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ENERGY ACCESS & THE NEXUS WITH WATER AND FOOD. DESIGN OF A PILOT PROJECT FOR IRRIGATION IN A RURAL INDIAN VILLAGE

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CONTENTS

List of figures

List of tables

Abstract

Aim of our thesis is the design of an appropriate solution to meet the energy needs for irrigation of a group of 15 farmers in the village of Katgaon (India, Maharashtra). This thesis is developed in the context of the “Sanjeevani Project” of Engineers Without Borders Milano. Goal of the project is the improvement of the socio-economic conditions of farmers in the village.

This work could be divided in four sections, reported in chronological order. Firstly we made a mission in India to study the context and to evaluate availability and consumption of energy resources in Katgaon. We collected data through the use of a questionnaire developed for this purpose. In the second section, we analysed the problems affecting the context and the objective of our work, using the Project Cycle Management (PCM) method. In the third phase, we used HOMER Energy to analyze the feasibility and the economic aspects of different energy systems. In particular, we considered different power plant sizes and different system designs (stand-alone, grid-connected, w/o presence of water tank). Finally, we reported some practical considerations for the installation of the appropriate system and our conclusions, with the use of a SWOT analysis.

Key words: energy for irrigation, rural Indian village, energy system design, solar PV, Project Cycle Management

Estratto in italiano

Scopo della nostra tesi è la progettazione di una soluzione appropriata per soddisfare il fabbisogno energetico di 15 contadini per l'irrigazione dei campi nel villaggio di Katgaon (India, Maharashtra). La tesi si inserisce all'interno del "Progetto Sanjeevani", che è svolto da ISF-MI in collaborazione con ProCluster Business Association (un'associazione indiana no profit che svolge attività sociali di supporto a progetti che contribuiscono al miglioramento delle condizioni di vita dei contadini in India) e Harnai (un'associazione di contadini locali). Lo scopo del progetto è il miglioramento delle condizioni socio-economiche dell'intero villaggio, e in particolare dei contadini, per contrastare il problema del suicidio dei contadini che affligge l'India e in particolare lo stato del Maharashtra.

Questo fenomeno, le sue cause e le sue ripercussioni sono descritti nell'introduzione. Inoltre, si analizza il contesto in cui si inserisce il progetto tramite un'analisi di indicatori sociali, economici ed energetici che descrivono le condizioni attuali dell'India. In questa analisi si confrontano i valori degli indicatori del paese India con quelli dei paesi facenti parte del gruppo definito BRICS (Brasile, Russia, India, Cina, Sudafrica) e di altri paesi in via di sviluppo situati nel Sud Est asiatico. In conclusione viene fatta una panoramica sullo stato attuale dei sistemi off-grid in India, sul ruolo del governo indiano nella loro diffusione, sull'importanza del coinvolgimento delle comunità in cui sono installati e sulle sfide che gli impianti off-grid devono affrontare.

Nel secondo capitolo viene descritto in dettaglio il villaggio di Katgaon tramite i dati raccolti durante la missione da noi svolta nei mesi di Novembre e Dicembre 2014 in India. In particolare si descrivono le problematiche legate alla fornitura di elettricità (blackout programmati, blackout e problemi di bassa tensione). Ai 15 beneficiari del progetto è stato sottoposto un questionario, da noi appositamente creato, il cui scopo era di raccogliere dati oggettivi e quantitativi utili per la progettazione. Prima della visita a Katgaon il questionario è stato testato più volte per valutarne l'efficacia e verificare la presenza di possibili errori o incomprensioni. Le informazioni raccolte sono sintetizzabili in sei categorie:

- Caratteristiche della famiglia: informazioni demografiche ed economiche;
- Caratteristiche dell'area: informazioni su terra coltivata (dimensione), bestiame e risorse d'acqua presenti;
- Attività agricola e allevamento: informazioni sui prodotti e sulle tecniche utilizzate;
- Aspetti energetici legati all'irrigazione: risorse disponibili e fabbisogno energetico;
- Aspetti energetici in ambito domestico: risorse disponibili e fabbisogno energetico per cottura dei cibi, illuminazione e riscaldamento dell'acqua;
- Analisi del mercato: mercati di destinazione e redditività dei prodotti agricoli.

Nel terzo capitolo è esposta un'analisi schematica del progetto seguendo la struttura del Project Cycle Management (PCM). Dunque viene effettuata un'analisi degli stakeholder individuando i beneficiari e coloro che sono interessati dal progetto. Per una più chiara comprensione si riporta una mappa che ne evidenzia interessi e potere. Quindi segue un'analisi delle problematiche presenti nel villaggio che, come richiesto dal PCM, sono schematizzate in un albero dei problemi. In questo albero si identificano, come problema principale, le difficili condizioni di vita dei contadini nel villaggio e si evidenziano le cause principali e gli effetti che queste hanno sugli abitanti. In seguito si definiscono gli obiettivi del progetto sotto forma di albero degli obiettivi. L'analisi degli obiettivi evidenzia che la soluzione del problema si otterrebbe tramite un progetto multidisciplinare e complesso che richiede un investimento elevato. Per questo motivo, nell'analisi della strategia, si delineano gli obiettivi specifici del nostro lavoro. In particolare l'obiettivo specifico del nostro progetto è il miglioramento delle condizioni economiche dei 15 contadini beneficiari del progetto pilota. Questo miglioramento si ottiene con la realizzazione di un impianto energetico che permetta di irrigare i campi con continuità in base alle necessità, e quindi di ottenere un incremento nella produttività del terreno e nei ricavi dalla vendita. Sulla base di questo albero si costruisce la Logical Framework Matrix (LFM) in cui si riportano le assunzioni per il conseguimento degli obiettivi e gli indicatori da utilizzare per il monitoraggio del progetto con le relative fonti di verifica.

Nel quarto capitolo è presentata un'analisi delle risorse energetiche disponibili nel villaggio ottenute tramite l'utilizzo di database della NASA e di dati raccolti in loco. Durante la nostra visita abbiamo installato un kit di misura per la valutazione delle risorse solare ed eolica, ma per problemi tecnici non abbiamo ottenuto dati sufficienti. Inoltre i dati sulla biomassa sono stati raccolti con l’ausilio del questionario. In questo capitolo si riportano infine le curve di carico per l’irrigazione e la metodologia usata per costruirle.

