Food and Agriculture Organization of the United Nations

Using *Prosopis* as an energy source for refugees and host communities in Djibouti, and controlling its rapid spread

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Food and Agriculture Organization of the United Nations
Rome, 2018

Recommended citation

Gianvenuti, A., Farah, I., Yasmin, N., Jonckheere, I. and Xia, Z. 2018. *Using* Prosopis *as an energy source for refugees and host communities in Djibouti, and controlling its rapid spread*. Rome, Food and Agriculture Organization of the United Nations (FAO).

ISBN 978-92-5-130741-0

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Acknowledgements

Arturo Gianvenuti, Idris Farah, Naila Yasmin, Inge Jonckheere and Zuzhang Xia prepared this report. They thank the FAO Djibouti Office, led by Fallou Guèye, and the UNHCR Djibouti Office, led by Abdoulaye Barry, who coordinated the analysis and the fieldwork in the Ali-Addeh and Holl Holl refugee camps. The authors also thank Abdoulkader Ismail, Leone Magliocchetti Lombi, Dario Cipolla, Remi D'Annunzio and Ugo Leonardi at FAO for reviewing the report and providing inputs and comments. Many thanks to Alastair Sarre for editing and Roberto Cenciarelli for layout.

Djibouti's Ministry of Agriculture, Water, Fishery, Livestock and Marine Resources requested FAO's technical assistance in planning the appropriate management and use of *Prosopis* as an energy source for cooking in the context of the Ali-Addeh and Holl Holl refugee camps and host communities and as a way of controlling the rapid spread of this species. The study was carried out as part of project TCP/DJI/3604/C1.

Acronyms and abbreviations

AOI	area(s) of interest
cm	centimetre(s)
DAF	Directorate of Agriculture and Forestry
DJF	Djiboutian franc
FAO	Food and Agriculture Organization of the United Nations
ha	hectare(s)
kg	kilogram(s)
km	kilometre(s)
LPG	liquefied petroleum gas
m	metre(s)
MAEPE-RH	Ministry of Agriculture, Water, Fishery, Livestock and Marine Resources
MHUE	Ministry of Housing, Urban Planning and Environment
mm	millimetre(s)
NDVI	Normalized Difference Vegetation Index
NIR	near infrared
ONARS	National Office for Assistance to Refugees and Victims
RGB	red, green and blue
SEPAL	System for Earth Observation Data Access, Processing and Analysis for Land Monitoring
TCP	Technical Cooperation Programme
UNHCR	United Nations High Commissioner for Refugees
USD	United States dollar(s)

Executive summary

Djibouti has limited natural resources and is struggling with an ongoing drought. It is also dealing with a protracted refugee crisis, with more than 23 000 refugees living in the country's Ali-Addeh and Holl Holl refugee camps. Domestic energy is a major challenge in the two camps: both use *Prosopis* fuelwood, which is collected at small-scale production sites more than 150 km from the camps and transported by truck. This is economically inefficient, and the quantity of fuelwood carried per truck is small because of the wood's low bulk density.

As in several other arid countries worldwide, *Prosopis* is an invasive species in Djibouti. On the other hand, *Prosopis* species can be huge assets capable of supporting tree-based enterprises and livelihoods and meeting energy demand.

Currently, the quantity of fuelwood and kerosene supplied to the refugees in the Ali-Addeh and Holl Holl camps is insufficient to meet fuel demand for cooking. The majority of refugees lack additional income to purchase fuels in local markets and therefore must walk up to 10 km searching for fuelwood in natural vegetation, a practice that is contributing to natural resource degradation.

It is clear that the refugee and host communities in Djibouti face major challenges in ensuring sufficient access to energy and securing sustainable livelihoods. There is an urgent need to improve the planning of woodfuel supply, assess fuel quality, and improve the efficiency of woodfuel delivery and use in the refugee camps.

FAO, in collaboration with Djibouti's Ministry of Agriculture, Water, Fishery, Livestock and Marine Resources and Ministry of Housing, Urban Planning and Environment, and the United Nations High Commissioner for Refugees, conducted the study presented in this report to assess the use of *Prosopis* woody biomass as a source of energy and options for increasing the efficiency of woodfuel supply chains. The study used socio-economic data collected through interviews, focus-group discussions, a desk review and a field visit, and a remote sensing analysis of *Prosopis* distribution, combined with field data, in four areas of interest in Djibouti: Douda, As Eyla, Tadjourah, and Hanlé. The report includes:

- an assessment of challenges in meeting energy demand in displacement settings in Djibouti;
- data on the distribution of *Prosopis* in the country and the quantity of standing *Prosopis* biomass at selected sites (which are also the country's main *Prosopis* areas); and
- an analysis of the economic potential of processing *Prosopis* woody biomass into briquettes and charcoal.

The major findings of the study are as follows:

- *Prosopis* species cover more than 5 000 hectares in the four sites.
- The total current annual fuelwood demand in the two refugee camps is estimated at 7 359 tonnes.
- The total standing biomass of *Prosopis* in the four sites exceeds 30 000 tonnes, and the potential annual wood yield is nearly 1 800 tonnes. The efficient use of this biomass could help meet the energy demand for cooking in the Ali-Addeh and Holl Holl refugee camps while assisting in the control of *Prosopis* and providing income-generating opportunities for members of the host communities involved in *Prosopis* harvesting and processing.

- A cost analysis determined that the average cost of supplying *Prosopis* to the refugee camps is as follows, for three forms of woodfuel:
  1) fuelwood (i.e. unprocessed firewood) – DJF 22.5/kg;
  2) briquettes (including manufacture) – DJF 34/kg; and
  3) charcoal (including manufacture) – DJF 67/kg (earth pit kiln) and DJF 49/kg (portable steel kiln).

The study gives rise to the following recommendations, among others:

- Allow freshly harvested *Prosopis* biomass to dry naturally in sunny, windy positions before transportation or further processing.
- Minimize transportation distances for *Prosopis* fuel through the appropriate selection of harvesting sites.
- Conduct research to identify technologies for the most cost-effective methods for harvesting *Prosopis* wood.
- Create an enabling environment and provide financial, technology and knowledge transfer to develop efficient *Prosopis* value chains for energy purposes at a large scale.
- Provide the private sector and other stakeholders with incentives, and government support, to undertake work that builds on a market approach for the use of *Prosopis* as a source of energy for the refugee and host communities.
- Support the national government and other stakeholders in their efforts to meet the energy needs of the refugee and host communities as well as to control the spread of *Prosopis*.

1 Introduction

1.1 Background

Djibouti has limited natural resources and is struggling to cope with an ongoing drought. It is also dealing with a protracted refugee crisis, with more than 23 000 mainly Somali refugees living in the country's Ali-Addeh and Holl Holl refugee camps. Many of the refugees have been in the camps for more than two decades, and women and children comprise more than 70 percent of the population. The United Nations High Commissioner for Refugees (UNHCR) is working with the Government of Djibouti to ensure the provision of both shelter and land for refugees, and the National Office for Assistance to Refugees and Victims (ONARS) is responsible for managing water, food distribution and security in the refugee-hosting areas. UNHCR is also addressing challenges in key sectors such as health and nutrition, water, education, self-reliance/livelihoods, and protection.

Domestic energy is a major challenge in the two refugee camps, both of which the Ministry of Housing, Urban Planning and Environment (MHUE) supplies with fuelwood[1] each month to support energy needs for cooking at the household level. The main source of fuelwood is *Prosopis*, which is collected at small-scale production sites in the Ali Sabieh and Dikhal regions, located more than 150 km from the camps, and transported directly by truck to the refugee camps. This is economically inefficient, and the quantity of fuelwood transported per truck is small because of the wood's low bulk density. Field observations and focus-group discussions have shown that fuelwood is distributed just after harvesting, and the high moisture content results in incomplete combustion, excessive smoke and low heat generation.

It is clear that the refugee and host communities face major challenges in ensuring sufficient access to energy and securing sustainable livelihoods. There is an urgent need to improve the planning of woodfuel supply, assess fuel quality, and improve the efficiency of woodfuel delivery and use in the refugee camps.

As in several other arid countries worldwide, *Prosopis* is an invasive species in Djibouti. It is often associated with the devastation of pastures and farmlands because of the high densities in which it occurs; on the other hand, given the full exchange of knowledge on their management, processing and use, *Prosopis* species can be huge assets capable of supporting tree-based enterprises and livelihoods and providing conservation benefits. This was demonstrated by the project, "Management of Invasive *Prosopis* to Alleviate Poverty and for Food Security in Djibouti" (TCP/DJI/3303), which was implemented in 2011–2013 as part of FAO's Technical Cooperation Programme (TCP) with the Government of Djibouti.

