	2.73	4.72	4.20	9.70	0.92	0.05	0.13	0.54
	Zabul	0.69	4.40	4.60	6.75	0.62	0.01	0.07	0.10
	Average	**1.61**	**4.57**	**2.85**	**5.97**	**0.72**	**0.04**	**0.05**	**0.30**
North	Baghlan	1.88	4.26	2.96	3.22	0.75	0.23	0.01	0.39
	Balkh	0.58	3.99	1.16	2.08	0.44	0.07	0.06	0.13
	Faryab	0.55	4.80	2.62	1.37	0.60	0.03	0.09	0.22
	Jawzjan	0.35	4.80	1.34	1.66	0.31	0.09	0.16	0.06
	Kunduz	2.56	5.57	0.75	4.15	0.81	0.28	0.17	0.60
	Samangan	0.49	3.53	1.47	1.38	0.80	0.06	0.03	0.14
	Sari pul	1.12	4.42	1.60	2.30	1.05	0.09	0.07	0.32
	Takhar	1.83	2.50	1.90	2.79	1.00	0.11	0.01	0.54
	Average	**1.22**	**4.12**	**1.88**	**2.42**	**0.70**	**0.13**	**0.06**	**0.30**
West	Badghis	0.55	9.94	4.37	3.08	1.10	0.05	0.15	0.21
	Farah	1.15	2.70	8.77	6.51	0.62	0.03	0.14	0.06
	Hilmand	1.68	6.90	6.55	8.62	0.57	0.04	0.32	0.06
	Hirat	0.70	4.55	4.43	2.80	0.67	0.03	0.10	0.18
	Kandahar	0.92	8.12	5.75	7.44	0.59	0.02	0.34	0.03
	Nimroz	0.60	4.35	8.70	7.76	0.86	0.03	0.54	0.00
	Average	**1.04**	**6.15**	**6.11**	**6.19**	**0.66**	**0.03**	**0.25**	**0.09**
Overall AVG		***1.60***	***4.28***	***3.91***	***5.87***	***0.64***	***0.05***	***0.10***	***0.22***

Source: FAO 2008

The study estimates that about 896,000 domestic biogas plants could be installed in Afghanistan using cattle manure. There are about 3.4 million households in the country (IOCN Institute 2009), so there is the potential to supply about 26% of the country's households with efficient and clean fuel to meet their energy needs. The analysis considers small-scale farmers that keep at least two-three cows as good candidates for installing household biogas units. Districts where households own more than two-three cattle were identified using data from the "Afghanistan National Livestock Census 2002-03" (FAO 2008), and the number of households in each of those districts was obtained from the "Agriculture Prospects Report" (MAIL 2009b). The results of this analysis are illustrated in Figure 12, and a summary by province is presented in Table 7. As shown in Table 7, there are several provinces (Khost, Kunar, Nurestan; Badakhshan, Laghman, and Uruzgan are relatively close) that have the potential to install biogas digesters at every household. It should be noted that the number of domestic digesters that could be installed in each district could be slightly higher or lower given that the Census captures data from 2002-03, and the livestock ownership is likely to have changed since then. Also, there may be additional households in other districts that own at least two-three cows, which qualify for installing biogas digesters, but are not captured in the Livestock Census. This analysis, however, should give a general idea of the potential for domestic biogas installations in Afghanistan and support decision-making processes.

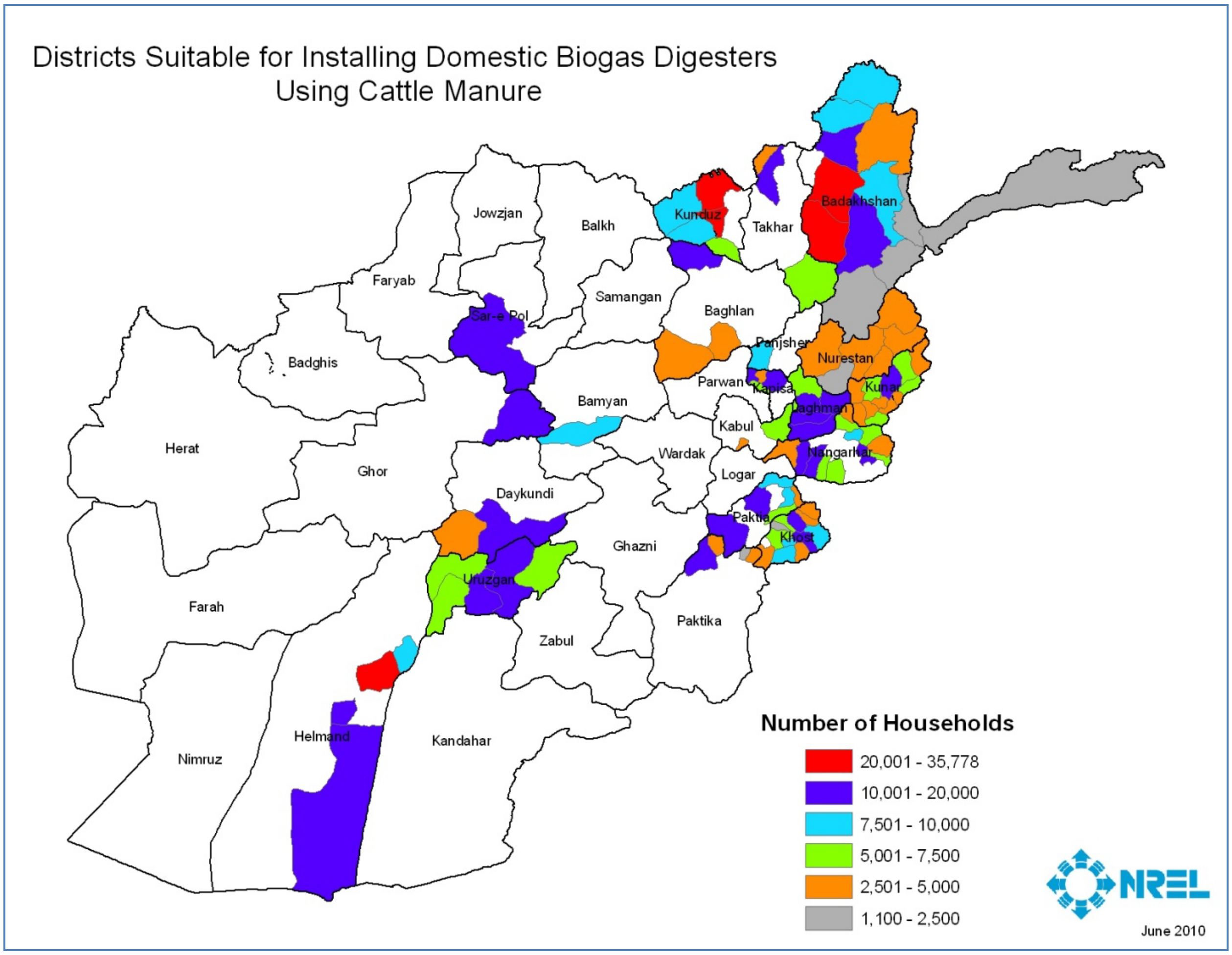


Figure 12. Districts suitable for installing domestic biogas digesters using cattle manure

Table 7. Number of Households that Could be Served by Biogas Digesters Using Cattle Manure

Province	Number of Households	Percent of Total Households
Badakhshan	132,038	91
Baghlan	26,968	19
Bamyan	8,080	14
Daykundi	15,504	22
Ghor	15,095	14
Helmand	62,113	66
Kabul	9,824	2
Kapisa	36,158	62
Khost	87,279	100
Kunar	67,269	100
Kunduz	85,755	56
Laghman	60,277	88
Nangarhar	101,370	59
Nurestan	19,788	100
Paktika	23,422	47
Paktya	51,871	82
Panjsher	7,967	39
Sar-e Pol	12,342	17
Takhar	27,174	18
Uruzgan	45,973	86
Total	896,267	42

The analysis illustrates that Afghanistan has the potential to increase the number of biogas plants installed in the country (currently 75) and further develop its biogas sector. There are, however, some technical and economic challenges that need to be addressed when considering a large biogas program. One technical challenge is water availability. Afghanistan has an arid to semi-arid climate, so water resources are scarce, particularly during drought periods. "A series of recent droughts and increasing air temperatures have reduced the size of glaciers in Afghanistan, posing additional long-term problems due to climate change. In the past 50 years, larger glaciers in the Pamir and the Hindu Kush Mountains have already shrunk by 30%, while some smaller ones have vanished altogether. More than 2.5 million people in Afghanistan are already affected by drought or are vulnerable to the impacts of recurrent drought and water shortages. The number may increase further due to global warming and further aridization." (NEPA-UNEP 2009). The Afghan Ministry of Water and Energy stated recently that the excessive use of groundwater for a variety of purposes has significantly depleted water tables and aquifers throughout Afghanistan and if the trend is not reversed, soon the country will face a severe shortage of drinking water (Afghanistan Online 2008). The biogas industry in the country could tackle the critical situation of water resources by using wastewater or low-quality water unsuitable for consumption. Data on these resources is not available; therefore the authors recommend future research to focus on a comprehensive assessment of the water needs and its availability for the biogas technology in Afghanistan.

Another technical challenge, which can be overcome to some extent, is related to cold climates. Cold temperatures have a negative impact on the fermentation process, which affects the plant's performance. The fixed-dome digester is used in temperate and cold climates because it is built underground. The existing digesters in Afghanistan are this type and are intended to cope with the wide temperature variations not only from season to season, but also from day to night. Variations in temperature during the day may range from freezing conditions at dawn to the upper 30°s C at noon (AWS 2010). The barrier of cold weather can be overcome to some extent by heaping compost on top of the digester to heat and insulate it. Farmers at high altitude in neighboring Nepal are using this technique under similar conditions to those in high-altitude Afghanistan. There are several pilot plants in Langtang, such as this one in Kyanjin Gompa, the highest settlement in Langtang Valley at 3,850m (Figure 13).