Nel quinto capitolo vengono descritte le simulazioni effettuate con l’utilizzo del software HOMER Energy. In questa analisi si considerano tre diverse configurazioni:

- Configurazione A: si considerano tutti i contadini all’interno di una determinata area indipendentemente dal fatto che appartengano al target group definito. Per la stima dei carichi si è fatto riferimento a un valore specifico di energia per acro.
- Configurazione B: si considerano singolarmente i 15 beneficiari del progetto pilota per ognuno dei quali sarà realizzata una soluzione singola.
- Configurazione C: si considerano 3 gruppi di contadini, beneficiari del progetto, allo scopo di realizzare 3 impianti di dimensione intermedie.

Per ognuna di queste configurazioni si valutano diversi scenari (in totale 63) che rappresentano le soluzioni implementabili nel contesto locale: impianto stand-alone, impianto connesso alla rete ed il possibile utilizzo di accumuli d’acqua. Data l’inaffidabilità della rete locale, per la configurazione C si effettua un’analisi approfondita sull’impatto che questa ha sulla soluzione progettata.

La logica utilizzata per la scelta della soluzione migliore per ciascun scenario è quella della ottimizzazione economica, in particolare del Net Present Cost (NPC). Per ogni configurazione ipotizzata, lo scenario connesso alla rete risulta essere quello con NPC minore rispetto allo scenario stand-alone, ma all’aumentare dell’inaffidabilità della rete diminuisce il divario tra i due scenari.

Dopo una attenta analisi economica, si effettuano delle considerazioni di natura pratica riguardanti l’installazione dell’impianto e le modalità di gestione. Per concludere si analizzano i punti di forza e di debolezza delle diverse configurazioni, con l’ausilio della matrice SWOT.

Chapter 1: Introduction

In this chapter we describe the project in which the thesis has been developed. Moreover we describe the economical, social and energy conditions of the country in which the project takes place. At the end of the chapter there is a review of the present condition of off-grid systems in India.

1.1 The project Sanjeevani

The idea of the project Sanjeevani was born in 2012 from the collaboration between Engineers Without Borders - Milan (ISF-MI), ProCluster Business Association, the association Parivartan, an association of Indian students and professionals based in Milan and the UNESCO Chair in Energy for Sustainable Development. The project started following the farming crisis which stroke India in the previous years and which gave rise to the problem of farmers' suicides. [1]

1.1.1 The problem of farmers' suicides

In a report written in 2009 we read "It is estimated that more than a quarter of a million Indian farmers have committed suicide in the last 16 years - the largest wave of recorded suicides in human history.[...] In 2009 alone, the most recent year for which official figures are available, 17,638 farmers committed suicide - that's one farmer every 30 minutes. While striking on their own, these figures considerably underestimate the actual number of farmer suicides taking place. Women, for example, are often excluded from farmer suicide statistics because most do not have title to land - a common prerequisite for being recognized as a farmer in official statistics and programs". [2]

The phenomenon of farmers' suicide has been affecting India since the late 1990s and since then the number of cases has increased to several thousands. At national level the problems affecting the agricultural sector spread to various regions as well, especially in 2014, when an upward trend of this phenomenon has occurred in the States of Maharashtra, Telangana, Karnataka and Punjab.

The reason of this dramatic phenomenon can be addressed in general, and probably with local exceptions, to cultural and socio-economic aspects related to a loss of reputation consequent to getting into debts and the impossibility to pay them off. Paradoxically, farmers are also encouraged to commit suicide by a measure adopted by the Indian government, aiming to alleviate the social impact of this phenomenon: it provides for financial help granted to the family of the deceased land owner. For some farmers indeed this financial help may represent an economic solution for their families and their debts.

Debts are usually incurred for several different reasons. Primarily they are related to the high expenditure for health care and treatment. Farmers do not seem to have access to good healthcare services and therefore have to bear huge hospitalization costs. No health insurances and schemes from government have been found. There are many insurance companies in India, but they do not have any interest in working in the rural areas; there are low premium insurance schemes in these companies for farmers, but no implementation.

Other reasons for indebtedness include education expenses for children and the costs for daughter's wedding (expenses incurred to organize the wedding ceremony and especially the dowry that has to be paid to the groom's family). These issues represent a relevant burden on the family economics of farmers that have no other income but agricultural products. To satisfy these needs, farmers generally borrow money from private money lenders ("Saukar") at a very high interest rate, with the consequence that they are not able to repay their debt in due time.

The lack of a 24-hours energy supply represents another serious problem in farming: without electricity from the grid, farmers cannot irrigate their fields. Some common cultivated products like sugarcane, grapes and cotton are strongly water-consuming crops and the lack of water, especially during the dry season, compromises the harvest.

The economic income of farmers is therefore based on one single opportunity related to the success of the annual production, and this represents a relevant risk since Indian environmental and weather conditions are subject to many threats, including in particular the variability of monsoon season. It is hence very important for farmers to obtain a good harvest in order to satisfy the needs of their families and maintain the financial cycle.

1.1.2 Description of the project

In this context, the Sanjeevani project has as goal the improvement of the socio-economic conditions of farmers in the village of Katgaon (Fig. 1.1), in the Indian State of Maharashtra. The project considers a first stage which involves a small number of farmers and aims to understand the real impact of the proposed solution in the context and the response of local people. A second stage, in which the solution is extended to more beneficiaries, is expected, but this phase is not considered in this analysis.

Fig. 1.1: Position of the Katgaon village reproduced from Google Maps

The pilot project currently includes two separate and complementary actions, which are the creation of an awareness campaign, called Farmer's Pride Campaign, to promote the importance of the role of farmers within the Indian society, and the design of a system to supply energy for local water pumping and irrigation in the village of Katgaon.

Thanks to Parivartan, ISF-MI has contacted Harnai, an association made up of sons of farmers working in Katgaon. Harnai carries out social activities, providing sanitation and helping farmers in the production of organic fertilizers. The possibility of locating the pilot project in Katgaon comes right from the contact with this association. From an initial interview with Harnai association, it has emerged that farmers cannot irrigate fields with continuity when necessary, because of an inappropriate electric system. [1]

Before going into the details of the project and our work, a general description of the context of India is given.