Also as part of the TCP, the Ministry of Agriculture, Water, Fishery, Livestock and Marine Resources (MAEPE-RH, 2014) developed the National *Prosopis* Management Strategy 2013–2018. The vision set out in this document is to "harness the conservation and economic value of *Prosopis* trees by maximizing their benefits and minimizing the negative impacts in Djibouti" with the purpose of "bringing *Prosopis* invasions under control through sustainable management, processing and promoting the use of its products for socio-economic development and environmental conservation". The overall objective of the strategy is to

1 In accordance with FAO terminology, the term "fuelwood" is used in this report to indicate woodfuel where the original composition of the wood is preserved (synonymous with "firewood"). Other forms of woodfuel discussed in this report are charcoal and briquettes.

sustainably manage invasive *Prosopis* by fully exploiting their commercial potential for improved livelihoods and social equity. The strategy has the following five specific objectives:

1) to establish/strengthen institutional and community structures for the sustainable management of *Prosopis* resources;
2) to create awareness via a sensitization programme on *Prosopis* and carry out capacity building among stakeholders;
3) to promote the commercialization of *Prosopis* products;
4) to develop a research-and-development blueprint for *Prosopis* management, processing and use in Djibouti; and
5) to conduct regular monitoring and evaluation during the implementation of the strategy and provide feedback for improvement.

Controlling *Prosopis* by using it, coupled with the effective management of this highly invasive species, offers a win–win approach to food and energy security and sustainable land management, especially in the face of an increasingly uncertain climate.

The present study examines the economic potential of processing *Prosopis* woody biomass into a more efficient fuel in a way that also provides a source of income for the host community, a safe, compliant energy source for refugees, and environmental protection on the ground.

1.2 Description and ecology of *Prosopis*

Prosopis is a genus of trees and shrubs in the Fabaceae (pea) family. According to the most recent complete taxonomical monograph, the genus comprising 44 species, of which 40 are native to the Americas and four to Asia and Africa (Pasiecznik *et al*., 2015). By far the most common *Prosopis* species in tropical dry areas is the shrubby, invasive and very thorny *Prosopis juliflora*, which was widely planted in the Horn of Africa, the Sahel and eastern Africa in the 1970s and 1980s.

Prosopis juliflora assumes different growth habits depending on tree density and water availability. Near rivers and other wet areas, and where individuals are close together, trees may grow straight and to a height of more than 15 m. In drier areas, individuals are commonly multi-stemmed shrubs with a height of 3–5 m.

Prosopis juliflora landraces often have multistemmed and prostrate habits, with long branches and a crown that may touch the ground. The tree bole is usually short, crooked and twisted. Erect forms also exist, but usually it is difficult to find boles that are straight for more than 1–2 m without branches or forks.

Prosopis is an important source of household energy for millions of people in arid and semiarid zones. The wood is hard, with a specific gravity of 0.70 grams per cm^3 or higher. The wood burns slowly and evenly and holds heat well. It produces excellent charcoal.

Prosopis pallida was introduced to Djibouti in the 1950s for shade and shelter and as a street tree in many towns. *Prosopis juliflora* was introduced in the 1980s, when it was planted in various parts of the country in an attempt to control desertification. Since then, *Prosopis* species have become dominant in many Djibouti landscapes (MAEPE-RH, 2014).

Prosopis juliflora is a fast-growing, nitrogen-fixing species that is tolerant of arid conditions and saline soils. In the right conditions, *Prosopis juliflora* can produce a suite of valuable goods – such as construction wood, fuelwood and charcoal – and perform ecosystem services such as soil conservation and the rehabilitation of degraded and saline soils. Nevertheless, the

Invasive Species Specialist Group of the International Union for Conservation of Nature has rated *Prosopis juliflora* as one of the world's top 100 least-wanted species (Lowe, Browne and Boudjelas, 2000).

1.3 Objectives

The overall objective of this study was to assess value chains for processing the available *Prosopis* woody biomass into a cost-effective fuel (i.e. briquettes or charcoal) for the refugee and host communities in Djibouti. The study includes an assessment of the spatial distribution and biomass stock of *Prosopis* in the four largest expanses of *Prosopis* in Djibouti. Following sections identify relevant stakeholders and assess the *Prosopis* woodfuel supply; woodfuel demand; and costed options for the use of *Prosopis* for energy.

2 Assessment methodology

2.1 Area of interest

In light of information obtained from previous studies and interviews conducted with relevant institutions (i.e. the Directorate of Agriculture and Forestry – DAF – of MAEPE-RH and the Directorate of the Environment of MHUE), the following four areas of interest (AOI) were selected for the *Prosopis* study:

1. Douda (Damerjog)
2. As Eyla (Plaine de Gob'aad)
3. Tadjourah
4. Hanlé.

Figure 1 shows the location and extent of these target areas, which comprise the four largest invasions (by area) of *Prosopis* in Djibouti (MAEPE-RH, 2014). Visual interpretation of high-resolution Google Earth images was used to delineate the AOI.

Figure 1. Location of the two main refugee camps, and the locations and extent of the four target areas, which are also the largest invasions of *Prosopis* in Djibouti

2.2 Socio-economic data collection

Socio-economic data were collected in the following four steps:

- **Step 1 – gathering information and collecting data.** Direct interviews and focus-group discussions were conducted with representatives of the refugee population in the Ali-Addeh camp, officials of the UNHCR Sub Office for the Ali Sabieh region, officials in the

Directorate of Environment of MHUE in Ali-Addeh, and local authorities and officials of relevant ministries.

- **Step 2 – desk review.** An analysis was carried out of, among other things, UNHCR reports, the National *Prosopis* Management Strategy 2013–2018, studies of *Prosopis* carried out in Djibouti, the report of a joint evaluation of the Ali-Addeh refugee camp by the United Nations agencies in Djibouti, and reports of projects implemented by the Directorate of Environment of MHUE.
- **Step 3 – field visit to *Prosopis* woodcutting areas in Hanlé and Tadjourah.** The field visit involved making contact with the agents responsible for *Prosopis* fuelwood harvesting and transportation from the harvesting site to the refugee camps; and interviews and meetings with local authorities to assess the whole value chain.
- **Step 4 – assessment of the annual woodfuel demand for cooking and the development of costed options for the use of *Prosopis* as a source of energy for cooking.**

2.3 Remote sensing analysis

Remote sensing data, in combination with field data, have been used in numerous studies to map *Prosopis* vegetation, and many such studies have reported that *Prosopis* has different spectral behaviour to endemic vegetation. Van den Berg, Kotze and Beukes (2013) combined terrain analysis and remote sensing techniques to map and monitor a *Prosopis juliflora* invasion in Northern Province, South Africa. They used the ratio of near-infrared to red bands and applied a threshold in the green time period, but differentiating between other green bushes and trees was difficult. Hoshino *et al.* (2012) studied *Prosopis juliflora* using Landsat 5 and applied a single threshold value for the Normalized Difference Impervious Index. Wakie *et al.* (2014) used time series of moderate-resolution data (250 m MODIS vegetation indexes) to map the current and potential distribution of *Prosopis juliflora* in Ethiopia, but the coarse resolution appeared to be suitable only when invasions covered very large areas. Mohamed *et al.* (2011) applied the Maximum Likelihood Supervised Classification algorithm and high-resolution QuickBird images to map *Prosopis*. Ayanu *et al.* (2014) used the same algorithm over Landsat and Aster data for *Prosopis* monitoring. Meroni *et al*. (2017) used Landsat 8 satellite images and ground data to map *Prosopis juliflora* in west Somalia.

Monitoring *Prosopis* using satellite data

The present study used freely available high-resolution Sentinel-2 satellite images to map the extent of *Prosopis* in Djibouti at selected sites. The Sentinel-2 satellite, which was launched on 23 June 2015, provides optical imagery worldwide. The system is designed to collect data at a spatial resolution of 10 m (red, green and blue – RGB – and near-infrared), 20 m (red edge 1–3, near-infrared 2, and shortwave infrared 1–2) and 60 m (aerosol, water vapour and cirrus), resulting in a total of 13 spectral bands (ten for mapping purposes and three for atmospheric correction and cloud detection). With its twin satellite (Sentinel B) in orbit from January 2017, the Sentinel system now has global coverage of the Earth's land surface and a revisit time of five days.

The best pixel mosaic of Sentinel-2 data for the driest month (June–August 2017) for each of the four AOI was created using the System for Earth Observation Data Access, Processing and Analysis for Land Monitoring (SEPAL).[2] SEPAL allows users to mask snow and cloud from images to produce almost-on-the-spot, user-ready images for analysis. Annex 1 provides further details on the use of the Normalized Difference Vegetation Index (NDVI) for assessing biomass calculation and vegetation distribution.

2 Sepal.io

Reference data collection

Visual and digital image interpretation techniques were used to obtain land-use and land-cover information in the study areas in order to identify *Prosopis* locations. Visual interpretation was done using the latest available high-resolution Google Earth images.