Source: Nepali Times 2010

Figure 13. Biogas plant in Kyanjin Gompa, Langtang Valley, Nepal

A major economic challenge is the cost of biogas plants. No data on the cost of digesters in Afghanistan was available at the time of this study, but the investment costs of similar type (fixed dome) in Nepal vary between 400 US$ and 800 US$, depending on plant size, location of construction, and geographic region (SNV 2010). This is a significant amount for the Afghan population (particularly in rural areas) considering that the income per capita is a mere 486 US$ per year (IMF 2010). The current biogas program in Afghanistan uses a differed payment strategy, where the owners of biogas units pay the cost over a period of 8-12 months (AEIC 2010). However, no financial support appears to be provided under the program. In comparison, Nepal has several financing options for domestic biogas plants: investment subsidies, credit facilities, and carbon credits. "The Government, banks, and donors are all contributing to the fund for providing investment subsidies on biogas plants. On average, the subsidy rate (a set amount) is 25%-35% of the total investment costs. Because many of the potential households may not be able to raise the required investment for the installation of a biogas plant, suitable credit facilities are crucial. About 31% of the total biogas plants installed are credit financed through one of the 200 microfinance institutions or other Nepalese banks. Under the Biogas Support Program (BSP), two small-scale carbon-accounting project bundles had been registered, representing nearly 20,000 biogas plants. The carbon revenues amounted to US$ 30 annually per biogas plant. In 2005 the applied methodologies were withdrawn, so currently new opportunities in the carbon market are investigated." (SNV 2010). The authors recommend further economic analysis, tailored to the Afghan situation, which would be able to look at the associated costs of this technology in more detail.

Nepal's biogas program is an internationally acclaimed success story and can serve as an example for a similar effort in Afghanistan. The BSP in Nepal has addressed these and other technical and economic challenges associated with biogas production. Therefore, Nepal's experience and recommendations would be invaluable to policymakers and industry developers in Afghanistan. The biogas plants installed through the BSP in Nepal provide many benefits, as shown in Figure 14.

An average biogas plant in Nepal serving a household of 6 or 7 people generates the following, main benefits:

- Saving of traditional cooking fuel such as firewood: 2,000 to 3,000 kg/year
- Reduction of workload: 1.5 to 3 hours/day
- Reduction of greenhouse gasses: up to 5.0 ton of CO2 equivalent/year
- Reduction of indoor air pollution: 3 persons/household are less exposed
- Toilet attachment: up to 65% of all biogas households have latrines connected to the biogas plants
- Potential increase of agricultural production or saving on the use of chemical fertilizer (biogas plants produce very high quality organic fertilizer – the bio-slurry): up to 40%
- Improved sanitation, less pollution to underground water

Source: GFA Envest 2009

Figure 14. Main benefits of an average biogas plant in Nepal

Forest Resources

Forests are an important natural resource in Afghanistan. They contribute to agricultural productivity – stabilize the soil, prevent erosion, enhance the land's capacity to store water, and moderate air and soil temperatures. A number of products and byproducts – including timber, charcoal, firewood, nuts, and medicinal plants – are directly obtained from trees. Also, forests provide habitat for a variety of birds and mammals, including some endangered species.

Forest resources in Afghanistan are in critical condition. An assessment by the Food and Agriculture Organization (FAO) in the late 1970s estimated that deciduous and evergreen forests covered 5% of the country's land area, including 1 million hectare (Mha) of oak and 2 Mha of pine and cedar growing mostly in the eastern part of the country (UNEP 2003). Open woodland dominated by pistachios, almonds, and junipers occupied a third of the land area. Today, however, most of the original forests have disappeared and woodland areas cover about 2% of total land. It is estimated that if deforestation continues at its present rate, all forest land will disappear in three decades (NEPA-UNEP 2009). The rate of deforestation is evident from satellite images taken at different times for comparison (Figures 15-17). The maps, developed by the United Nations Operational Satellite Applications Programme (UNOSAT), illustrate the rate of forest depletion in Afghanistan. In the northern provinces of Takhar and Kunduz, forest lands disappeared completely from 1977 – 2002. Very few forested areas remain in Badghis. The provinces of Nuristan, Kunar, and Nangarhar are experiencing severe deforestation, as well as the provinces of Paktya, Khost, and Paktika. There are many factors contributing to forest depletion in Afghanistan. These include overgrazing, which prevents forest regeneration and increases vulnerability; heavy use of forest resources for firewood and as a construction material; and war conflicts associated with massive destruction of trees and forest fires. Illegal logging, particularly for export to neighboring countries, is another factor driving the decline and degradation of forests in the country. A report by the National Environmental Protection Agency of the Islamic Republic of Afghanistan (NEPA) and UNEP indicates that during 1992–2002 (including the Taliban's use of the forest trade as a source of revenue), massive logging and smuggling significantly contributed to forest reduction in the eastern provinces of Afghanistan – 50–200 timber truckloads a day or 150,000–500,000 m^3 of wood annually. Local communities have lost control over the resources on which they depend for their survival, and forest resources are now largely used for immediate profit by organized crime syndicates and traders (NEPA-UNEP 2009). Additionally, poor forest management, lack of incentives for reforestation, lack of community involvement and awareness, and agricultural and urban encroachments on forest land also contributed to the severe decline of forest cover in Afghanistan (UNEP 2009).