1.2. Context analysis: India

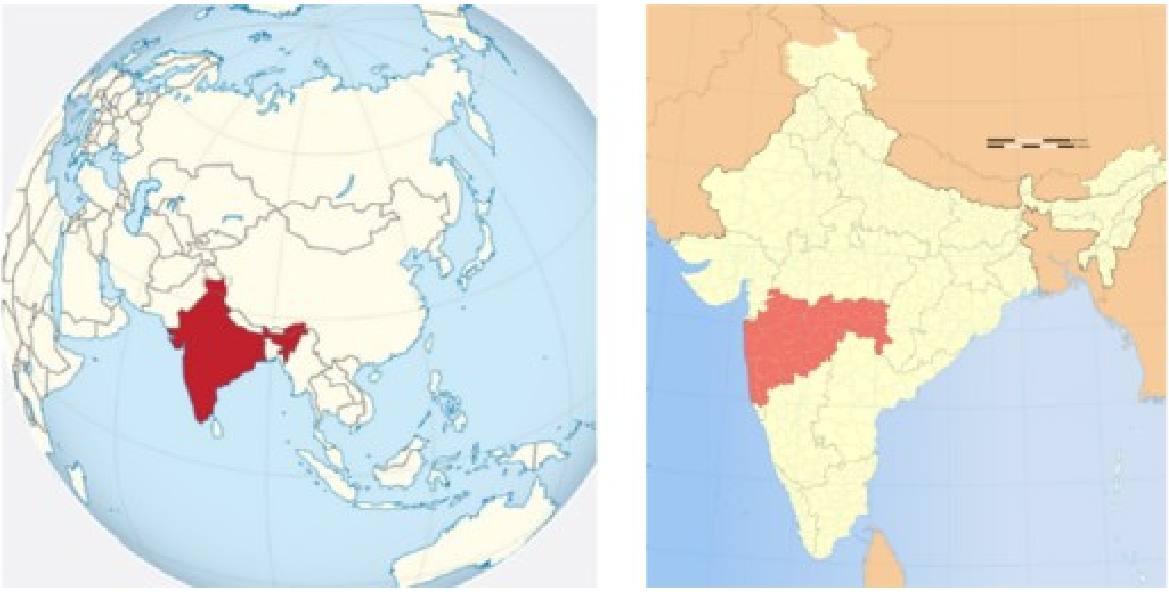


Fig. 1.2: India and the State of Maharashtra reproduced from [3]

India, officially the Republic of India (Bharat Ganrajya), is located in South Asia. It is the seventh-largest country by area, the second-most populous country with over 1.2 billion people, and the most populous democracy in the world. The Indian economy is the world's tenth-largest by nominal GDP and third-largest by purchasing power parity (PPP). Following market-based economic reforms in 1991, India became one of the fastest-growing major economies. It is considered a newly industrialised country. However, it continues to face the challenges of poverty, illiteracy, corruption, malnutrition, inadequate public healthcare and terrorism.

To fully understand the current condition it is essential to analyze, through the use of some indicators, the economic, social and energy-environmental conditions comparing India with average world indicators and other selected countries.

1.2.1 Energy assessment of India

We briefly describe the current situation of Indian energy sources, before introducing some indicators that will be used for comparisons with other selected countries.

Energy sources

India is the world’s fourth highest energy consumer after the USA, China and the Russian Federation. In per capita terms, however, an average Indian citizen uses about 15 times less energy than an average US citizen, produces about 17 times less GHG emissions and uses about 30 times less electricity.

Renewable energy sources (excluding large hydro) accounted for 12.2% of India's overall power generation capacity in 2012. The Ministry of New and Renewable Energy (MNRE) estimates that there is a potential of around 90,000 MW for power generation from different renewable energy sources in the country, including 48,561 MW of wind power, 14,294 MW of small hydro power and 26,367 MW of biomass. Though India has a huge renewable energy potential, availability of renewable energy sources is widely dispersed. In some states the potential for renewable energy is insignificant (e.g. Delhi), whereas some states have abundant renewable sources: wind energy is abundant in Gujarat, Karnataka, Maharashtra, Tamil Nadu, Jammu and Kashmir; solar energy is concentrated in Gujarat, Rajasthan, Ladakh, Maharashtra and Madhya Pradesh; the small hydro potential in the country is concentrated in hilly states of Himachal Pradesh, Uttaranchal, Jammuand Kashmir, Arunachal Pradesh and Chattisgarh. The biomass potential is more difficult to evaluate and should be assessed carefully in every situation. [4]

As regards the solar source, India is among the leading countries having good Direct Normal Irradiance (DNI), which depends on the geographic location, earth-sun movement, tilt of Earth rotational axis and atmospheric attenuation due to suspended particles. India is estimated to have huge potential for solar energy which is about 5000 trillion kWh per year. The solar radiation incident over India is equal to 4–7 kWh per square meter per day [5] with an annual radiation ranging from 1200–2300 kWh per square meter [6]. It has an average of 250–300 clear sunny days [5] and 2300–3200 hours of sunshine per year. In the Table 1.1 a comparison between the solar PV status in India and in the world is shown. [7]

RES	World status	World leader	India status	Potential	Leader
Solar PV	100 GW–2012	Germany	1.84 GW–2013	4–7 kWh/km^2/day	Gujarat

Table 1.1: Comparison of Solar PV with country in lead & India's status with the state in lead

Also for the wind power we present a description of the Indian current situation. India is the 3rd largest annual wind power market in the world: the development of wind power in India began in the 1990s and has drastically increased in the last few years. Table 1.2 shows a comparison of the status of wind power between India and the rest of the world.

RES	World status	World leader	India status	Potential	Leader
Wind	283 GW–2012	China	17.6 GW–2013	47 GW	Tamil Nadu

Table 1.2: Comparison of wind source with country in lead & India's status with the state in lead

The potential in wind has been estimated as 102,778 MW at 80 m height and as 49,130 MW at 50 m height at 2% land availability (see Fig. 1.3). Wind resource assessment is a continuous process for the identification of potential areas for wind farming. There are 220 sites having wind energy density of at least 200 W/m^2 at 50 m height.

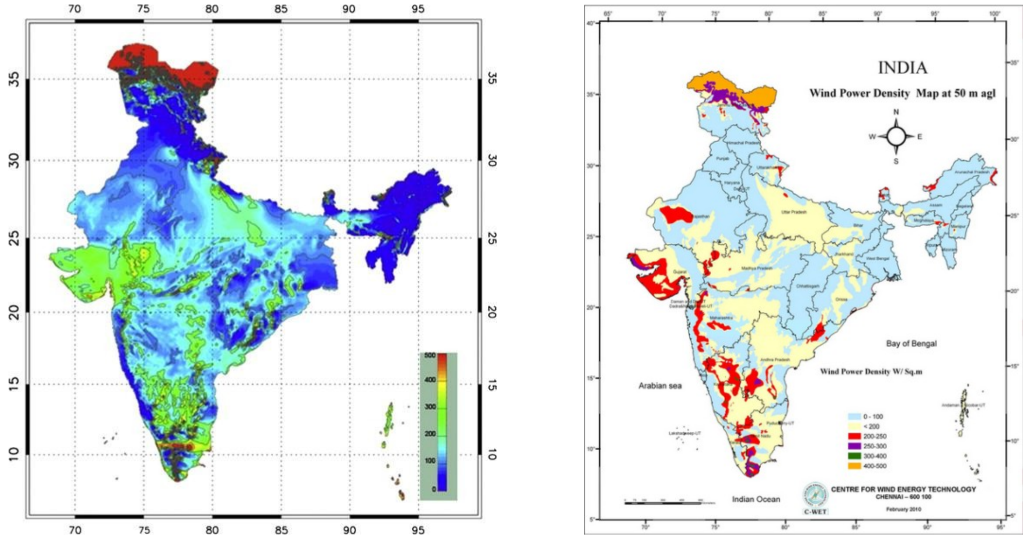


Fig. 1.3: Wind power density map at 80 m and 50 m (W/m^2) reproduced from [8]