Training data were collected separately for all AOI using false-colour RGB of Sentinel-2 with the band combination of near-infrared, red and green. The near-infrared band helps differentiate evergreen *Prosopis* from other vegetation classes. Figure 2 shows a false-colour composite for Douda, where red indicates the presence of *Prosopis*, dark green shows the distribution of other vegetation, and cyan indicates built-up and clear areas. Because the study focused on mapping the extent of *Prosopis* using the most recent freely available data, only three land-use/land-cover categories were considered: *Prosopis*; other vegetation; and other (Table 1).

Table 1. Map classes

Class code	Class name	Description
1	*Prosopis*	*Prosopis* dominant
2	Other vegetation	Vegetation other than *Prosopis*
3	Other	All features other than vegetation (e.g. water, bare soil and built-up areas)

On the field visit to the Douda site, the team observed that *Prosopis* vegetation was quite homogeneous in terms of growth and as a dominant species. According to the field survey, the area ringed in black in Figure 2 was cleared of *Prosopis* species to create a nature reserve comprising only indigenous species (e.g. *Acacia* spp.). This information was used in the remote sensing analysis to study the behaviour of different tree species within various spectral channels and to differentiate *Prosopis* from other vegetation.

Source: FAO

Figure 2. False-colour red, green and blue of Sentinel-2 data, Douda, Djibouti

Random Forest classification

The Random Forest classification algorithm (Breiman, 2001) was used in the study for supervised classification. Training data for defined classes in each AOI were used to perform a supervised classification using a plugin[3] in QGIS (a free, open-source geographic information system).

2.4 Biophysical field data collection

The field team carried out biophysical field measurements in the target *Prosopis* zone at Douda. Field measurements were made in seven plots, each with a 9-m radius. The following parameters were measured: basal diameter; diameter at a height of 30 cm; height; number of stems >2 cm diameter; and species/genus/family. Other observations were also recorded. A further three plots were inaccessible on the ground because they were within impenetrably dense *Prosopis* groves.

Field plot measurements in Douda, Tadjourah Region

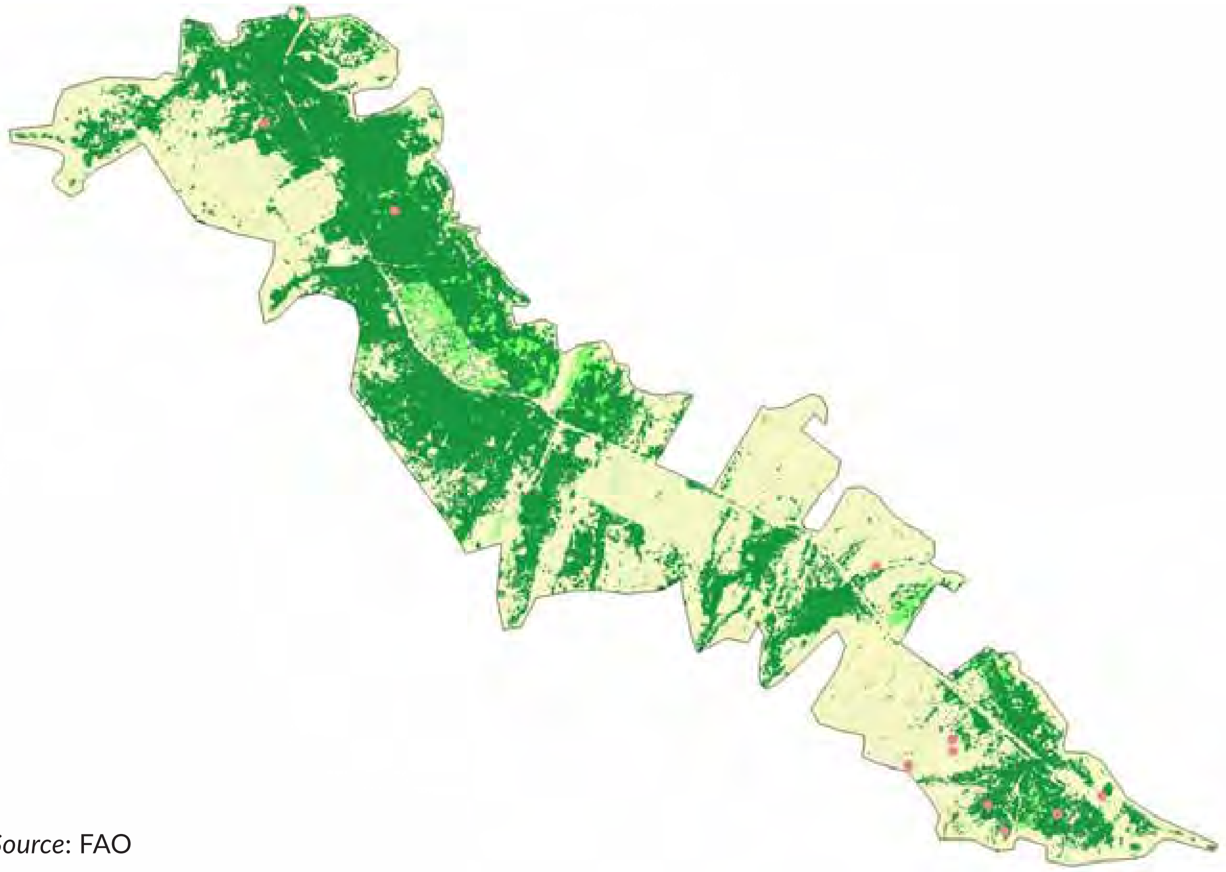
A random sample was generated for the Douda site using the QGIS Random Forest tool. All points were first interpreted visually using very-high-resolution images with the aim of identifying plots with different vegetation and *Prosopis* densities. Two main criteria were considered in plot selection for field data:

1) plots with different vegetation/*Prosopis* density; and

2) plot accessibility.

3 https://plugins.qgis.org/plugins/dzetsaka

Figure 3 shows the spatial location of field plots visited by the field team at Douda.



Source: FAO

Figure 3. The location of field plots visited by the field team (shown by pink dots)

2.5 Biomass calculation

The area of each land-use/land-cover category was calculated using R software and converted to hectares. Standing biomass stock was calculated for the individual sample plots using field dendrometric data and the species-specific allometric biomass equation of Chaturvedi and Behl (1996).

The following equation was used:

$$\textit{Aboveground biomass} = (-0.0816) + 0.7442 \times D30^2 \times \textit{height} \times \textit{no.of stems}$$

Where D30 = diameter at a height of 30 cm.

The estimated biomass and the *Prosopis* land-cover class were multiplied to obtain the final biomass values. Stems and branches (fresh biomass weight) were included in biomass stock estimates. The calculated biomass was averaged across all plots and the mean value used for estimating the total biomass at each site.

3 Results

3.1 Identifying stakeholders

The main actors involved in *Prosopis* management and the fuelwood value chain for the refugee camps are:

- local communities and inhabitants in the woodcutting areas (woodcutters);
- suppliers responsible for transporting fuelwood to the camps;
- the Directorate of Environment in MHUE;
- the Directorate of Agriculture in MAEPE-RH;
- the UNHCR Djibouti Office;
- the FAO Djibouti Office; and
- the local authorities of the regions concerned (Dikhil, Ali Sabieh and Tadjourah).

Each of these is discussed further below.

Local community

People living in the *Prosopis* harvesting areas – mostly shepherds and out-of-school youth – are involved directly in cutting wood as an income-generating activity. Woodcutters work individually or in groups to meet demand for *Prosopis* wood. They cut the wood, package it in bundles, and transport the bundles – usually using donkeys – to storage locations.

Contractual providers

Various service providers are contracted under a project implemented by the Directorate of the Environment and the UNHCR Djibouti Office to ensure that residents in the Ali-Addeh and Holl Holl refugee camps have access to energy for cooking. They buy wholesale bundles of *Prosopis* wood from woodcutters and transport the wood to the refugee camps. According to information collected from local authorities and project managers, service providers are selected according to the following criteria:

- They must come from the local community in the areas where the wood is cut.
- They must own a truck to transport the wood.
- They must sign a contract with the Directorate of the Environment and UNHCR.

The service providers share access to the harvest areas and deal with specific agents and individual fuelwood suppliers.

Ministry of Housing, Urban Planning and Environment

The MHUE is a key player in the *Prosopis* woodcutting process. As part of the environmental protection policy, it ensures compliance with the legal rules and regulations. Together with UNHCR, the Directorate of the Environment is the implementing partner of an ongoing project aimed at ensuring energy access for refugees. The management unit of the project coordinates activities by subcontracting with selected providers; acting as focal point for the refugee camps; monitoring operations at logging sites; and reporting to the UNHCR's Djibouti Office.

Ministry of Agriculture, Water, Fishery, Livestock and Marine Resources

The MAEPE-RH developed the National *Prosopis* Management Strategy 2013–2018, the overall objective of which is to sustainably manage invasive *Prosopis* by fully exploiting its commercial potential to improve livelihoods and increase social equity; the strategy also has five specific objectives (see above). The MAEPE-RH's Directorate of Agriculture supports capacity development in farmers' and herders' associations and cooperatives whose members are involved directly in woodcutting.