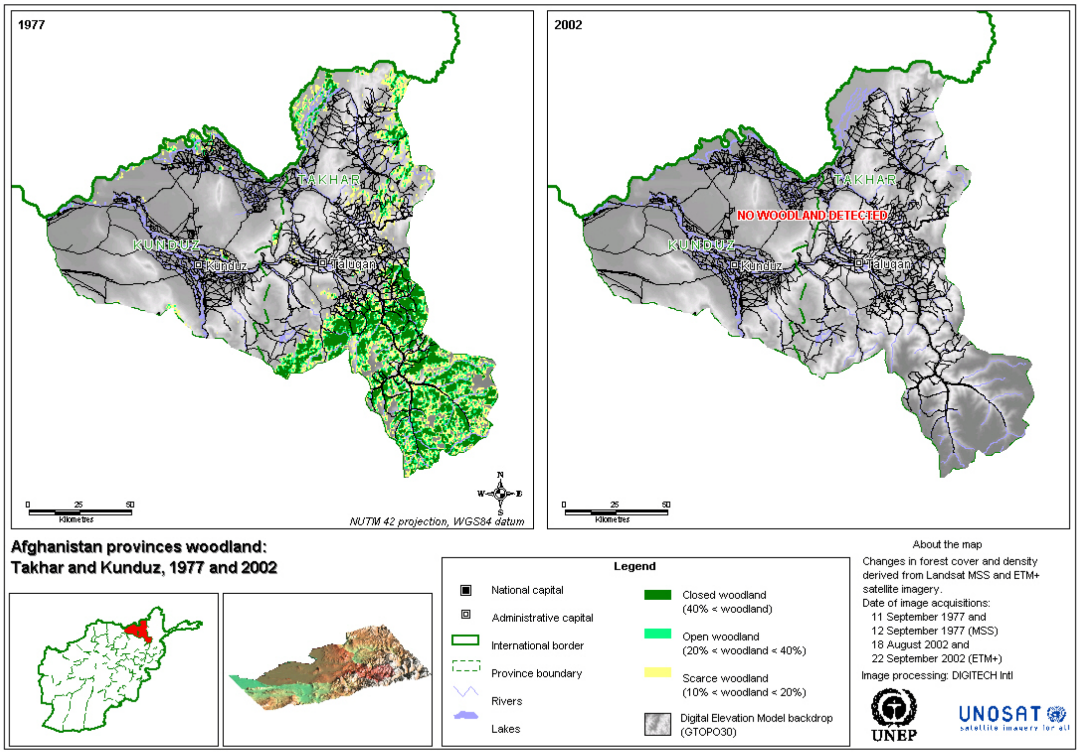


Figure 15. Woodland change in Takhar and Kunduz Provinces, 1977 – 2002

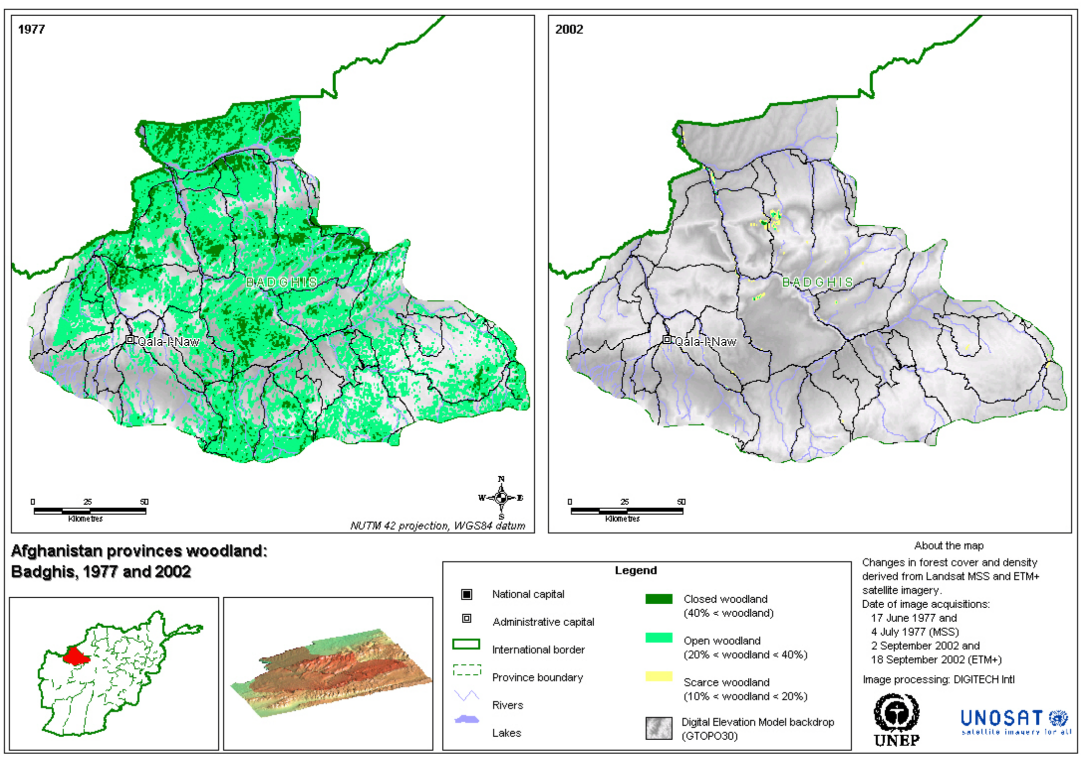


Figure 16. Woodland change in Badghis Province, 1977 – 2002

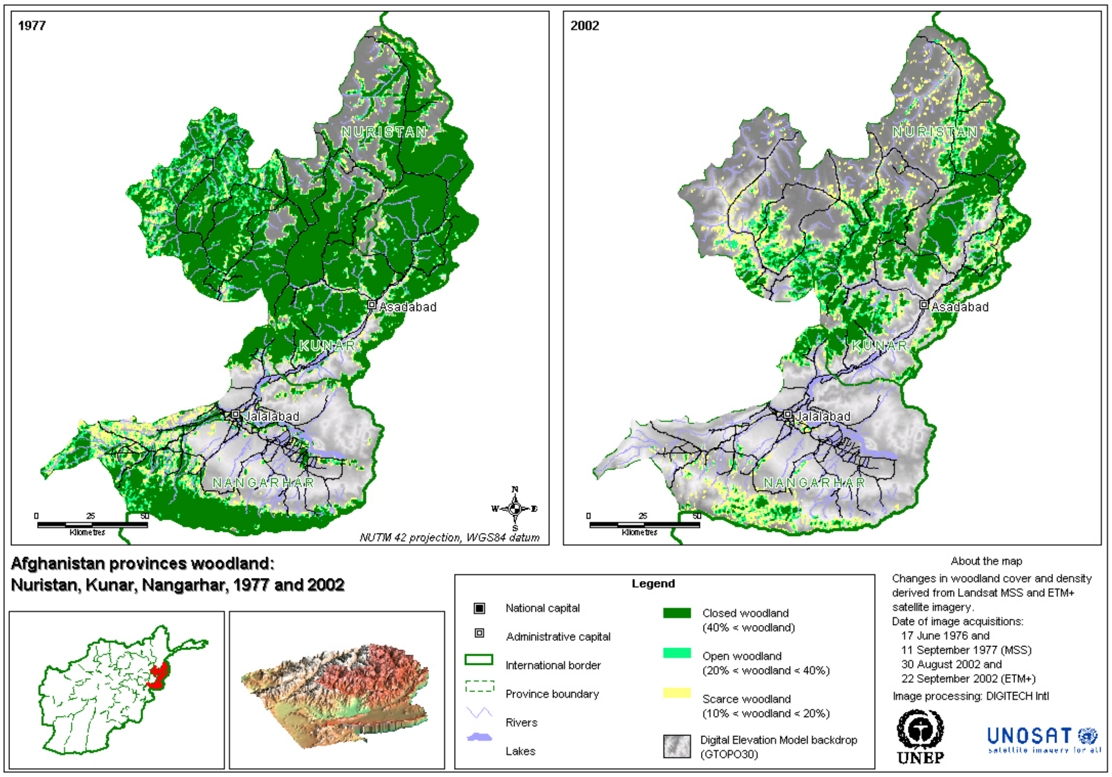


Figure 17. Woodland change in Nuristan, Kunar, and Nangarhar Province, 1977 - 2002

Because of the critical stage of forest resources in Afghanistan, the analysis shows that they should not be considered a viable energy source unless sustainable management practices are implemented and followed to allow for their recovery and regeneration. Given the nature of Afghanistan's agriculture, the solution to increased forest resources will not be plantations. A more likely scenario includes developments similar to the adjacent country of Turkmenistan, where the Blaustein Institutes of Desert Research (BIDR) is studying the growth of Black saxaul (*Haloxylon aphyllum*), a shrub species growing in specially designed water catchments alongside rangeland or Lalmi, which can be used as an animal feed and fuelwood (BIDR 2010).

Now, and most likely in the near future, Afghanistan doesn't have the quantity of forest resources to support electricity generation at a large scale in a sustainable manner. Also, the country will need to implement more efficient technologies for using forest and other biomass resources. The stoves used for cooking and heating are often very primitive and have poor combustion efficiency; and some households use open fires, which results in excessive and unsustainable biomass use.

Urban Waste

The concentration of population and activities in urban areas is responsible for the generation of waste. This waste, often referred to as municipal solid waste (MSW), is generated by households and the commercial and industrial sectors. The waste material includes plastics, paper, textiles, glass, metal, wood, food, and other organic wastes. MSW, particularly the biogenic portion, is a resource that can be converted to electricity, heat, and gaseous and liquid fuels through thermo-chemical (combustion, pyrolysis, and gasification), and biochemical (anaerobic digestion and fermentation) conversion processes.

The use of waste as an energy source provides two important benefits: environmentally safe waste management and disposal, as well as the generation of clean electric power. Waste-to-energy (WTE) combustion reduces the volume of trash by about 90%, resulting in a 90% decrease in the amount of land required for garbage disposal. Ash remaining from the combustion process (usually less than 25% of the input on a weight basis) is typically buried in a landfill with ferrous and other metals removed before that. By using biogas emitted from landfill sites, also called "landfill gas", about 60-90% of the methane can be captured, depending on system design and effectiveness. Because all landfills generate methane, it is logical to use the gas for energy generation rather than emitting this highly potent greenhouse gas to the atmosphere.

UNEP reports that Afghanistan has no proper sanitary landfills, and is currently relying on unmanaged dumpsites for waste storage (UNEP 2003). These dumpsites are often situated in proximity to major communities, which poses threat to humans' health and water resources. "For example, the siting of Kandahar's Mian Koo dumpsite in a dry river valley on the side of a mountain above the city is completely inappropriate. Heavy rains will almost certainly send hundreds, if not thousands of tonnes of waste back into the city via the river system. A similar situation exists at Herat's Qamar Qalla landfill where waste is spread over a large gravel area in a dried-out riverbed in a mountain valley above the city. The first period of sustained rainfall could wash the dump's contents back down into Herat. In Kabul, the Kampani dumpsite is located upstream and extremely close to a drinking water well field that may soon be expanded in order to meet the city's growing demand for water. The potential for cross-contamination of the water supply is significant. Mazar-e-Sharif, by contrast, could provide a model for the rest of Afghanistan: located within a reasonable distance from the town centre, a recycling/transfer station could be located nearby, and a shallow-depth landfill constructed on site. At the same time, it is distant enough from the town as not to present a problem to the urban community." (UNEP 2003).

There are increasing efforts to better manage landfills, regulate waste collection, and remove the existing dumps. Donor agencies such as the World Bank, UN-Habitat, USAID, and NGOs are assisting the Municipality of Kabul in the development of better management practices and construction of landfills. For example, the World Bank led an environmental assessment conducted by Gauff Engineers, of the Frankfurt and ICON-Institute Cologne, to identify suitable locations for new landfills outside Kabul. The team identified six promising sites and one is moving forward with the construction design. This will be the first engineered sanitary landfill in the region and will serve as a model for many municipalities in Afghanistan (Forouhar, Peterson 2007).

This study evaluates the MSW resources in Afghanistan to illustrate its electricity generation potential. WTE and landfill gas-to-energy (LGE) facilities tend to be built at the landfills of large urban centers to ensure steady supply, although small-scale projects could be developed in rural areas. Therefore, the study estimates the WTE potential in major populated places in Afghanistan (those with more than 30,000 people). To estimate the MSW generated in these places, the analysis uses 2010 population numbers (World Gazetteer 2010) and a waste generation rate of 0.4 kg/person/day adopted from Glawe et. al. 2006. Although this generation rate is for Kabul, it was used for all urban areas given the lack of data for other locations. The results of this analysis are illustrated in Figure 18. Naturally, the cities with large population such as Kabul, Kandahar, Herat, Mazari Sharif, and Jalalabad are also centers with a large concentration of waste.