Despite this potential, about 70% of India's electricity generation capacity is still from fossil fuels, with coal accounting for 45% of India's total energy consumption followed by crude oil and natural gas at 22.5% and 6.2% respectively. The total primary energy supply is shown in Fig. 1.4, according to IEA report of 2012.

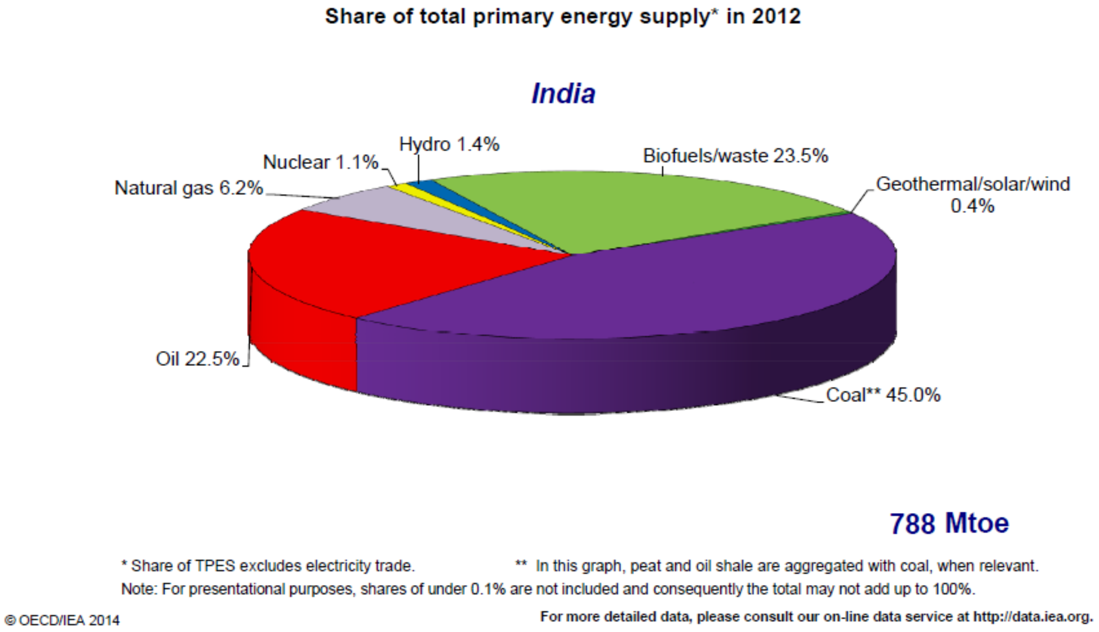


Fig. 1.4: Share of total primary energy for India in 2012 reproduced from [9]

Electrification and grid development

Electricity in India is the largest final use of primary energy. In 2006 81% of power was produced from coal: Indian policy makers look favourably at coal, given its high domestic availability and security of coal supplies globally.

According to the World Coal Institute, India is the sixth largest electricity generating country, as well as the sixth largest electricity consumer. Despite this, the electrification rate is only 75% as of 2009. The population estimated to have no access to electricity is 288.8 million. Some 140,000 Indian villages out of 586,000 remain to be electrified and in many of the officially electrified ones, quality of service is such that they do not resemble true electrification. About 625 million people do not have access to modern cooking fuels and traditional fuels still provide 80–90% of the rural energy needs.

Geographic distribution of power generation capacity in India is unevenly dispersed with a mismatch in supply and demand in different regions. In India, the transmission and distribution (T&D) system is a three-tier structure comprising of distribution networks, state grids and regional grids. The central transmission utility, PowerGrid India, operates approximately 98,368 km of transmission lines at 800/765 kV, 400 kV, 220 kV & 132 kV, as well as at over 500 kV HVDC. [4]

Development of infrastructure is necessary for satisfying the requirements of agriculture and other economic activities, including irrigation pump sets, small and medium industries, and social services like health and education.

Future trends

India’s rapidly growing economy and population leads to a relentless increase in electricity demand. From the New Policies Scenario presented in the WEO 2014, India’s rate of electricity demand growth results to be among the fastest globally, averaging 4.4%. Nonetheless, there remains a need for further growth: 300 million people lack access to electricity today and per capita electricity use at the end of the projection period remains low. Maintaining India’s booming electricity demand requires large capacity addition. The IEA predicts that by 2020, 327 GW of power generation capacity will be needed, which would imply an addition of 16 GW per year. This need is reflected in the target that the

Indian government has set in its 11th Five Year Plan (2007–2012), which envisages an addition of 78.7 GW in this period, 50.5 GW of which is coal. The 12th Five Year Plan (2012-2017) projects larger increases in energy imports, with import dependence on coal and oil set to increase to 22.4% and 78% respectively. Renewable capacity is also projected to increase to 54,503 MW by the end of the 12th Plan.

The graph in Fig. 1.5 shows the Indian electricity generation by sources and the CO_2 intensity in the New Policies Scenario.