FAO

FAO has supported the Government of Djibouti since 2008 through projects aimed at mapping the distribution of *Prosopis* and demonstrating livelihood options through its use. Working in collaboration with the MAEPE-RH, it has, for example, installed and tested four diesel-powered mills for producing flour from *Prosopis* seed pods – one each in As Eyla (Gob'aad), Hanlé, Damerjog and Tadjourah. In Hanlé, more than 5 000 kg of *Prosopis* flour was milled in a single week using pods collected earlier in the year. This flour was sold to commercial livestock farmers – constituting the first cash income earned by an agricultural cooperative in Djibouti from the sale of *Prosopis* pod flour.

FAO has also helped introduce improved charcoal kilns – producing better-quality charcoal in less time than traditional earth kilns – and to demonstrate aspects of *Prosopis* stand management, such as thinning, pruning and stump removal.

UNHCR

The UNHCR's Djibouti Office provides funding for the supply of fuelwood to refugee households in the Ali-Addeh and Holl Holl camps, ensuring that the work plan agreed with the Directorate of the Environment is fully implemented.

Local authorities

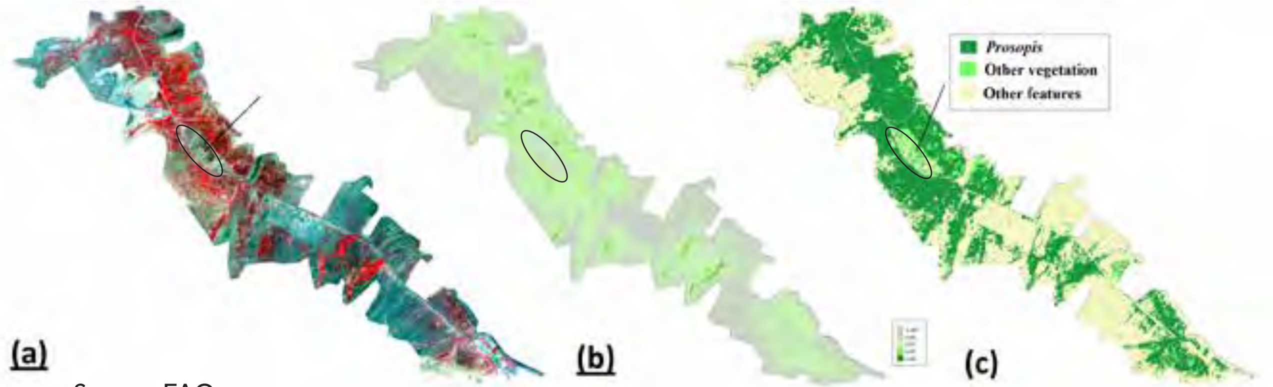
Local authorities in the areas of *Prosopis* logging operations, especially the prefectural government and regional council office, are key stakeholders. For example, they ensure that woodcutting involves only *Prosopis* trees in accordance with legal provisions on the environment and the conservation of indigenous species. For this purpose, the police and gendarmerie verify authorizations for service providers and oversee wood transportation.

3.2 Assessing *Prosopis* woodfuel supply

Mapping the distribution of *Prosopis*

Several spectral measures related to vegetation presence were calculated and tested at the Douda site. To refine the methodology, the supervised classification was adopted for the present study and applied to all study sites. Figure 4 shows vegetation distribution at Douda, according to false-colour RGB, NDVI and supervised classification.

The best results were obtained using a supervised classification of dry-season images. The difference between the dry- and wet-season images was not large, but dry-season images were better suited to differentiating *Prosopis* from other vegetation. Field observations in the dry season indicate that *Prosopis* remains relatively green throughout the year – because of its deep rooting system (Yoda *et al*., 2012) and metabolic and ecophysiological coping mechanisms (Sen and Mehta, 1998) – whereas indigenous species dry out, turn yellow and eventually shed their foliage. In the wet season, *Prosopis* and other vegetation are likely to be spectrally similar, resulting in the reduced classification accuracy observed when using only wet-season satellite data.

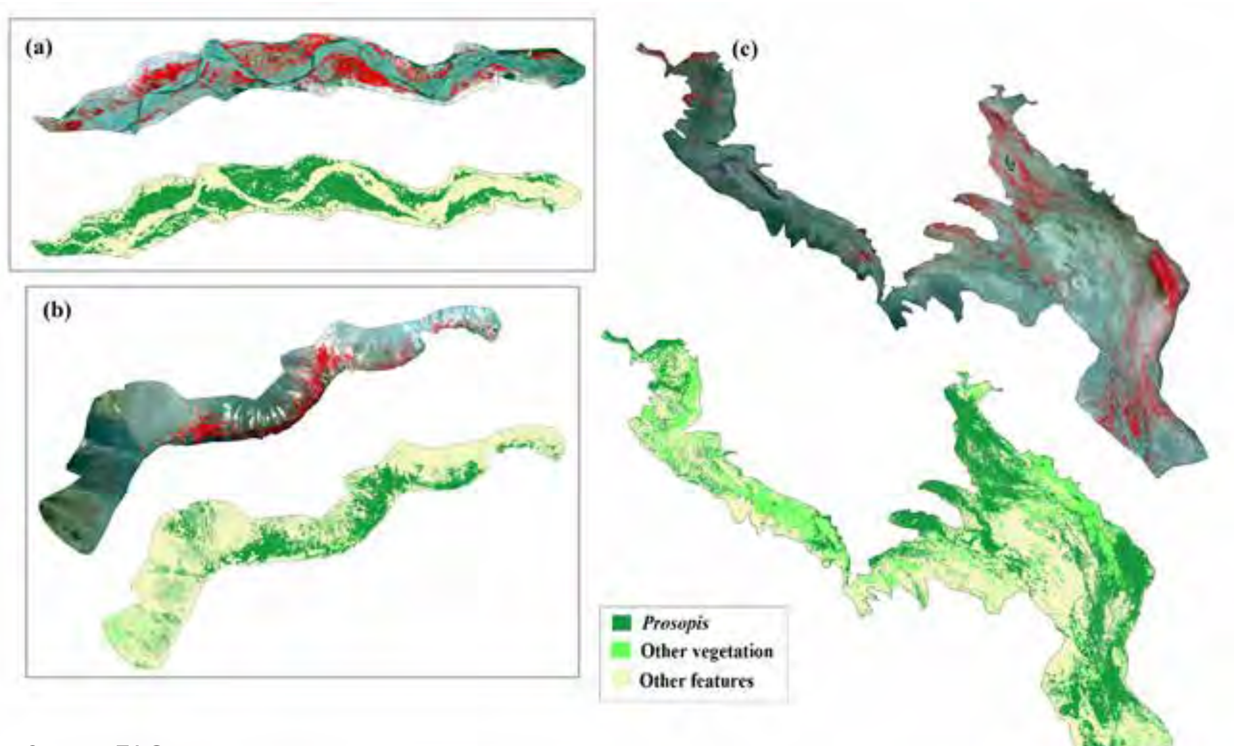


Source: FAO

Figure 4. Vegetation distribution at Douda using false-colour red, green and blue, Normalized Difference Vegetation Index and supervised classification

Notes: (a) False-colour RGB (near infrared, red and green) of Sentinel-2 data and land cover at Douda; (b) vegetation distribution at Douda using the NDVI; and (c) results of supervised classification at Douda. The black rings show an area that was cleared of *Prosopis* to establish a natural reserve comprising only indigenous species.

High-resolution Sentinel-2 satellite images were used to map the extent of *Prosopis* in the selected sites. The phenological signals of *Prosopis juliflora* were best detected by the near-infrared band in Sentinel-2 in combination with the red and green bands. Table 2 shows the percentage of land covered by *Prosopis* at each site and figures 4 and 5 show this visually. At the Douda site, for example, *Prosopis* was determined to be present on 43 percent (1 066 ha) of the total area. *Prosopis* is the dominant species on more than 5 000 ha across the four sites.



Source: FAO

Figure 5. False-colour red, green and blue of Sentinel-2 data and land cover for (a) As Eyla, (b) Tadjourah and (c) Hanlé

Table 2. Area of land covered by *Prosopis* in the four areas of interest

Site	Total area (ha)	Area covered by *Prosopis* (ha)	Percent area covered by *Prosopis*
Douda	2 507	1 066	43
Hanlé	7 915	2 737	35
As Eyla	972	440	45
Tadjourah	3 178	864	27
Total	**14 572**	**5 107**	

Estimates of *Prosopis* biomass stock

Field data collected at Douda were used to estimate the *Prosopis* biomass. According to field data and previous studies conducted in Djibouti, the four sites present homogenous characteristics in terms of the predominance of *Prosopis* and growth rates. Therefore, all four sites were considered identical for the purposes of estimating biomass, based on the characteristics observed at Douda. The dominant species in the area is *Prosopis juliflora*. Other minor species in the study area are *Acacia tortilis*, *Acacia asak* and *Balanites* spp.