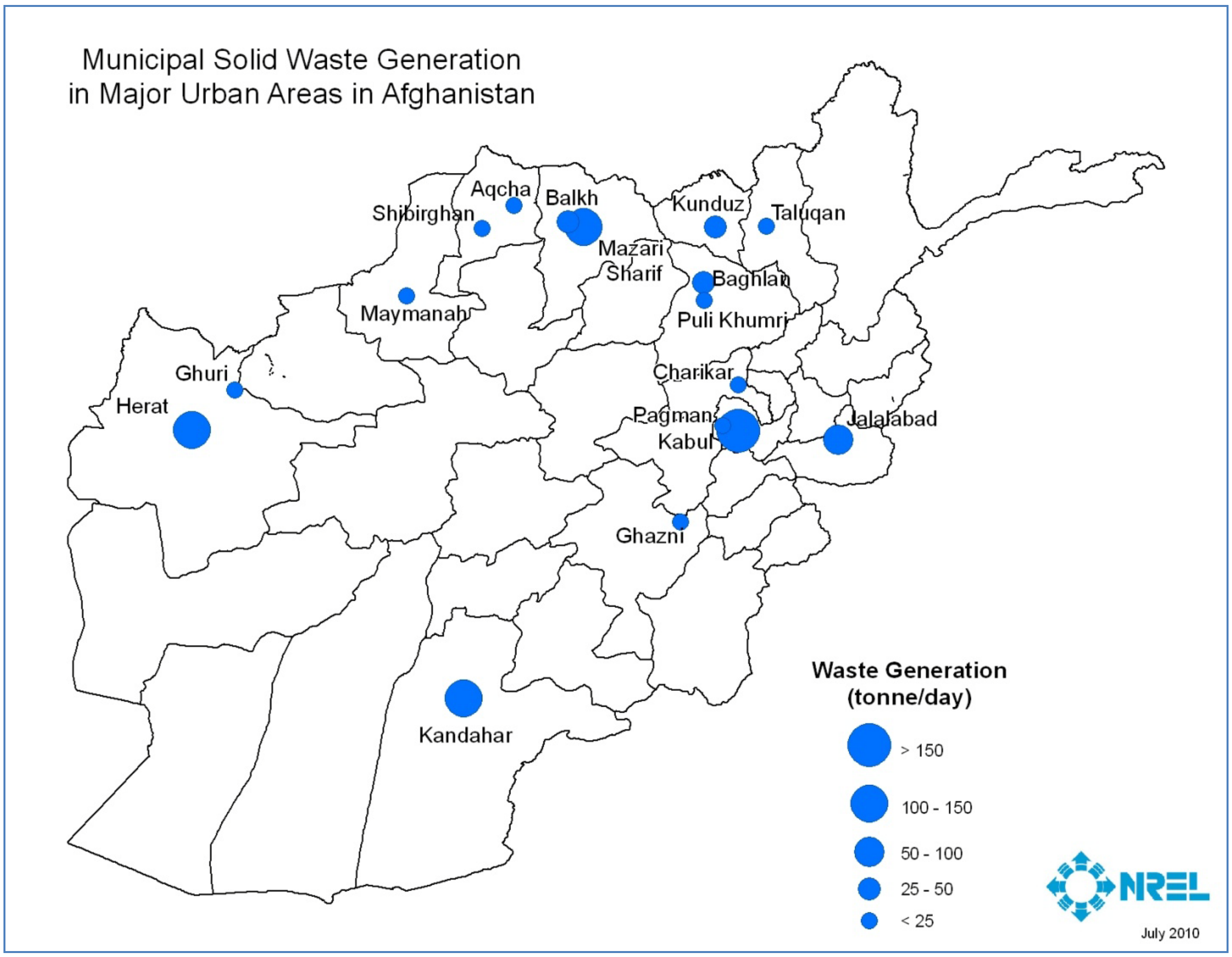


Figure 18. Municipal solid waste generation in major urban areas

Most of the MSW material is combustible at high-temperature incineration. This includes paper, food and field waste, plastic, rubber, and wood. However, materials such as glass, metals, ceramics, and clay are noncombustible. The amount of MSW generated annually in Afghanistan's major urban areas is estimated at about 600,000 tonnes (Table 8). Several studies point out that more than 50% of the waste in Kabul contains inert material (soil, gravel, stone, and dust), so it is noncombustible; there is some medical and industrial waste that is noncombustible as well. Therefore, about 40% of the waste generated in the city could actually be used for electricity generation. Because of the lack of data for other locations, this percentage was used for all urban areas. A typical WTE plant generates about 550 kWh per tonne of waste combusted. Modern WTE plants have efficiencies for power generation of 20%-25%, and new designs based on thermo-chemical conversion such as gasification could exceed 30%. The electrical energy from the combustible portion of the MSW in Afghanistan's major urban areas, using thermo-chemical conversion, is estimated at 134 GWh per year.

The authors recognize that the waste generation, composition, and collection rate vary by city, so one number doesn't fit all population centers. However, given the lack of data for all locations, this is the most suitable approach to illustrate the WTE potential in Afghanistan. The urban areas in the country are experiencing major population growth and a development boom, so the waste generation is expected to grow – and with that, so does the WTE potential.

Table 8. Municipal Solid Waste Generation and Electricity Potential in Major Urban Areas

Urban Area	Population	MSW Generation (tonne/yr)	Combustible MSW (tonne/yr)	Electrical Energy via Thermo-Chemical Conversion (GWh/yr)
Kabul	2,327,146	339,763	135,905	74.7
Baghlan	76,409	11,156	4,462	2.5
Puli Khumri	38,613	5,637	2,255	1.2
Ghuri	50,902	7,432	2,973	1.6
Herat	354,892	51,814	20,726	11.4
Kandahar	361,727	52,812	21,125	11.6
Ghazni	54,212	7,915	3,166	1.7
Jalalabad	156,284	22,817	9,127	5.0
Taluqan	46,292	6,759	2,703	1.5
Kunduz	112,689	16,453	6,581	3.6
Mazari Sharif	289,926	42,329	16,932	9.3
Shibirghan	38,970	5,690	2,276	1.3
Balkh	94,474	13,793	5,517	3.0
Charikar	36,652	5,351	2,140	1.2
Pagman	40,526	5,917	2,367	1.3
Maymanah	61,731	9,013	3,605	2.0
Aqcha	36,106	5,271	2,109	1.2
Total	4,177,551	609,922	243,969	134

Population numbers are for 2010 derived from World Gazetteer; Waste generation rate of 0.4 kg/person/day; Thermo-chemical pathway considers combustion technology generating 550 kWh/tonne of waste.

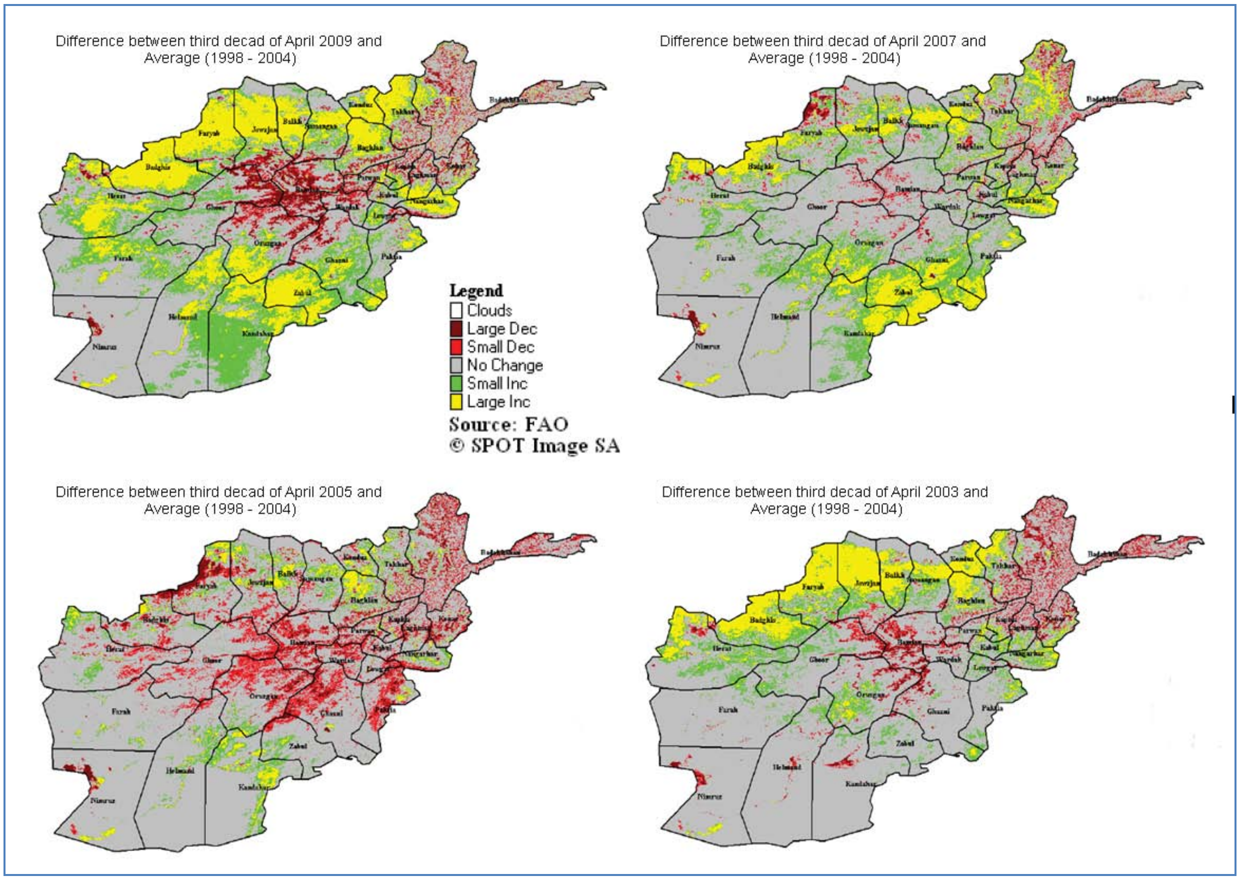
An alternative treatment of the organic waste fraction is landfill-based anaerobic digestion. The volume of gas produced depends on several factors: the amount, type, and age of waste; moisture content; temperature; pH; and site conditions. Without a particular site in mind, it is difficult to estimate the energy potential of MSW through bio-chemical conversion in Afghanistan. Also, it is difficult to put a timeframe on landfill gas recovery. As opposed to bio-digesters where waste feedstock is converted to biogas in controlled, optimized conditions, anaerobic decomposition in a landfill is uncontrolled and very slow. It may take several years before the level of production is sufficient to fuel an electricity generator; however, an advanced technology exists to accelerate the digestion process within a few months. Based on earlier observations regarding waste composition, it appears that Kabul, and perhaps other cities, don't have much organic waste going to landfills. In general, organic waste is higher in rural areas. Therefore, combustion or other thermo-chemical conversion pathways would be more suitable for energy recovery from waste in the country's urban areas.

Potential Biomass Resources

Predicting a plant's productivity is normally done using models that link soil information, solar energy input (mathematically predictable), temperature, and available moisture with the plant growth characteristics. For Afghanistan, the annual variation in precipitation for the same month of the year results in incorrect productivity predictions for rainfed lands. For irrigated lands, where moisture is not so limited, it is possible to forecast plant yields; these also can be generated from the historical record for specific plants and cultivars in any case.