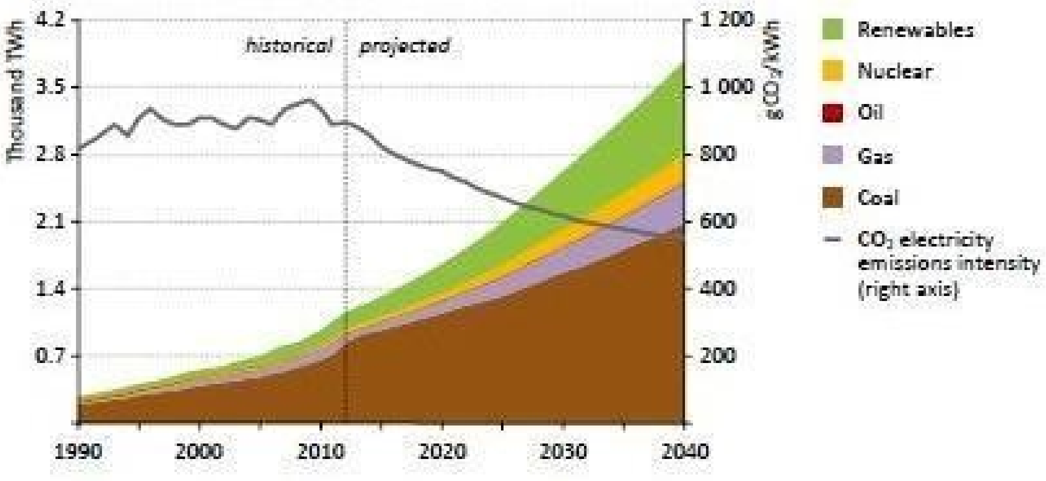


Fig. 1.5: India electricity generation by source and CO_2 intensity in the New Policies Scenario reproduced from [10]

Coal-fire plants continue to play a central role in the mix of sources for electricity generation, despite their share decreases from 72% to 55%. India plans to give nuclear power a key role, with the rate of addiction doubling after 2020. Renewables benefit from strong policy support. Led by solar PV, wind and hydropower, they account for over 40% of India’s capacity additions in the period to 2040, increasing their share from 15% to 26%.

Energy Development Index (EDI)

In this paragraph, we analyze the Energy Development Index, which considers energy and social aspects and is internationally used for the analysis and comparison of different countries.

The enhanced Energy Development Index (EDI), introduced for the first time in the WEO 2012, is a multi-dimensional indicator that tracks energy development country-by-country for 80 countries, distinguishing between developments at the household level and at the community level. In the household level, it focuses on two key dimensions: access to electricity and access to clean cooking facilities. When looking at community level access, it considers modern energy use for public services (e.g. schools, hospitals and clinics, water and sanitation, street lighting) and energy for productive use, which deals with modern energy use as part of economic activity (e.g. agriculture and manufacturing).

Country			**India**
Rank			**41**
EDI			**0.30**
Household level energy access	Access to electricity indicator	Electrification rate	0.75
		Per-capita residential electricity consumption	0.11
		Electricity access indicator	0.29
	Access to clean cooking facilities indicator	Share of modern fuels in residential total final consumption	0.14
	Household level indicator		**0.22**
Community level energy access	Public Services	Per-capita public services electricity consumption	0.06
	Productive use	Share of economic energy uses in total final consumption	0.69
	Community level indicator		**0.38**
Use of additional assumptions 5 = maximum use of original data; 0 = assumptions based on cross-country comparison used for all variables			5

Table 1.3: Normalized variables of Energy Development Index 2010 reproduced from [11]

India is ranked 41st with an EDI value of 0.30 (the highest value is 0.92, the lowest one is 0.04). The values of all the indicators that form the EDI for India are reported in Table 1.3.

Fig. 1.6 ranks four countries according to their overall EDI score, showing the relative contribution of each of the constituent indicators.

It is interesting to note that for India the indicator is calculated only on the base of real data available for the country. As regards the household level the electrification rate is quite high (75%), but the per capita residential energy consumption is low (11%). This could reveal a low reliability of the electric grid. Also the share of modern fuels in residential total final consumption is low, reaching the value of 14%. As regards the community level the per capita public services electricity consumption is really low (0.06%), while the share of economic purposes in total final consumption is almost the 70%.

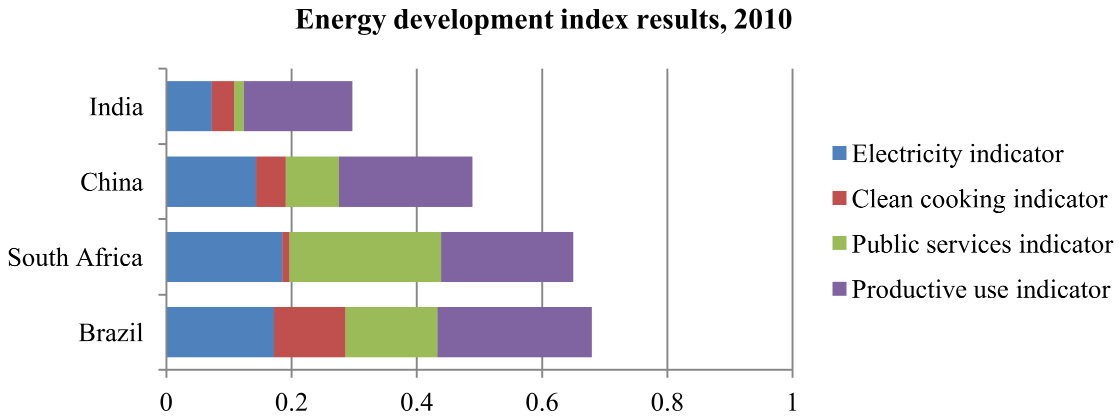


Fig. 1.6: Energy Development Index results (2010) for selected countries reproduced from [12]

Using the available data it is possible to compare the EDI indicator of countries belonging to the group defined as BRICS (a precise definition for this group is reported in the following paragraph). India has the lowest EDI value among these countries. Brazil, South Africa, China and India rank respectively 11th, 14th, 26th and 41st in the global ranking. The EDI values of South Africa and Brazil are more than twice the Indian value. The difference is due to a higher access to electricity both at household and at community level. Regarding the access to clean cooking facilities South Africa presents the lowest value, but this does not affect the overall EDI value in a significant way. The situation of China is more similar to the Indian one. Also in this case the difference between these countries depends more on access to electricity, rather than on access to clean cooking facilities. It is moreover worth noting that the EDI value for China has been increasing by almost 0.15 since 2002, whereas for the other abovementioned countries the value has been increasing by only approx. 0.05.

1.2.2 Economic assessment of India

Regarding the economic sphere, India is one of the five developing countries gathered with the acronym BRICS.

BRICS is the acronym for an association of five major emerging national economies: Brazil, Russia, India, China and South Africa. The grouping was originally known as "BRIC" before the inclusion of South Africa in 2010. The BRICS members are all developing or newly industrialised countries, but they are distinguished by their large, fast-growing economies and significant influence on regional and global affairs. The term "BRICS" was coined in 2001 by then-chairman of Goldman Sachs Asset Management, Jim O'Neill, in his publication *Building Better Global Economic BRICs*.

Gross Domestic Product (GDP)

As of 2014, the five BRICS countries represent almost 3 billion people, or approximately 40% of the world population. The five nations have a combined nominal GDP of US$ 16,039 trillion, equivalent to approximately 20% of the gross world product, and an estimated US$ 4 trillion in combined foreign reserves. The BRICS have received both praise and criticism from numerous commentators.