Field data showed that the highest value for standing biomass (stems and branches) was 13.6 tonnes per ha (fresh biomass weight). To estimate total standing biomass (stems and branches), the average volume (6 tonnes per ha, fresh biomass weight) was multiplied by the total area covered by *Prosopis* at each site. The biomass yield potential of stands of naturally regenerated *Prosopis juliflora* trees younger than five years has been estimated at 1.40 tonnes per ha (Saraswathi and Chandrasekaran, 2016). In this study, a conservative annual yield of 0.35 tonnes per ha was assumed; Table 3 presents estimated total biomass and potential annual yield for each site.

Table 3. Estimated standing biomass of *Prosopis* and potential annual wood yield at the four study sites

Site	*Prosopis* cover (ha)	Biomass (tonnes)	Potential wood yield (tonnes/year)
Douda	1 066	6 396	373
Hanlé	2 737	16 422	958
As Eyla	440	2 640	154
Tadjourah	864	5 184	302
Total	**5 107**	**30 642**	**1 787**

3.3 Assessing woodfuel demand

UNHCR, ONARS and MHUE have set up a standard process for distributing fuelwood to refugees in the Ali-Addeh and Holl Holl camps. Refugees receive a certain quantity of fuelwood depending on household size, with a range from 20 kg per month for a one-member household to 80 kg for ten-member households (Table 4).

Table 4. Monthly fuelwood provision, by household size

No. of household members	Quantity of fuelwood (kg/month)
1	20
2	30
4–5	40
8	60
10	80

According to interviews with UNHCR officers in Djibouti and a focus-group discussion in Ali-Addeh, the distributed fuelwood typically lasts about ten days. The fuelwood is usually distributed fresh – that is, very soon after harvesting. When used for cooking, it produces a large quantity of smoke; the people in the Ali-Addeh refugee camp cook indoors without appropriate ventilation.

A resident of the Ali-Addeh refugee camp cooks indoors on an improved mud stove, with inadequate ventilation

A total of 3 513 households benefit from the distribution of fuelwood – 3 195 households in the Ali-Addeh refugee camp and 318 households in the Holl Holl refugee camp. According to interviews conducted in the field, a total of 1 504 tonnes of fuelwood is distributed annually to the two refugee camps. This quantity is insufficient, with the estimates in Table 5 indicating that the total fuelwood demand amounts to 8 154 tonnes per year. Most people in the camps use either three-stone fires or improved mud stoves.

In addition to fuelwood supply, ONARS distributes 2 litres of kerosene per person per month. This distribution is irregular, however, meaning that prolonged shortages of domestic fuel occur in the camps. The distributed kerosene meets cooking-energy needs for about ten days.

Combined, the fuelwood and kerosene distributed to refugees in the Ali-Addeh and Holl Holl camps do not fully meet energy needs for cooking, and most refugees, who lack income to purchase additional charcoal or other fuel in the local market, must walk up to 10 km to gather additional fuelwood in the mountains. Refugees capable of purchasing domestic fuel pay approximately DJF 1 200 for two bags of charcoal per month, and those who purchase extra kerosene pay approximately DJF 300 for 1.5 litres, which might last 7–8 days for one person[4].

Given that 40 kg of fuelwood distributed to a four-member household will last ten days, on average, the estimated fuelwood consumption per person is about 1 kg per day. Table 5 shows the total estimated fuelwood demand in the Ali-Addeh and Holl Holl refugee camps, assuming that fuelwood is the sole energy source for cooking.

Table 5. Estimated fuelwood demand for the Ali-Addeh and Holl Holl refugee camps

Camp	Number of registered refugees and asylum seekers	Estimated fuelwood demand (tonnes/month)	Estimated fuelwood demand (tonnes/year)
Ali-Addeh	15 759	473	5 673
Holl Holl	4 684	141	1 686
Total	**20 443**	**614**	**7 359**

3.4 Costed options for the use of *Prosopis* for energy

The study examined how the estimated *Prosopis* biomass might best be transformed into a more cost-effective, technically feasible fuel to support the energy needs of refugees. A costed-options analysis of fuelwood, briquettes and charcoal scenarios was conducted.

Fuelwood

Prosopis fuelwood is the main current source of household energy for cooking in the Ali-Addeh and Holl Holl refugee camps. As discussed above, UNHCR, ONARS, MHUE and local authorities jointly oversee and fund a process to supply fuelwood to the refugee and host communities.

The *Prosopis* fuelwood value chain begins where the *Prosopis* trees grow (Figure 6). Woodcutters bundle the fuelwood they harvest and bring it to sites that are accessible to transport trucks. The fuelwood is weighed and then loaded onto trucks and transported to the refugee camps. The Ali-Addeh refugee camp is more than 150 km from the logging area in Hanlé, about 190 km from the site at Tadjourah and less than 100 km from the Douda site. The fuelwood is weighed again on arrival at the camp and stored. Camp officials distribute the fuelwood to refugees according to a standard schedule and procedure.

To better understand economic aspects of the *Prosopis* fuelwood supply to the Ali-Addeh refugee camp and to analyse the value chain, the costs of activities at each stage of the chain were identified. Given that the *Prosopis* biomass stock at Hanlé is estimated at 16 422 tonnes, and the annual biomass increment is 958 tonnes, this site could supply fuelwood to meet

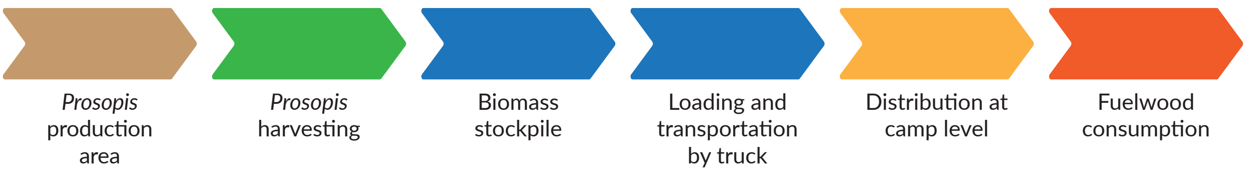


Figure 6. *Prosopis* fuelwood value chain

4 The exchange rate in February 2018 was USD 1 = DJF 177.

A *Prosopis* distribution point at the Ali-Addeh refugee camp

the total demand of the Ali-Addeh camp (estimated at 5 673 tonnes per year) for 3–4 years. This scenario assumes that the refugee population uses only fuelwood as a source of cooking energy. To ensure a fuelwood supply from Hanlé for a longer period, it is crucial to consider a combination of the following potential interventions – reduce fuelwood consumption through the introduction of improved stoves and burning dry wood; supplement supply from other harvesting areas (e.g. Douda and As Eyla – see Table 3); and explore alternative energy sources for cooking.

Collection cost

According to information gathered from informants at the harvesting site and from providers, the rate paid to individual woodcutters is typically DJF 500 per fuelwood bundle weighing 40 kg. Thus, the average fuelwood collection is DJF 12.5 per kg (DJF 12 500 per tonne).[5]

Transport cost

The cost of transport from the roadside to the refugee camps is dependent on distance. Table 6 shows the breakdown of costs for transporting one load of *Prosopis* fuelwood by truck for a distance of about 150 km from the production area to a refugee camp.

5 The exchange rate in February 2018 was USD 1 = DJF 177.

This truck is used to transport *Prosopis* fuelwood from the harvesting zone to refugee camps

Table 6. Breakdown of transport cost

Item	Unit price (DJF)	Quantity	Total cost (DJF)
Driver	5 000	1	5 000
Fuel	180/litre	50 litres	9 000
Vehicle repair and maintenance costs (assumed to be 50% of fuel cost)			4 500
Other vehicle ownership costs (e.g. depreciation, insurance)	20 000	1	20 000
Labour for loading and unloading	1 000	2	2 000
			40 500

According to information gathered from interviews and observations, one truck can transport, on average, about 4 tonnes of fuelwood. Therefore, the estimated transport cost is about DJF 10 000 per tonne (DJF 10 per kg).

Total cost

Table 7 summarizes the total unit cost of supplying *Prosopis* fuelwood to the refugee camps.

Table 7. Summary costs of fuelwood supply

Description	Cost	Share of total cost (%)
Harvesting	DJF 12 500/tonne	55.5
Transport	DJF 10 000/tonne	44.5
Total fuel supply cost	**DJF 22 500/tonne**	
Unit fuel supply cost	DJF 22.5/kg	

Briquettes

A *Prosopis* briquette value chain would involve the current fuelwood value chain and the introduction of briquette-making technology that is appropriate for the scale of production and local conditions (Figure 7). Briquetting is a process for converting biomass to solid fuel – usually cylindrical blocks with a diameter of 50–120 mm – involving compaction or densification to increase energy density.

The pre-treatment of biomass is necessary to ensure that the biomass is suitable for briquette production. In this study, the pre-treatment involved air-drying to reduce wood moisture content and grinding to reduce the size of wood particles to 6–8 mm. A further stage of pre-treatment could involve wood carbonization before briquetting (this step is considered separately in the option of improved charcoal production). At the packaging and storage step, briquette moisture content is measured and controlled to ensure high quality.