Crop cultivation without irrigation on dry lands (Lalmi) relies entirely on the rainfall that regularly occurs in the winter and early spring. The average seasonal precipitation maps in the Appendix illustrate the winter and spring cycle. Accordingly, most crops on these lands are planted in the October–November period at least where low winter temperatures would not kill the early growth. However, the annual variation in precipitation is literally from 25–200% of the average, with drought at one extreme and flooding at the other. An indication of this variance is the wide difference in rainfed wheat crop production during 2002–2009 reported by the Ministry of Agriculture, Irrigation and Livestock (MAIL). The average production was about 1.0 Mt with a standard deviation of 0.56 Mt; however, the range was from 0.22 Mt to 1.68 Mt (MAIL 2009b).

Another indicator of the annual variation in precipitation is the satellite-derived vegetation data for Afghanistan. There is a strong relationship between precipitation and biomass production – in non-irrigated areas, increased rainfall leads to more plant development. Some experts believe that vegetation data provides a better representation of rainfall patterns than point data representing ground stations. Figure 19 illustrates the Normalized Difference Vegetation Index (NDVI) for different years in which the third week of April is compared with the seven-year average. It clearly demonstrates the annual variation in vegetation development, thus precipitation patterns, and the difficulty in predicting crop-production levels.



Source: MAIL 2009a

Figure 19. NDVI variation between the years 2003, 2005, 2007, and 2009

Most arable lands in Afghanistan are irrigated to some degree. Agriculture accounts for more than 95% of water consumption, primarily from rivers and streams. This is followed by kareze (a historic Persian system of underground water collection), springs, deep-well pump, and other systems. Water availability in Afghanistan is dependent on both rainfall and snow melt in the Hindu Kush, which supplies more than 80% of Afghanistan's water resources. Unfortunately, drought and warming air temperatures in recent years have reduced the water flow of rivers and the size of the glaciers in Afghanistan. Ground water is being drawn at a rate greater than replenishment.

Irrigation is clearly the key to reasonably stable production of any crop in Afghanistan. The purely rainfed production is so varied each year that it would make it very difficult to produce any crop in the drought years. With climate change, the future of both rainfed and irrigated crop production in the country is very daunting especially because of predictions that drought will become the normal season by 2030; in recent history, it was a temporary or cyclical event (SEI 2009). Increased rainfall with increasing temperatures will not offset further loss of snow in the mountains and the more rapid spring melt. A sequence of untimely rainfall and increased evapotranspiration will affect the spring season more than any other. The key message from climate projections for Afghanistan by the Stockholm Environment Institute (SEI) is: "The vulnerability of the agricultural sector to increased temperatures and changes in rainfall patterns/snow melt is high. Increased soil evaporation, reduced river flow from earlier snow melt, and less frequent rain during peak cultivation seasons will all impact upon agricultural productivity and crop choice availability. Crop failure levels due to water shortages and the amount of potentially productive land left uncultivated will likely increase. More water intensive staple crops will become less attractive to farmers, with a likely increase in the attractiveness of those that are more drought hardy, including opium poppy. By 2060, large parts of the agricultural economy are likely to have become marginal without significant investment in water management and irrigation."

Energy Crops Potential

Ethanol and biodiesel are the liquid biofuels most widely used in transport vehicles today. Ethanol (C_2H_5OH, ethyl alcohol) is produced by the fermentation of carbohydrate materials. Today, ethanol is made from starches and sugars, which are primarily grown as food or as animal feed. Ethanol is used for production of alcoholic beverages; for industrial purposes (as a solvent, disinfectant, or chemical feedstock); and, in recent years, as a blending agent with gasoline to increase octane and reduce carbon monoxide and other smog-causing emissions. Biodiesel is a liquid fuel made from vegetable oils and animal fats through a chemical process (transesterification) that reacts the feedstock with alcohol (usually methanol) to produce chemical compounds known as fatty acid methyl esters (FAME). Biodiesel is the name given to these esters when they meet specifications such as the American Society for Testing and Materials (ASTM) D6751 for use as transportation fuel. Biodiesel is used in blends with petroleum diesel or in its pure form.

There is poor food security in Afghanistan, which is a situation that doesn't favor biofuels production. In 1980, the subsistence agricultural economy with a population of less than 20 million people was generally able to provide adequate nutrition through the additional income from export of high-value livestock, vegetables, fruits, and nuts. The current population of almost 30 million people combined with the recent trends in drought, floods, and the destruction of infrastructure contributed to the food security deterioration. In 2010, about one-third of the population is dependent on the World Food Program for subsistence (WFP 2010).

Discussions of new crops in Afghanistan often occur in the context of the counter-narcotics program. It is evident that for a new crop to be considered, the extent of adoption will depend on the land-holding pattern, availability of water, crop requirements, and the overall economic competitiveness of the new crop.

Assuming that the issues of land-holding patterns and water availability are the same as the opium crop the poppy (*Papaver somniferum L.)*, which has been widely grown in Afghanistan, it is worth examining the growth characteristics and crop requirements. According to the Handbook of Energy Crops (Duke 1983), the poppy "thrives in rich, well-manured soil, in hot to warm regions. Deep, warm, moderately moist, medium heavy soils, well cultivated, and limed meet the requirements for poppy growing. Soils with pH neutral or slightly alkaline preferable. Ranging from Cool Temperate Wet Steppe to Wet through Subtropical Dry to Moist Forest Life Zones, poppy is reported to tolerate annual precipitation of 3.1 to 17.3 dm (mean of 34 cases = 16.0), annual temperature of 5.6 to 23.5°C (mean of 34 cases = 10.9), and pH of 4.9 to 8.2 (mean of 25 cases = 6.5). It does poorly in the humid tropics." This indicates that common oilseed plants – canola, soybean, sunflower and safflower – could be grown in similar areas that have been successful with opium poppy, based on the soil moisture and temperature requirements as described by Purdue (Duke 1983) for these crops.

Mustard (*Brassica juncea*) has been grown in Afghanistan for a long time; in fact, its geographic origin is presumed to be Eastern Afghanistan and the Himalayan region. Its widespread distribution in Afghanistan and the periods of planting reflect the availability of water as shown in Table 9.

Table 9. Oilseed Planting and Harvest Dates in Afghanistan

Region	Planting	Harvesting	Species
North	March - April	September	Not specified
East Central	April	August - September	Mustard, Sesame, Flax
Central	April - May	September	Mustard, etc.
Southeast	October - November	March - April	Not specified
East	October - November	April	Mustard, Sesame, Flax
Southwest	April - June	November	Mustard, Sesame, Flax, Sunflower

Source: ICARDA 2002

Other than in the nonirrigated East and Southeast, where planting has to be on Lalmi before the winter rains, the remaining areas of growth for mustard are mainly irrigated. These are usually second crops with plantings in the spring-summer after the winter wheat crop. Typically, the mustard relatives in the *Brassicaceae* family, e.g., canola (*Brassica napus*) and camelina (*Camelina sativa*) will grow in the same places and under the same conditions as mustard. Because mustard is a widely known crop in Afghanistan, then it is likely that canola and camelina will do well on irrigated lands (planted in the spring-summer after the winter wheat harvest).

New oilseed crops as well as new varieties of these crops that some farmers are already growing are being evaluated in Afghanistan by MAIL, different donor agencies, and NGOs. During 2002-2006, in an effort to introduce alternative crops to poppy, USAID provided farmers in four provinces (Helmand, Kandahar, Zabul, and Uruzgan) with improved cotton seed variety, better farm technology, and more efficient processing of cotton gin (USAID 2010). The International Center for Agricultural Research in Dry Areas (ICARDA) reported research on soybean, new varieties of sesame and flax, canola, and safflower (ICARDA 2005). The United States Department of Agriculture (USDA) is supporting the soybean and sesame seed cultivation. Researchers identified soybean varieties that are suitable for northern Afghanistan, with some varieties yielding as much as 2.5 t/ha if planted following a wheat crop. Canola is considered well-suited for northern Afghanistan as well, if sown in the fall. The research states that it could grow well even in dry areas if sown in the late winter and early spring. Safflower is another oilseed crop considered in Afghanistan. It is drought-resistant and well-adapted to dryland cropping – and early results indicate that safflower can be grown successfully when planted as an early spring crop (ICARDA 2005). Another oilseed crop from the mustard family, pennycress (*Thlaspi arvense*), also could have great potential in Afghanistan. While crops such as canola, soybean, and safflower are used in food applications, camelina and pennycress are usually not and they grow well on marginal lands and require minimal water, fertilizer, and pesticide.

The challenge with displacing poppy cultivation is the value proposition. Oilseed commodity prices (e.g., canola and soybean) are still only two-three times that of wheat, and yields in Afghanistan are likely to be lower than world averages even on irrigated land, which further reduces the farmers' margin. An analysis of the price of wheat in Afghanistan (Favre 2005) shows that from 1996,–2005 the local Afghanistan prices tracked the international commodity prices of U.S. No. 2 soft red winter wheat, except at times when there are significant local shortages, such as during the Taliban period. Because of the land-locked nature of Afghanistan, it may seem more surprising that for some periods, the local price has been the same as the international commodity price and does not reflect local transportation costs. Therefore, it would appear that oilseed cultivation maybe sensitive to the international commodity price as well.

One recent analysis (Arden and Fox 2010) breaks out of the international price constraint by presuming that the International Security Assistance Force (ISAF) would be a customer for the biodiesel produced in Afghanistan to offset importing their fuel. It also presumes that the ISAF would pay the fully burdened cost of fuel (FBCF) for diesel oil replacement in military use. The FBCF is listed as 400 US$/gal or almost 120,000 US$/t. Diesel oil in the U.S. retail markets in 2010 has a price of 2.10 US$/gal or only 630 US$/t. At the time of this writing, vegetable oils were selling on the market for about 750–850 US$/t with oilseed prices at less than half, depending on their oil content. So, in this specific case, there is a major financial incentive. The selected crop is safflower, and the initial area of planting proposed is 61,500 ha (located near a large U.S. or ISAF base in Kandahar province, because the southern provinces of Kandahar and Helmand account for 73% of Afghanistan's poppy cultivation), approximately 50% of the area planted with poppy in 2009. The production would be about 50 kt in a 90 million US$ investment in a biodiesel transesterification plant with capacity of 60 dam^3 (15 million gallons) per year.