In particular it is interesting to assess the value and the trend of GDP per capita at purchasing power parity, usually indicated with GDP (PPP). GDP (PPP) represents the gross domestic product converted to international dollars using purchasing power parity rates. An international dollar has the same purchasing power over GDP as the US dollar has in the United States. GDP at purchaser's prices is the sum of gross value added by all resident producers in the economy plus any product taxes and minus any subsidies not included in the value of the products. It is calculated without making deductions for depreciation of fabricated assets or for depletion and degradation of natural resources. Data are in current international dollars based on the 2011 ICP round.

In particular, we see that the GDP per capita (PPP) of India, from a starting point of $2,060.6 in 2000, grew to $5,411 in 2013 while the world has witnessed an increase from a value of about $7,840 in 2000 to a value of $14,397 in 2013. This shows that despite the strong economic growth of India, which has tripled the GDP per capita (PPP) in only 13 years, this country is still far from world average, placing itself as a country still developing. To support this thesis it is interesting to recall that the average GDP per capita (PPP) of East Asia & Pacific (developing only) (EAP) was equal to $3,190 in 2000 and increased to a value of $10,794 in 2013, which is a value significantly higher than that of India. It should be further noticed that if India's GDP per capita has more than doubled in 13 years, this is not positive when compared with other EAP developing countries where there has been a much higher growth rate (+240%).

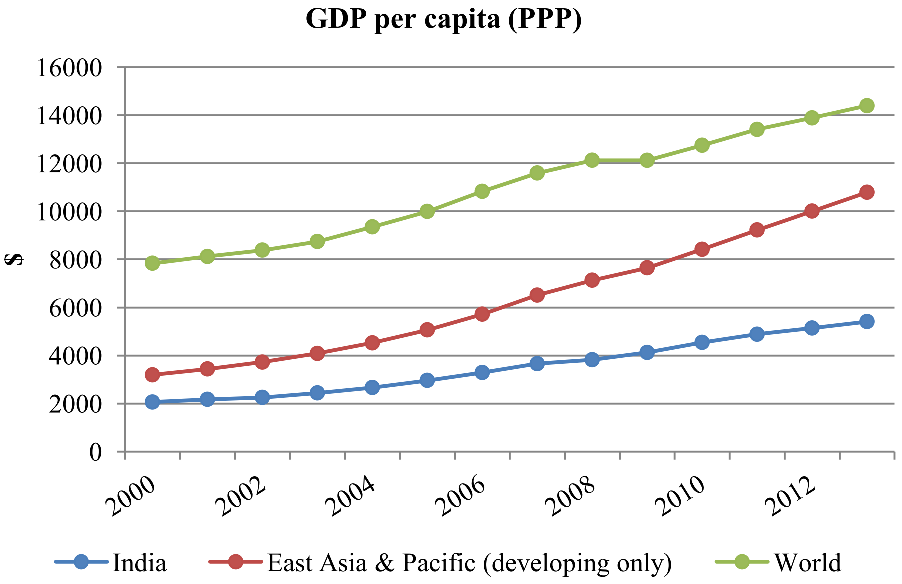


Fig. 1.7: Trend of GDP per capita (PPP) for India, East Asia & Pacific (developing only) and World from 2000 to 2013 reproduced from [13]

It is reported in Fig. 1.7 the trend of GDP per capita for the aforementioned countries since the year 2000.

A more precise analysis involves an economic comparison, between India and the BRICS, with the use of GDP per capita (PPP).

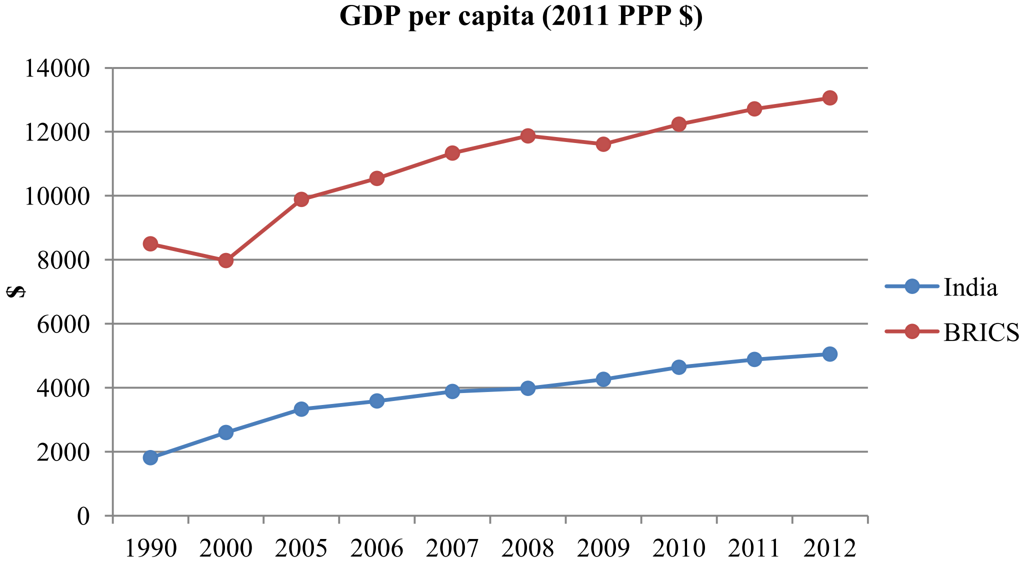


Fig. 1.8: Trend of GDP per capita (2011 PPP $) for India and BRICS countries from 1990 to 2012 reproduced from [13]

Also from the graph in Fig. 1.8 it is clear that in India there has been a slow economic growth that leads to a deeper gap with the other BRICS.

Poverty gap

To fully understand the condition of poverty in which we find the Indian population another interesting indicator can be consider: the poverty gap.

Poverty gap is the mean shortfall from the poverty line (counting the nonpoor as having zero shortfall), expressed as a percentage of the poverty line. This measure reflects the depth of poverty as well as its incidence.

From the latest data available on internet in India this indicator had a value of 41.6 in 2005 and decreased in only 5 years by more than 9 percentage points reaching a value of 32.6. For this indicator we can do the same considerations as for the GDP per capita (PPP): even in this case there is a significant decrease in the value, which nevertheless remains high compared with developed countries (Medium human development: 16.0 in 2010; High human development: 0.3 in 2010).

As mentioned above, to analyze a country it is not sufficient to evaluate only the economic aspect but rather a careful analysis in the social, health and environmental fields is required.