The bulk density of briquettes should exceed 500 kg per m^3 – significantly higher that the bulk density of *Prosopis* fuelwood, at about 350 kg per m^3. Thus, briquetting could reduce the cost of transport (per unit of energy) from the production site to the refugee camps. The physical characteristics of briquettes make their storage easier and more efficient than fuelwood. Given the higher bulk density of briquettes, a smaller volume would be required to store an equivalent amount of energy as fuelwood; moreover, briquette transport would hit the weight limit of carriers before it hit the volume limit (this is a limitation to bear in mind for fuels with higher bulk density, such as pellets, the bulk density of which usually exceeds 650 kg per m^3). Table 8 sets out the key assumptions used in this analysis in estimating the production cost of briquettes.

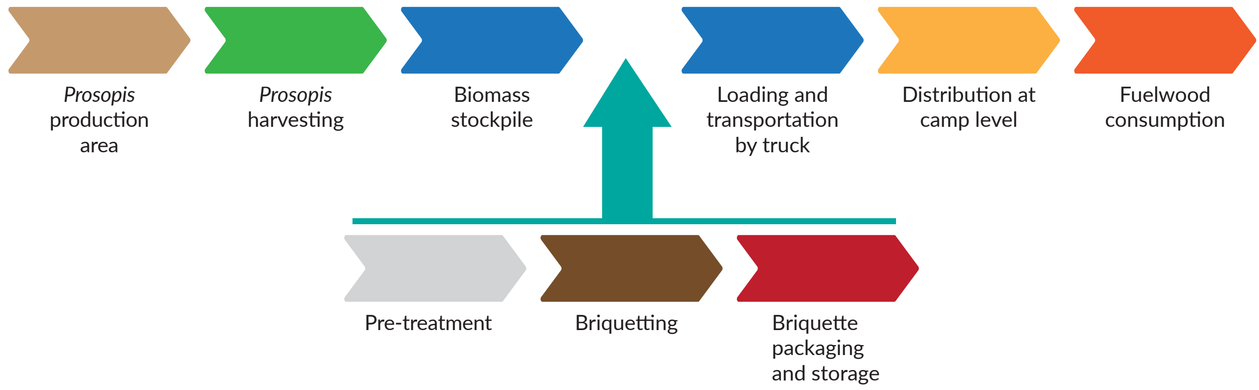


Figure 7. *Prosopis* briquette value chain

Table 8. Key assumptions used in the cost analysis of the briquette option

Parameter	Data	Source of information
Annual quantity of *Prosopis* biomass harvested for energy (moisture content 40%)	4 242 tonnes	Estimated
Annual quantity of briquettes (moisture content 12.5%)	3 075 tonnes	Estimated
Density of bulk briquette	580 kg/m^3	Birwatkar *et al.* (2014)
Energy content (lower heating value)	17.6 megajoules per kg (moisture content 10–15%)	Khan, Ahmad and Ismail (1986); Krajnc (2015)
Maximum capacity of briquette production, per press	800 kg/hour	Machinery and equipment suppliers
Type of equipment	No. 2 press with cooling lines; No. 1 silo; No. 2 wood chipper; No. 2 hammer mill	Machinery and equipment suppliers
Operating days	300 days, 8 hours per day	
Electricity consumption (including pre-treatment)	43.8 kilowatt hours per tonne of briquettes	Machinery and equipment suppliers
Total no. of unskilled workers	6	FAO (2014)
Total no. of skilled workers	2	FAO (2014)
Miscellaneous costs (labour benefits, health and life insurance, operating supplies, laboratory charges)	20% of total labour cost	FAO (2014)
Distance from harvest site to plant	2–5 km	Field estimate
Estimated cost of transporting *Prosopis* wood to plant	DJF 35/tonne/km	Field estimate
Lifetime of the project	5 years	
Estimate cost of equipment over its lifetime (imported machines such as roller press and grinding machine)	USD 268 000	Machinery and equipment suppliers
Installation cost	10% of equipment cost	Machinery and equipment suppliers
Estimate cost of building and land for briquetting plant	USD 2.62 per tonne	FAO (2014)
Plant overhead	5% of maintenance cost	FAO (2014)
General and administrative costs	5% of inputs cost, labour cost, maintenance cost, plant overheads	FAO (2014)
Pre-treatment	The equipment includes No. 2 wood chipper and No. 2 hammer mill. It is assumed there is no cost for open-sun drying. Electricity consumption takes pre-treatment machinery into account	

The production of the briquette plant was assumed to be 1.28 tonnes of briquettes per hour; assuming 300 operating days per year and an eight-hour day, annual briquette production would be about 3 075 tonnes. This production was determined given the potential supply of fresh biomass from Hanlé of 4 242 tonnes per year, comprising the annual wood increment plus 20 percent of the standing biomass. Table 9 summarizes the results of the cost analysis for the briquette option. The major costs comprise wood harvesting (50 percent of the total), transport (21 percent), electricity for running the grinding and pressing machines (about 7 percent), and the cost of labour for briquette production (5 percent). The capital depreciation (including equipment, buildings and installation) over a five-year period accounts for about 11 percent of the total annual cost. The estimated unit cost of supplying briquettes from Hanlé to the Ali-Addeh camp is DJF 34 per kg.

Table 9. Cost analysis for supplying *Prosopis* briquettes to the refugee camps

Inputs	Unit	Unit price (DJF)	Quantity (unit/yr)	Total (DJF/yr)
Prosopis wood (collection cost)	tonne	12 500	4 242	53 025 000
Electricity	kWh	55	134 685	7 407 675
Total inputs				**60 432 675**
Labour		Unit price (DJF/ person-day)	Quantity	Total (DJF/yr)
Unskilled		1 500	6 workers	2 700 000
Skilled		5 000	1 worker	1 500 000
Miscellaneous (20% of labour costs)				840 000
Total labour				**5 040 000**
Storage		Unit price (DJF/ tonne)	Quantity (tonnes/yr)	Total (DJF/yr)
Briquette storage capacity		100	333	33 313
Transport		Unit price (DJF/ tonne)	Quantity (tonnes/yr)	Total (DJF/ year)
Cost of transporting biomass to the briquette plant		105	4 242	445 410
Cost of transporting briquettes to the camps		7 000	3 075	21 525 000
Total transport				**21 970 410**
Investment			Total (DJF)	Depreciation (DJF/yr) over 5 yrs
Equipment			47 506 800	9 501 360
Building			7 130 003	1 426 001
Installation			4 750 680	950 136
Subtotal investment			**59 387 483**	

Table 9 (continued)

Depreciation		11 877 497
Maintenance (10% of total depreciation)		1 187 750
Total investment		**13 065 246**
Other costs		Total (DJF/yr)
Plant overhead		269 387
General and administrative		3 346 491
Total other costs		**3 615 878**
Total costs	Total (DJF/yr)	% of total
Total operating costs	87 476 398	84
Total fixed costs	13 065 246	12
Total other costs	3 615 878	3
Total fuel supply cost	**104 157 522**	
Unit cost of fuel supply (DJF/kg)	34	

Note: These data are for an annual briquette production volume of 3 075 tonnes.

Charcoal

Producing charcoal from *Prosopis* biomass in efficient kilns could be a cost-effective option for supplying energy to the refugees and host communities. After cutting the *Prosopis* wood, the process involves carbonizing the wood in kilns and then packaging, storing, transporting, distributing and consuming the charcoal produced (Figure 8).

Based on data from the literature and modelling, a shift from traditional charcoal-making kilns to highly efficient modern kilns could reduce greenhouse gas emissions at this stage of the value chain by 80 percent. Further efficiencies could be gained by reducing charcoal waste, such as by transforming charcoal dust into briquettes (FAO, 2017).

The low initial capital requirement for charcoal-making, the simple methods mostly used, and a supportive policy environment for the control of *Prosopis* through use have helped make the charcoal trade extremely attractive to pastoral communities. Table 10 sets out the key assumptions used in this analysis in estimating the production cost of charcoal.