While the use of nonedible oils, e.g., camelina and pennycress, would obviate competition with food markets, the farmers have a different perspective. To reduce risk, the choice of food-quality oil crops such as safflower, sunflower, canola, and soybean would provide additional market opportunities. The byproduct meal also would have value as an animal feed, without restrictions due to toxicity (some nonedible species, such as *Jatropha curcas*, have toxic varieties).

The vegetable oils could be used directly in slow diesel engines as straight vegetable oil (SVO); however, the low winter temperatures would make this difficult to achieve. Therefore, it might be better to transesterify the vegetable oils and gain greater compatibility with the diesel system – either for transportation or for stationary applications.

Conclusions

This study estimated the biomass resources available in Afghanistan and evaluated potential resources that could be used for energy purposes. The analysis also presented information on the Afghanistan ecosystem, which is under both direct threats from people and indirect effects of climate change, as well as the consequences of an infrastructure that has been damaged from almost four decades of war. Remote sensing data demonstrate the pressure of people on the almost extinct forests of Afghanistan and the extraordinary variation in water availability for rainfed agriculture, while irrigation itself is starting to exceed the available water resources. Our major findings are as follows:

1. This study identified biogas generation from animal manure and waste-to-energy from urban discards as the most promising sustainable biomass technologies using existing resources in Afghanistan. Biogas technology is more applicable to rural regions and WTE is best suited for urban areas.
    a. Biogas technology provides many benefits to households including reductions in indoor air pollution, reductions in firewood use and collection time (especially for women), and increases in crop production by using the spent slurry as a fertilizer.
    b. Cost of biogas systems could be an issue. Effective public-private partnerships are critical to the success of biogas technology deployment in Afghanistan. For example, Nepal's Biogas Support Program combines the participation of the private sector, microfinance organizations, community groups, and nongovernmental organizations, which has resulted in a steady increase of biogas systems during the past decade.
    c. Waste management in Afghanistan's large populated places is one of the country's most serious environmental problems. Kabul, Kandahar, Herat, Mazari Sharif, and Jalalabad are centers with large concentrations of waste that could be used as an energy source. The WTE technology provides two important benefits: environmentally safe waste management and disposal, as well as the generation of clean electric power.
2. Crop residues are already in use as animal feed, for farm applications, and construction material. They represent a significant component of the solid biomass fuels used for cooking and, therefore, are not available for electricity generation or transportation fuels production (such as cellulosic ethanol). Moreover, crop production in Afghanistan is run by households for self-consumption or local markets, so it can't generate large concentrations of residues to support power generation at scale.
3. Forest resources are limited and the country doesn't have sufficient quantity to support electricity generation at a large scale in a sustainable manner. The fuelwood issues require a threefold approach to deal with the scarcity situation. It will be important to reduce the energy demand while still providing the same service for cooking and space heating. NGOs' efforts have identified that insulation of buildings in northern or high-altitude areas would positively impact fuelwood consumption directly; while improved cookstoves, including ovens, would also help reduce consumption (Nienhuys 2009). There is also a need for increased fuelwood supplies, which could be ensured by planting trees and shrubs. Reforestation would provide not only fuel, but also restore local livelihoods and manage erosion. In dry areas, the "trees" are likely to be shrubs

adapted to arid areas and would require new approaches to irrigation, such as rainwater-capture techniques.

4. Climate and terrain are major limitations on the potential biomass resources in Afghanistan – large areas of arable land are not available for energy cropping. With climate change, the future of both rainfed and irrigated crop production in the country is very daunting based on predictions that drought will become the normal season by 2030 (compared with the recent history of it being a temporary or cyclical event). It's also evident that large parts of the agricultural land are likely to become marginal without significant investment in water management and irrigation by 2060.
5. Annual oilseed production for both food and fuel applications could be undertaken to offset cooking oil imports and provide local biofuels. Common oilseed plants (canola, soybean, sunflower, and safflower) could be grown in similar areas that have been successful with opium poppy – this would also provide alternative crops for farmers in those regions. Also, two other oilseed crops from the mustard family (camelina and pennycress) could have great potential in Afghanistan. These crops are nonedible; grow well on marginal lands; and require minimal water, fertilizer, and pesticides.
6. High value-added crops can generate high returns to the farmer. However, the current illegal poppy crop, while demonstrating this, is hard to substitute with legal crops. The traditional value of energy relative to food makes energy an improbable replacement for the opium economy.

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Appendix

Table 10. Orchard, Vineyard, and Processing Residues

Orchards and Vineyards	Area (ha)	Area (acres)	CRR (BDT/acre/yr)	Biomass (BDT/yr)	Biomass (DMT/yr)
Apple	7,000	17,297	1.43	24,735	22,439
Peaches	1,920	4,744	1.3	6,168	5,595
Apricot	8,000	19,768	1.3	25,699	23,314
Plums	3,500	8,649	0.98	8,476	7,689
Figs	2,700	6,672	1.43	9,541	8,655
Pomegranate	8,000	19,768	1.04	20,559	18,651
Grapes	57,600	142,333	1.3	185,033	167,859
Walnut	2,300	5,683	0.65	3,694	3,351
Almond	12,000	29,653	0.85	25,205	22,865
Olive	2,300	5,683	0.98	5,570	5,053
Total	105,320	260,251		314,679	285,472
Processing Residues	**Area (ha)**	**Area (acres)**	**Yield (BDT/acre/yr)**	**Biomass (BDT/yr)**	**Biomass (DMT/yr)**
Almond shell	12,000	29,653	0.45	13,344	12,105
Walnut shell	2,300	5,683	0.62	3,524	3,197
Olive (pits)	2,300	5,683	0.31	1,762	1,598
Total	16,600	41,019		18,629	16,900

Area data from CSO 2008-09; CRR – crop to residue ratio – from CEC 2008; BDT - bone dry ton (short ton); DMT - dry metric ton

Table 11. Crop Residues from Cereal Production by Province

Province	Wheat	Wheat Residues	Barley	Barley Residues	Rice	Rice Residues	Maize	Maize Residues	Total Cereal Production	Total Residues
Badakhshan	67,000	120,600	0	0	13,500	22,950	0	0	80,500	143,550
Badghis	65,000	117,000	10,900	14,170	3,000	5,100	1,000	2,300	79,900	138,570
Baghlan	105,000	189,000	7,300	9,490	85,200	144,840	1,100	2,530	198,600	345,860
Balkh	173,000	311,400	39,000	50,700	21,300	36,210	7,400	17,020	240,700	415,330
Bamyan	34,000	61,200	3,300	4,290	1,900	3,230	0	0	39,200	68,720
Daykundi	15,000	27,000	4,300	5,590	0	0	6,100	14,030	25,400	46,620
Farah	36,000	64,800	10,000	13,000	3,000	5,100	3,100	7,130	52,100	90,030
Faryab	106,000	190,800	48,100	62,530	0	0	30,700	70,610	184,800	323,940
Ghazni	127,000	228,600	25,000	32,500	3,200	5,440	24,200	55,660	179,400	322,200
Ghor	44,000	79,200	7,700	10,010	3,100	5,270	1,300	2,990	56,100	97,470
Helmand	245,000	441,000	16,500	21,450	0	0	8,900	20,470	270,400	482,920
Herat	192,000	345,600	14,300	18,590	28,000	47,600	1,600	3,680	235,900	415,470
Jowzjan	75,000	135,000	34,400	44,720	0	0	16,400	37,720	125,800	217,440
Kabul	62,000	111,600	0	0	0	0	0	0	62,000	111,600
Kandahar	108,000	194,400	1,100	1,430	0	0	30,700	70,610	139,800	266,440
Kapisa	29,000	52,200	600	780	3,600	6,120	20,400	46,920	53,600	106,020
Khost	27,000	48,600	500	650	9,800	16,660	10,600	24,380	47,900	90,290
Kunar	25,000	45,000	200	260	17,100	29,070	14,500	33,350	56,800	107,680
Kunduz	165,000	297,000	5,200	6,760	81,700	138,890	1,800	4,140	253,700	446,790
Laghman	41,000	73,800	1,600	2,080	40,200	68,340	5,500	12,650	88,300	156,870
Logar	102,000	183,600	1,800	2,340	3,100	5,270	4,700	10,810	111,600	202,020
Nangarhar	185,000	333,000	700	910	22,000	37,400	21,000	48,300	228,700	419,610
Nimruz	31,000	55,800	5,000	6,500	0	0	4,100	9,430	40,100	71,730
Nurestan	3,000	5,400	0	0	0	0	7,400	17,020	10,400	22,420
Paktia	54,000	97,200	2,400	3,120	3,000	5,100	18,400	42,320	77,800	147,740
Paktika	39,000	70,200	18,000	23,400	3,800	6,460	6,100	14,030	66,900	114,090
Panjsher	11,000	19,800	1,000	1,300	0	0	10,200	23,460	22,200	44,560
Parwan	63,000	113,400	400	520	7,600	12,920	3,800	8,740	74,800	135,580
Samangan	49,000	88,200	2,400	3,120	4,500	7,650	400	920	56,300	99,890
Sar-e Pol	69,000	124,200	13,100	17,030	0	0	2,900	6,670	85,000	147,900
Takhar	122,000	219,600	46,400	60,320	40,900	69,530	7,000	16,100	216,300	365,550
Uruzgan	59,000	106,200	9,800	12,740	5,600	9,520	5,100	11,730	79,500	140,190
Wardak	65,000	117,000	1,700	2,210	4,600	7,820	0	0	71,300	127,030
Zabul	30,000	54,000	500	650	0	0	3,500	8,050	34,000	62,700
Total	2,623,000	4,721,400	333,200	433,160	409,700	696,490	279,900	643,770	3,645,800	6,494,820