1.2.3 Social condition assessment in India

Human Development Index (HDI)

In the social field, an indicator commonly used is the Human Development Index (HDI), which encloses a set of parameters essential and sufficient to describe the social conditions of the context examined.

The HDI was created to emphasize that people and their capabilities should be the ultimate criteria for assessing the development of a country, not economic growth alone. The HDI can also be used to question national policy choices, asking how two countries with the same level of GNI per capita can end up with different human development outcomes. These contrasts can stimulate debate about government policy priorities.

The Human Development Index (HDI) is a summary measure of average achievement in key issues of human development: a long and healthy life, being knowledgeable and having a decent standard of living. This indicator is based on the idea that human development consists mainly of creating an environment in which people can develop their full potential. Without the aforesaid issues many choices are simply not available, many opportunities in life remain inaccessible and the fight against poverty continues to be only a "chimera". In this sense the Human Development Index (HDI) is a composite statistic of life expectancy, education, and income indices used to rank countries into four tiers of human development.

If for very high human development countries this value increased from 0.757 in 1980 to 0.890 in 2013, in India we see a very different picture with a value of 0.369 in 1980 grown to 0.586 in 2013. Again it can be seen a remarkable growth but also a marked difference from the values of the developed countries. In contrast to what was seen in the economic analysis, there is a data in favour of India: according to data from the World Bank the average value of the Human Development Index for low human development countries is equal to 0.493 in 2013, a value much lower to the Indian one. We can therefore say that about human development, India is not among the countries with the lowest value, but rather among the medium human development countries for which the average value is slightly higher (equal to 0.614 in 2013).

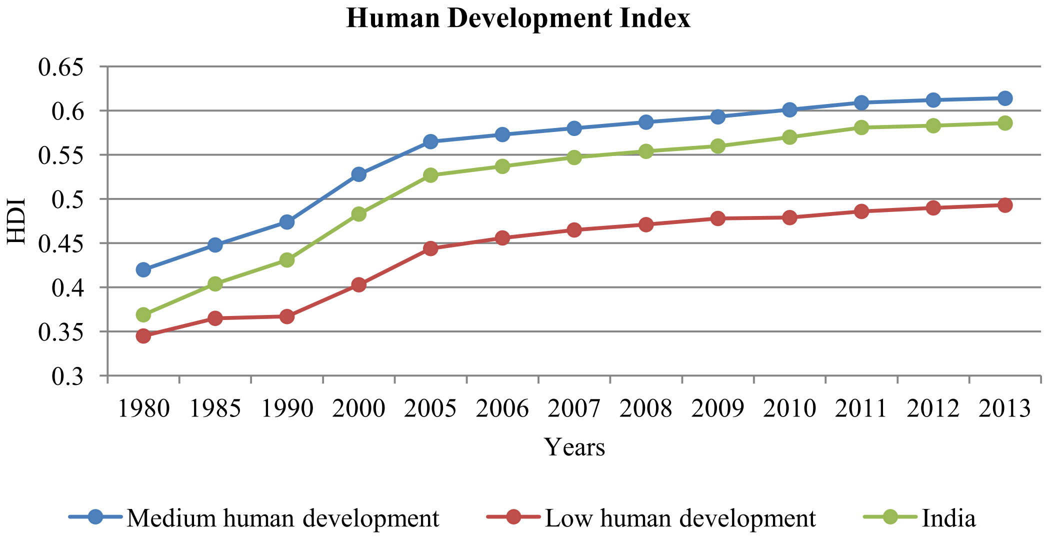


Fig. 1.9: Trend of Human Development Index for India, low HDI and medium HDI countries from 1980 to 2013 reproduced from [14]

As can be seen from the graph in Fig. 1.9, India is under the social aspect in a better condition than low human development countries with a value of the HDI slightly lower than middle human development countries.

Life expectancy and death rate

To analyze the conditions of hygiene and health of the country is deemed necessary to use more than a single indicator.

To present an exhaustive description of health situation in India we chose the following indicators: life expectancy at birth and crude death rate (per 1,000 people).

Life expectancy at birth indicates the number of years a newborn infant would live if prevailing patterns of mortality at the time of its birth were to stay the same throughout its life.

In India this indicator amounted to 66 in 2012 compared with a world average equal to 70.8 in the same year.

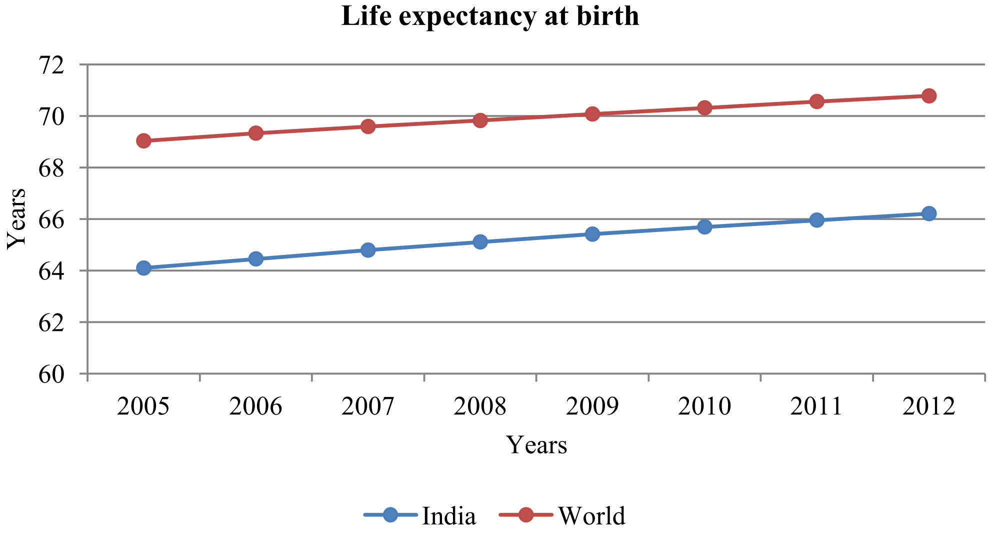


Fig. 1.10: Trend of life expectancy at birth for India and World from 2005 to 2012 reproduced from [13]

Even if the value of this indicator for India is lower than the global one, in Fig. 1.10 a positive trend can be read with a growth from a value of 64 in 2005 to 66 in 2012.

Crude death rate indicates the number of deaths occurring during the year, per 1,000 people estimated at midyear. Subtracting the crude death rate from the crude birth rate provides the rate of natural increase, which is equal to the rate of population change in the absence of migration.

The crude death rate has a world average value equal to 8.0 in 2012 and is equal to the value that we find in India.

In this case, as well as in previous economic analysis, India is placed in a worst position than countries in developing East Asia.