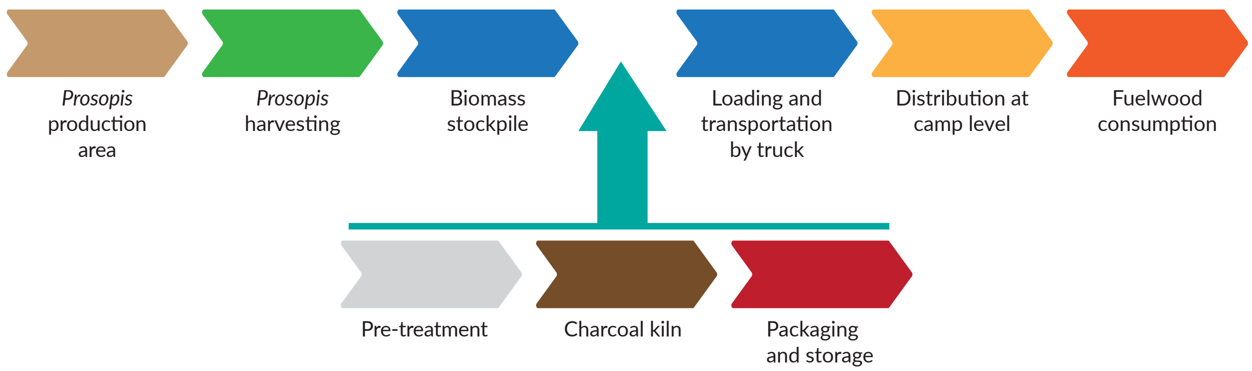


Figure 8. ***Prosopis*** **charcoal value chain**

Table 10. Key assumptions used in the cost analysis of the charcoal option

Charcoal parameter	Data	Source of information
Bulk density	250 kg/m^3	FAO (2017)
• Energy content (lower heating value)	28 megajoules/kg	FAO (2017)
• Operating days	300 days, 8 hours/day	
• Types of kiln selected	Traditional earth pit and portable steel kilns	
Total unskilled workers	Traditional earth pit kiln: 1 unskilled worker per kiln; portable steel kiln: 1 unskilled worker and 1 skilled worker for every two kilns	Field interviews
Equipment cost, traditional earth pit kiln	No costs included	
Estimate purchase cost of portable steel kiln	USD 1 000	Energypedia (2017)
Traditional earth pit kiln efficiency	20%	FAO (2017)
Portable steel kiln efficiency	30%	FAO (2017)
Pre-treatment	The cost of open-sun drying is excluded	

Type of kiln	Traditional earth pit	Portable steel
Annual charcoal production (tonnes/yr)	848	1 273
Production capacity (tonnes/yr)	50	150
Days per cycle	8	2–3
Total no. of kilns	17	8

Note: Data are for an annual wood harvest of 4 242 tonnes.

The types of charcoal kiln used in the cost analysis of charcoal in this study are the traditional earth pit kiln and the portable steel kiln.

In traditional earth pit kilns, a pit is excavated, an amount of wood is placed in the pit, and the woodpile is covered with the excavated earth to seal up the chamber. The capital investment is minimal – with nothing more than a shovel (for digging the pit) and an axe (for cutting the biomass to size) required. This method is inefficient, however, and, if kilns are poorly managed, much of the wood is burned to ash because it gets too much air. The average duration of burns (i.e. from time of firing to time of sealing up the kiln for cooling) is eight days. The production capacity of one traditional kiln operating 300 days per year (8 hours per day) is estimated at about 50 tonnes of charcoal per year.

A previous TCP project in Djibouti had already tested a portable steel kiln. These kilns are available in various sizes, and key advantages include their mobility (so they can be taken to the wood source) and their short production cycle. In this study, the production capacity of the portable steel kiln operating 300 days per year (8 hours per day) is assumed to be 150 tonnes of charcoal per year. Portable steel kilns represent a significant capital investment (up to USD 1 000). Many operate on the reverse-draught principle, in which carbonization starts at the top and goes downward with the aid of chimneys at the bottom. The chimney location provides greater control of carbonization and the kilns are capable of converting fuelwood to charcoal at an efficiency of 30 percent (compared with 20 percent for traditional earth pit kilns; FAO, 2017). Field interviews indicate that mobile steel kilns have a 2–3-day production cycle.

Taking into account the production capacity of the two types of kiln considered in this study and their conversion efficiency, it is estimated that 17 traditional kilns or eight portable steel kilns would be required to process the potential annual supply of wood biomass from Hanlé. As for the briquettes option, production capacity was estimated based on the annual wood yield plus 20 percent of the standing biomass over a period of five years. Table 11 summarizes the results of the assessment of charcoal supply. The use of efficient kilns means the more efficient use of wood, thereby increasing output and reducing inputs in terms of wood and labour. This translates into more cost-effective charcoal production, less the costs of production. The estimated unit cost of supplying charcoal from Hanlé to the Ali-Addeh and Holl Holl refugee camps is 67 DJF per kg for traditional kilns and 49 DJF per kg for portable steel kilns.

Table 11. Cost analysis for supplying charcoal manufactured from *Prosopis* wood

		Traditional earth pit kiln		Portable steel kiln	
Inputs	Unit price (DJF/tonne)	Quantity (tonnes/yr)	Total (DJF/yr)	Quantity (tonnes/yr)	Total (DJF/yr)
***Prosopis* wood (collection cost)**	8 920	4 242	37 838 640	4 242	37 838 640
Labour	Unit price (DFJ/ person-day)	Quantity (workers)	Total (DJF/yr)	Quantity (workers)	Total (DJF/yr)
Unskilled workers	DJF 1 500	17	7 650 000	8	3 600 000
Skilled workers	DJF 3 000	0	0	4	3 600 000
Total labour			**7 650 000**		**7 200 000**
Storage	Unit price (DJF/tonne)	Quantity (tonnes)	Total (DJF/yr)	Quantity (tonnes)	Total (DJF/yr)
Storage charcoal capacity	100	71	7 070	106	10 605
Transport costs	Unit price (DJF/tonne)	Quantity (tonnes/yr)	Total (DJF/yr)	Quantity (tonnes/yr)	Total (DJF/yr)
	13 000	848	11 029 200	1 273	16 543 800
Investment	No. of years	Total (DJF)	Depreciation (DJF/yr)	Total (DJF)	Depreciation (DJF/yr)
Equipment	5	0	0	1 504 493	300 899
Subtotal investment				**1 504 493**	
Depreciation					300 899
Maintenance (10% of depreciation)					30 090
Total investment					**330 988**
Total costs		Total (DJF/yr)		Total (DJF/yr)	
Total operating costs		56 524 910		61 593 045	
Total fixed costs		-		330 988	
Total annual fuel supply cost		**56 524 910**		**61 924 033**	
Unit cost of fuel supply (DJF/kg)		67		49	

3 Conclusions and recommendations

The study presented in this report assessed three options for supplying fuel from *Prosopis* biomass to meet current energy demand for cooking in the Ali-Addeh and Holl Holl refugee camps.

The study estimated that the main production area, Hanlé, has a total standing biomass stock of 16 433 tonnes (fresh biomass weight) of *Prosopis* and a potential annual wood increment of 958 tonnes. The total biomass stock of the four largest expanses of *Prosopis* in Djibouti is estimated at 30 642 tonnes (fresh biomass weight), and the potential annual wood increment is estimated at 1 787 tonnes. The efficient use of this biomass could help meet the energy demand for cooking in the Ali-Addeh and Holl Holl refugee camps while controlling the spread of *Prosopis* and providing an income-generating opportunity for members of the host community involved in *Prosopis* harvesting and processing.

The analysis included the possible use of *Prosopis* for energy, and a thorough assessment of associated processing technologies and their characteristics was undertaken. Ultimately, the study did not reveal a single optimal option; nevertheless, viable options on the use of *Prosopis* have been explored, leading to several recommendations.

Table 12 provides comparative information for a range of fuels that could be used for cooking in the refugee camps, including liquefied petroleum gas (LPG) and kerosene. Although data are provided for each fuel separately, it may be viable to provide the refugee community with several fuel options in order to meet demand.

Table 12. Fuel energy comparison, and estimated fuel requirements for cooking

Fuel option	Energy content (megajoules/kg)	Quantity of fuel required equivalent to 1 kg of fuelwood	Indicative cookstove efficiency (%)	Total fuel required per person per year[a]
Fuelwood	14.4 megajoules/kg	1.0	20	348 kg
Briquette	17.6 megajoules/kg	0.8	30	185.4 kg
Charcoal	28 megajoules/kg	0.5	30	119 kg
LPG	49.5 megajoules/kg	0.3	60	33.7 kg
Kerosene	46.2 megajoules/litre	0.3	43	50 litres

Note: [a] Estimated fuel requirements take into consideration the energy content of the fuel as well as cookstove efficiency.

Table 13 shows the quantity of fuel required from various energy sources to meet cooking-energy demand in the Ali-Addeh and Holl Holl refugee camps.

The potential fuelwood production at Hanlé would be able to meet 58 percent of demand, and the increased efficiency achieved by the manufacture of briquettes, combined with increased cookstove energy efficiency, would enable production at Hanlé to meet 78 percent of demand. The charcoal option would enable production at the Hanlé site to meet 50 percent of demand. Therefore, each value chain would require additional biomass supply from other *Prosopis* sites to meet demand (and, even then, the charcoal option would meet only 90 percent of total demand) – or other energy sources, such as LPG or kerosene, would be needed. Overall, the production of briquettes from *Prosopis* biomass is an attractive option for meeting cooking-energy needs in the Ali-Addeh and Holl Holl refugee camps.