Production in 2008-09 from CSO's Afghanistan Statistical Yearbook 2008-09

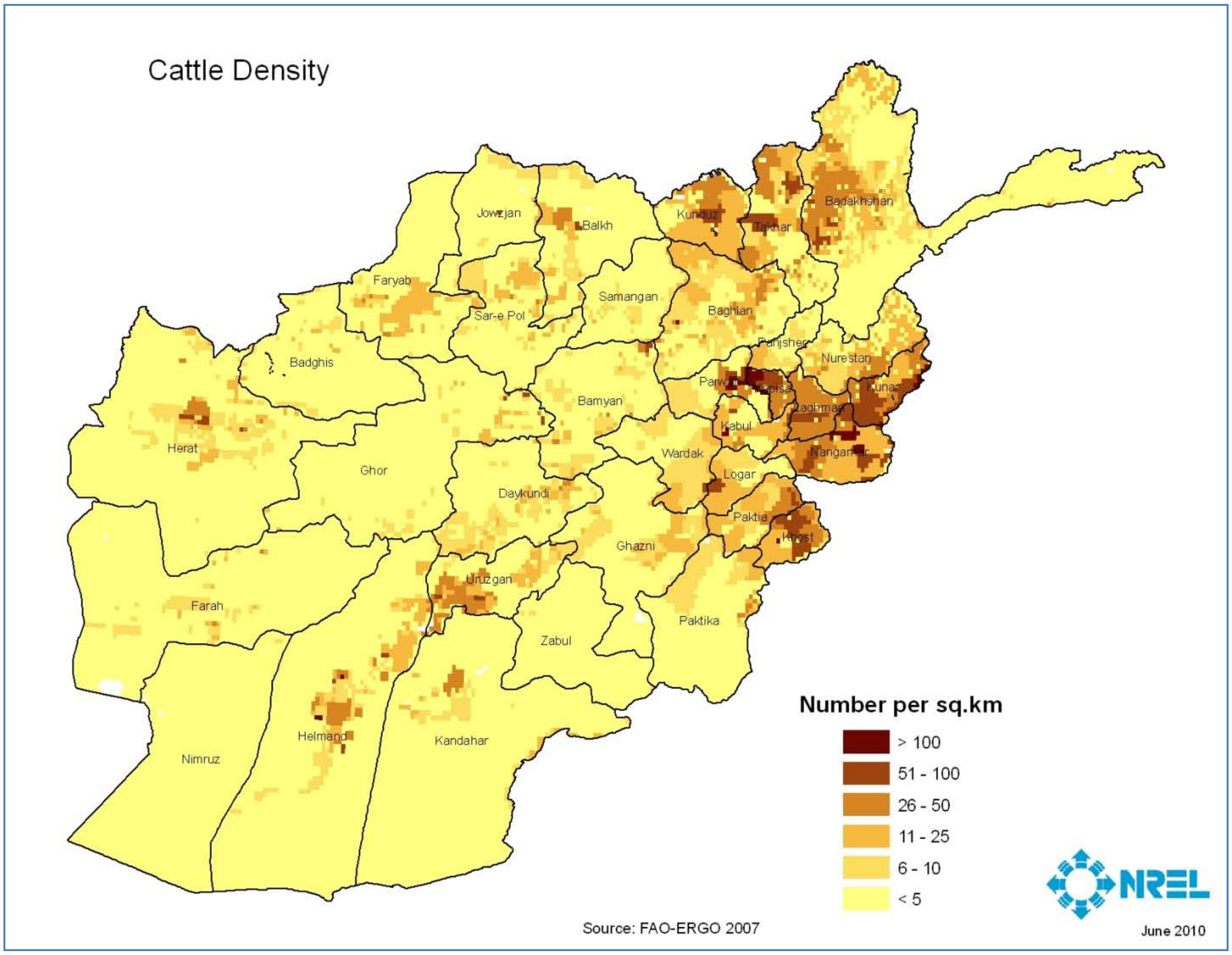

Figure 20. Cattle density

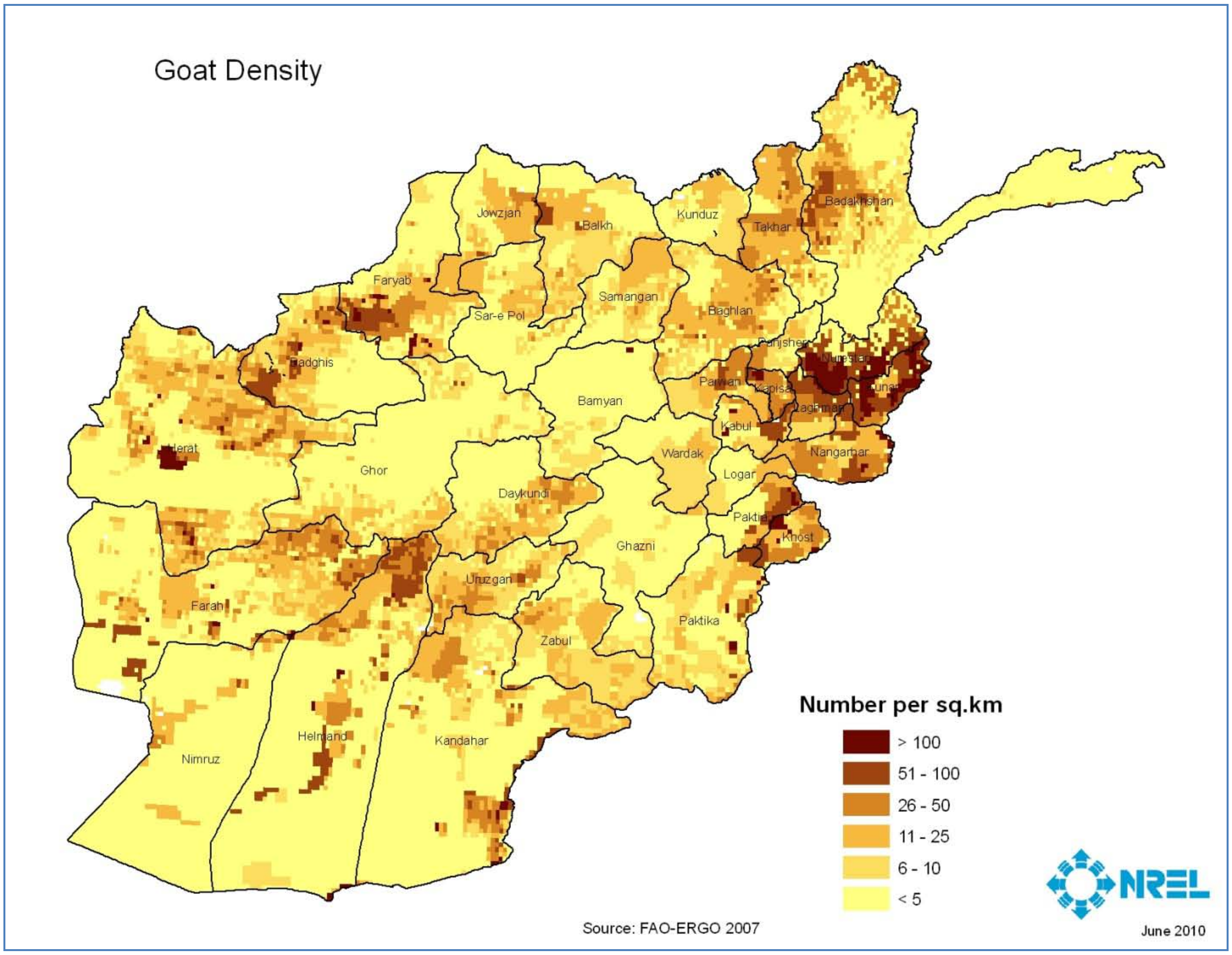

Figure 21. Goat density

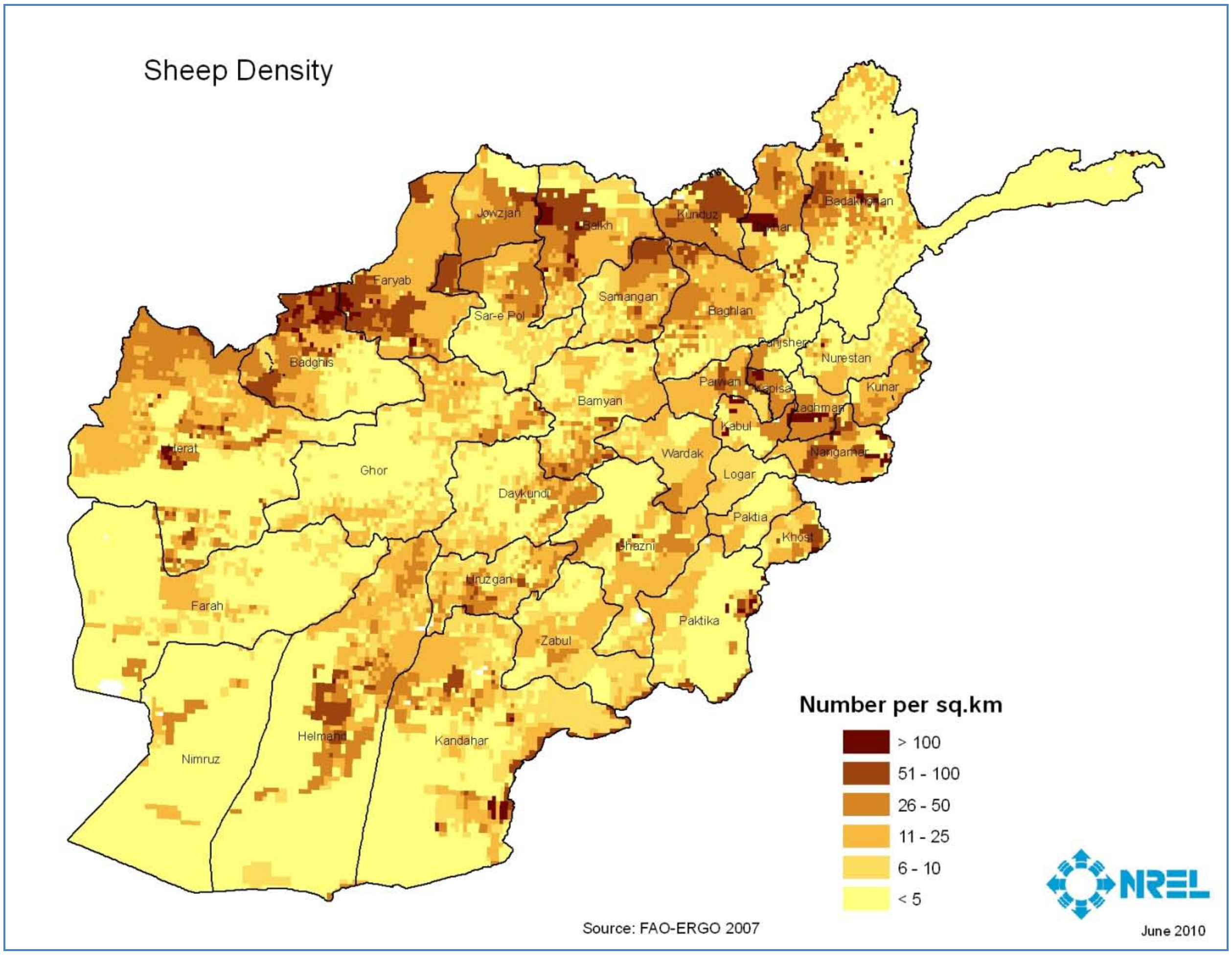

Figure 22. Sheep density

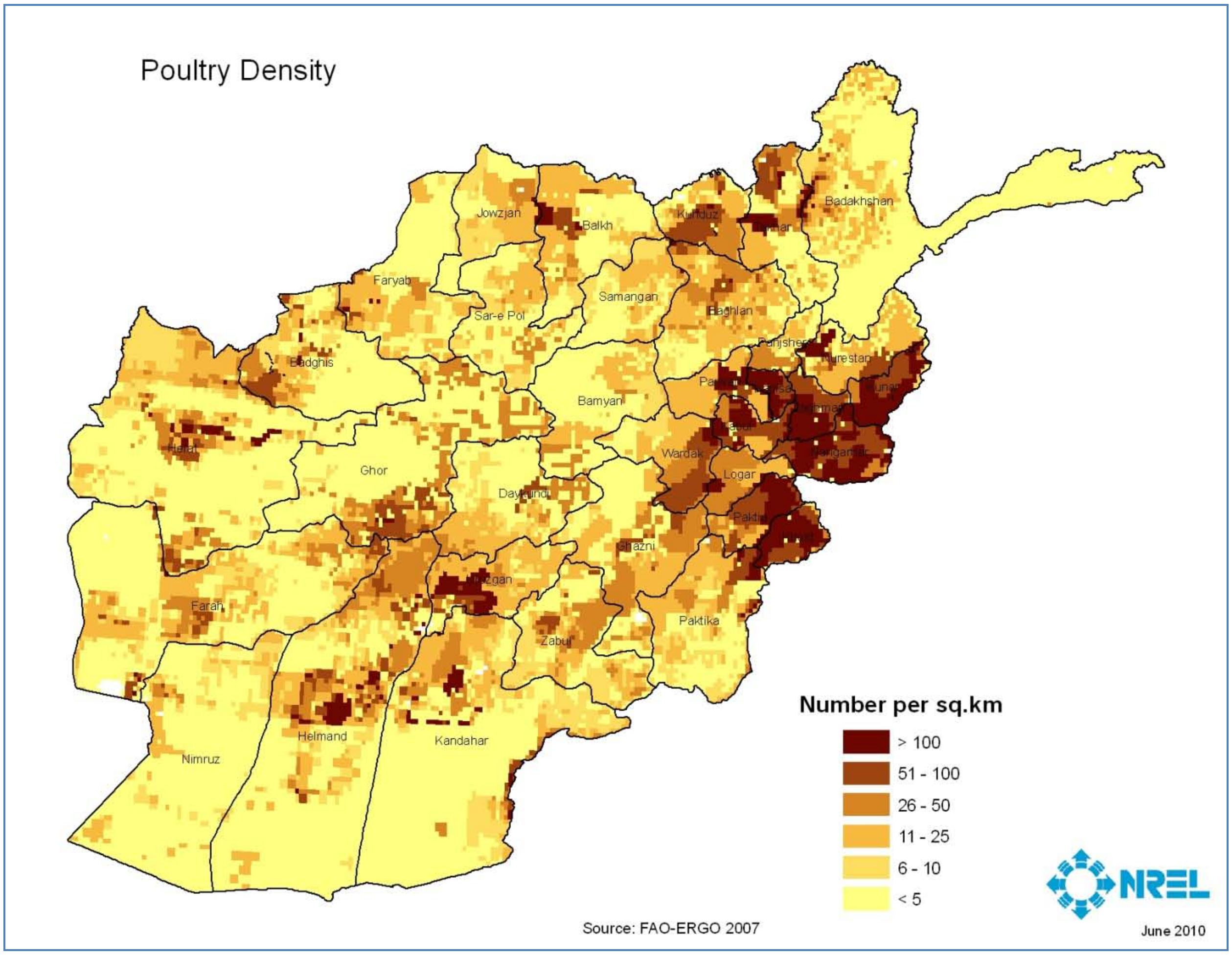

Figure 23. Poultry density

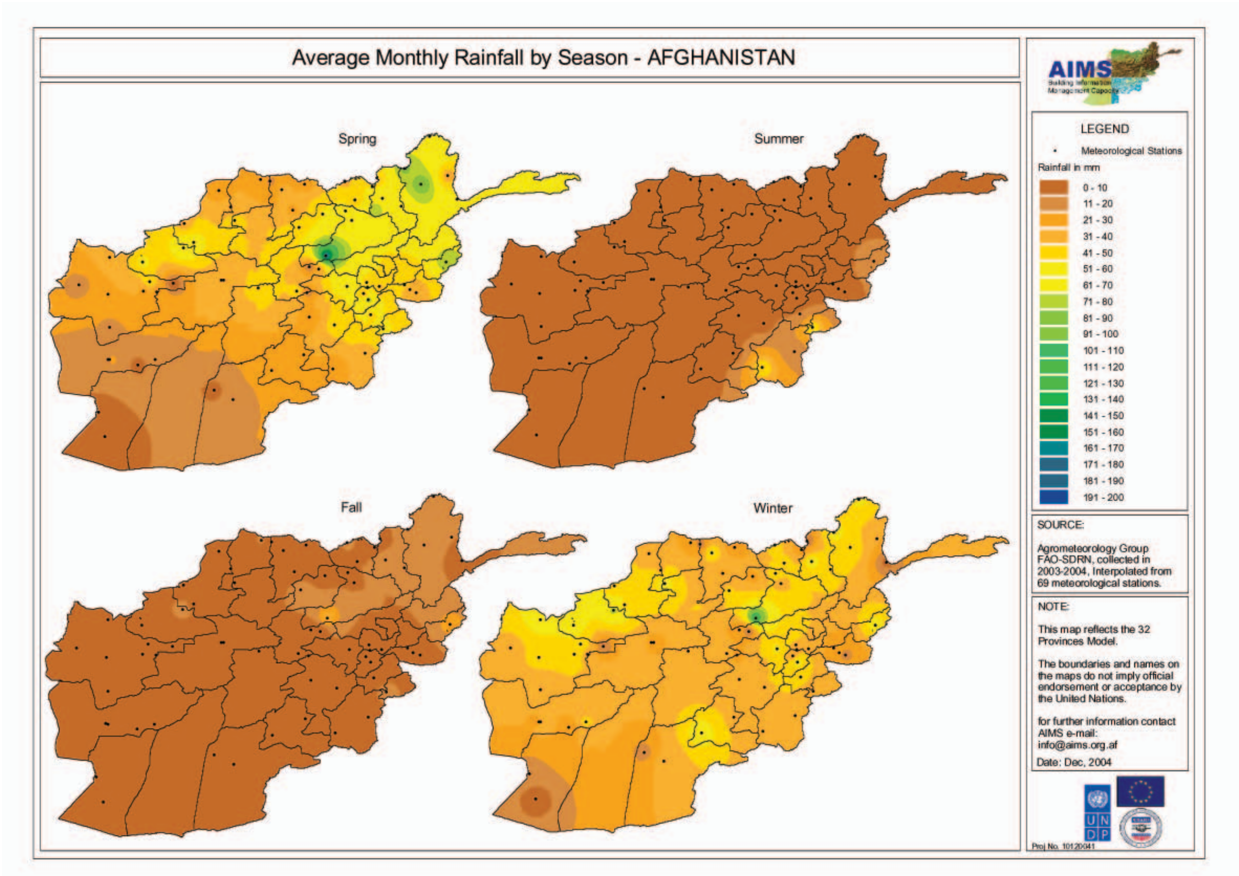

Figure 24. Average monthly rainfall by season

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14. ABSTRACT *(Maximum 200 Words)*
Afghanistan is facing many challenges on its path of reconstruction and development. Among all its pressing needs, the country would benefit from the development and implementation of an energy strategy. In addition to conventional energy sources, the Afghan government is considering alternative options such as energy derived from renewable resources (wind, solar, biomass, geothermal). Biomass energy is derived from a variety of sources -- plant-based material and residues -- and can be used in various conversion processes to yield power, heat, steam, and fuel. This study provides policymakers and industry developers with information on the biomass resource potential in Afghanistan for power/heat generation and transportation fuels production. To achieve this goal, the study estimates the current biomass resources and evaluates the potential resources that could be used for energy purposes.

15. SUBJECT TERMS
Afghanistan; biomass; biomass resources; biogas; Afghanistan climate; Afghanistan geography; Afghan energy; domestic fuels; agricultural resources; crop residues; irrigated lands; opium poppy; animal waste; domestic biogas; feedstock; forest resources; urban waste; woodland; potential biomass resources; energy crops

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