Table 13. Quantity of fuel required to meet annual energy demand for cooking at the Ali-Addeh and Holl Holl refugee camps, and the potential supply from the four *Prosopis* sites

		Hanlé		As Eyla		Douda		Tadjourah	
Fuel	Annual quantity required for the Ali-Addeh and Holl Holl refugee camps	Potential supply (tonnes/year)	Percent of total demand	Potential supply (tonnes/year)	Percent of total demand	Potential supply (tonnes/year)	Percent of total demand	Potential supply (tonnes/year)	Percent of total demand
Fuelwood	7 359 tonnes	4 242	58	682	9	1 652	22	1 037	14
Briquette	3 925 tonnes	3 075	78	648	17	1 569	40	985	25
Charcoal	2 523 tonnes	1 273	50	205	8	496	20	311	12
LPG	714 tonnes								
Kerosene	1 067 000 litres								

Table 14 reports the results of the cost comparison between fuels and associated improved stoves.

Based on the analysis in this study, an additional advantage of using briquettes is that this option would require less biomass than the other options to meet the cooking-energy demand in the two refugee camps.

It should be noted that the costs included in the analysis are based on a desk review and direct interviews with stakeholders involved in the fuelwood value chain. The purpose was to evaluate and compare the different technologies for using *Prosopis* for energy. Whichever option is ultimately chosen, a proper feasibility analysis would be required to take other factors into account.

Table 14. Comparison of the annual costs of supplying various fuels and improved cookstoves to the Ali-Addeh and Holl Holl refugee camps

Fuel options	Fuel supply cost	Cost per unit of energy (DJF/MJ)	Total fuel required per person annually (kg)	Cost per person per year (DJF)	Total quantity of fuel required options	Total annual cost of fuel for cooking (DJF)	Initial stove set-up cost for 5 200 households (DJF)	Annualized cost of stoves[a] (DJF)	Total annualized cost of fuel and cookstoves for Ali-Addeh and Holl Holl (DJF)
Fuelwood	DJF 22.5/kg	1.6	348	7 821	7 359 tonnes/yr	165 577 500	4 940 000	1 235 000	166 812 500
Briquette	DJF 34/kg	1.9	185	6 303	3 925 tonnes/yr	133 443 200	6 240 000	1 560 000	135 003 200
Charcoal[b]	DJF 49/kg	1.8	119	5 840	2 523 tonnes/yr	123 631 200	6 240 000	1 560 000	125 191 200
LPG	DJF 480/kg	9.7	34	16 180	714 tonnes/yr	342 528 000	44 200 000	11 050 000	353 578 000
Kerosene	DJF 110/ litre	2.4	50	5 543	1 067 litres/yr	117 352 824	46 020 000	11 505 000	128 857 824

Notes: [a] An average of four years was assumed as the lifespan of the cookstoves (although this might vary, depending on cookstove type).

[b] Charcoal produced using improved kilns.

The findings of this report give rise to the following recommendations:

- **Set up drying areas for fresh harvested *Prosopis* biomass in sunny, windy positions in harvesting areas. Cut wood into small pieces and allow it to dry naturally before transportation or further processing.** This is important to reduce the moisture content of wood and improve the overall efficiency of the value chains. Fuelwood, briquettes and charcoal should be stored in dry places. The moisture content of the fuel should be measured at various stages of the value chain to check the quality of the fuel and to avoid problems such as the production of large quantities of smoke during combustion and reduced energy density per volume (which, for example, would increase transport costs and reduce the quality of the fuel).
- **Minimize transport distances for *Prosopis* fuel through the appropriate selection of harvesting sites.**
- **Conduct research to identify technologies for the most cost-effective methods for harvesting *Prosopis* wood**. Field tests are needed to evaluate the optimum combination of manual and mechanical labour.
- **Create an enabling environment and provide financial, technology and knowledge transfer** to develop an efficient *Prosopis* value chain for energy purposes at a large scale.
- **Provide the private sector and other stakeholders with incentives and government support to undertake work that builds on a market approach.** The production of a cleaner and more efficient fuel from *Prosopis* requires interventions at various stages of the value chain, including market development, support for business models and plans, and increased access to credit.
- **Promote changes in behaviour to increase the adoption of more efficient cooking systems though practical demonstrations and training activities for beneficiaries.** To create demand for fuels such as briquettes, the final products must be reliable to ensure consumer uptake, especially if new types of cooking stove are also being introduced.
- **Support the national government and other stakeholders in their efforts to meet the energy needs of the refugee and host communities as well as to control the spread of *Prosopis*.** Practical training is recommended to raise awareness in local communities and within government about the environmental harm that *Prosopis* can cause as an invasive species and the importance of controlling its spread through appropriate management and use.
- **Disseminate the lessons learned from previous initiatives** in the country related to the use of *Prosopis* for energy, such as the use of improved charcoal kilns and other best practices.
- **Develop a business plan to support a pilot project for the efficient use of *Prosopis* for energy.** The main objective of such a project would be to initiate a new, functional *Prosopis* biomass value chain – harvesting, storage, pre-treatment, processing, transportation and efficient end use – to improve access to energy for cooking in the refugee camps, thereby improving food security and nutrition and the well-being of the refugee and host communities.

Annex 1. Normalized Difference Vegetation Index

Vegetation indices are commonly used in remote sensing for the assessment of vegetation characteristics. The Normalized Difference Vegetation Index (NDVI) is the most widely used index for vegetation monitoring with respect to calculating biomass, measuring leaf area index, estimating yield and monitoring vegetation distribution (Panda, 2005). Vegetation spectral indices combine information from two or more spectral channels to enhance the vegetation signal while minimizing soil, atmospheric and solar irradiance effects (Jackson and Huete, 1991). Equation 1 shows the formula of NDVI.

$$NDVI = (NIR - Red) / (NIR + Red) \quad \text{(equation 1)}$$

In Sentinel 2, band 8 is near-infrared (NIR) and band 4 is red. Equation 2 shows the formula for NDVI using Sentinel-2 data.

$$NDVI = (Band\ 8 - Band\ 4) / (Band\ 8 + Band\ 4) \quad \text{(equation 2)}$$

In the study, the temporal distribution of the vegetation was identified using the NDVI. *Prosopis* juliflora is an evergreen species, so images from the dry season (June–August) were used to differentiate *Prosopis* from other types of vegetation in the study area. Figure 9 shows NDVI value patterns for selected points. The figure shows that, even in the driest period, the NDVI value for *Prosopis* is always high compared with other vegetation classes. An NDVI value greater than 0.20 in dry seasons can be interpreted as representing *Prosopis*. NDVI values were collected at random points for three land-cover classes in the dry months of June–August from Sentinel-2 data.

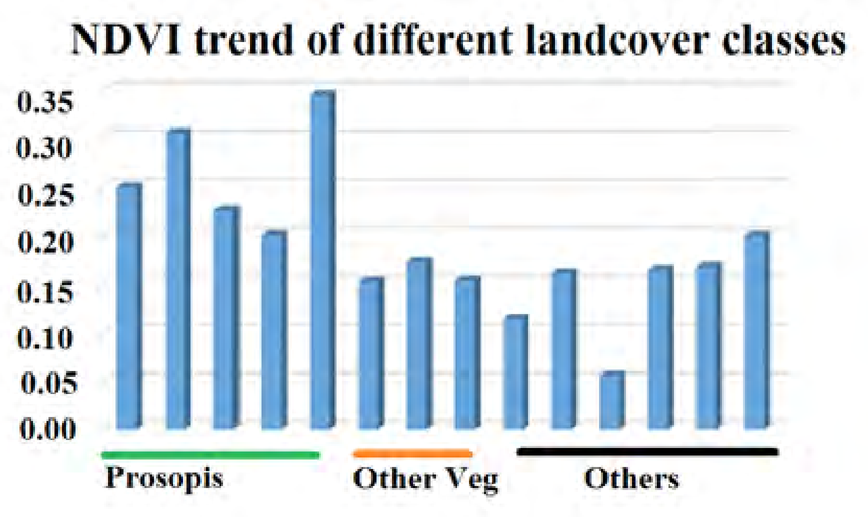


Figure 9. Dry-season NDVI values for the three landcover classes

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Djibouti has limited natural resources and is struggling with an ongoing drought. It is also dealing with a protracted refugee crisis, with more than 23 000 refugees living in the country. Domestic energy is a major challenge for the refugees: they use *Prosopis* fuelwood, which is collected at small-scale production sites more than 150 km from refugee camps. There is an urgent need to improve the planning of woodfuel supply, assess fuel quality, and increase the efficiency of woodfuel delivery and use in the refugee camps.

This report assesses the challenges in meeting energy demand in displacement settings in Djibouti. It presents data on the distribution of *Prosopis* in the country and analyses the economic potential of processing *Prosopis* woody biomass into briquettes and charcoal. It finds, among other things, that the production of briquettes from *Prosopis* biomass would be a cost-effective option for meeting cooking-energy needs for refugees and host communities in Djibouti.

ISBN 978-92-5-130741-0

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CA0163EN/1/06.18