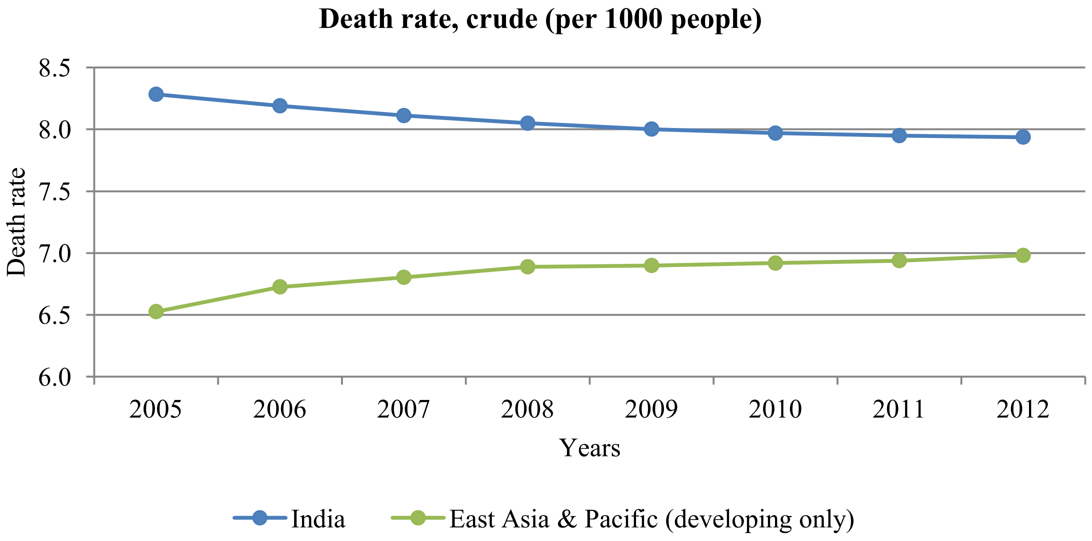


Fig. 1.11: Trend of death rate, crude (per 1000 people) for India
and East Asia and Pacific (developing only) from 2005 to 2012 reproduced from [13]

Although in India we find a higher value, it is also true that the graph in Fig. 1.11 shows a comforting slight decrease of the value in contrast to what occurs on average in East Asia and Pacific developing countries, where we see a reverse trend.

1.3 Consideration on off-grid plants in India

Before proceeding, an extensive literature search was conducted to understand how similar projects have responded to the problem, which obstacles they have found and which factors allowed them to get a successful result.

In India, the off-grid electrification has been carried out under some programs administered by the Ministry of New and Renewable Energy (MNRE) and implemented primarily through designated state renewable energy development agencies. In addition, various NGOs have also been attempting to create electricity access through off-grid options with funding support from MNRE, bilateral and multilateral aid agencies. TERI (The Energy and Resources Institute), a non-governmental organization in India, has been implementing the "lighting a billion lives" (LaBL) program since 2008 and has covered more than 1900 villages across 22 states (as of December 2012), benefitting around 450,000 people, and has also taken its footprints to some countries in East and West Africa. The Remote Village Electrification (RVE) program of the government, initiated in

2001, covers un-electrified census villages and hamlets that are not likely to receive grid connectivity. This program electrified 8033 villages and hamlets as of December 2010 [15]. Among other things, MNRE currently offers a 30% capital subsidy for off-grid electricity generation; entrepreneurs have to apply for a subsidy, and if the proposed scheme is deemed to meet regulatory guidelines, the state pays the subsidy.

The Government of India's current policy is not sufficiently integrated to allow off-grid electrification to realize its full potential. Government programs do not effectively coordinate grid and off-grid efforts, and the policy environment also does not encourage private entrepreneurs to generate off-grid electricity for rural communities. Based on discussions with Indian experts on the off-grid space, entrepreneurs in the field do not have a clear understanding of all the villages designated for the grid extension in the coming years. The scheme at national level is being implemented by individual state governments according to their own plans, and the nodal agencies responsible for the implementation are not deciding on grid extension in explicit coordination with their off-grid electrification counterparts.

An explanatory example of this situation is the Sagar Dweep Island in the West Bengal. Here an initial project for solar lanterns was initiated already in 1994, and the initial positive results allowed a more comprehensive off-grid electrification that brought many benefits to the inhabitants of the island. Following the installation of a solar photovoltaic system, access to power at night has promoted the expansion of many economic activities, helping students studying later, shop-keepers working at night and in addition a decrease of indoor air pollution was registered. Despite the successful implementation of an off-grid electricity system the local government has determined that the island should be connected to India's main grid. As grid power has become available, the off-grid enterprises are being phased out, an example of duplicated efforts. At the same time, grid extension to a community that already has an exceptionally effective off-grid system means that some other villages with no electricity at all remain un-electrified.

The first step to get the objective of rural electrification is therefore a coordinated and clear regulation of the electricity system. As long as there are ongoing grid extension efforts but offering power to some segments of rural population through the grid would be expensive or where the grid is not enough to satisfy the demand, off-grid electrification is a potentially useful complement to the conventional approach.

The importance of community participation

Community participation is widely accepted as a pre-requisite to ensure equity and sustainability of rural electrification efforts. It is observed in all the studies that local participation have helped in reducing theft and distribution losses, improved billing and revenue collection efficiency and more importantly ensure stable delivery of electricity [16] [17]. Further, it is also observed that there has been more success where intermediary organizations have helped the local planning process. In off-grid programs the involvement of rural communities, particularly their participation in decision-making committees, had added a value to the planning process and given communities a sense of ownership.

Another important side of "local participation" involves monitoring and maintenance. In fact, since many plants are located in remote areas, these two aspects seem to be the most critical determinants of limited success of many programs in the regions. Urmee and Harries [18] argue that where this responsibility had been outsourced to technicians or equipment suppliers, as found primarily in government funded programs, dissatisfaction with the timeliness of the maintenance was frequently reported by program implementing agencies. To solve this problem, it is observed that appropriate training and capacity building has played a key role for ensuring effective maintenance and monitoring of the systems and thereby their sustainability, also creating workplaces. The initiatives have to give importance to sensitization and training of every stakeholder at different stages of project implementation for ensuring sustainability [19]. This includes community sensitization and engagement prior to the inception of the project at any site to assess the need and ensure acceptability of the project by the beneficiaries.

Challenges

There are many challenges - technical, financial, regulatory, and institutional - hindering electricity access in India, as in lots of other developing Countries. A large number of off-grid electrification projects have not succeeded as focus has been on technical installation without paying sufficient attention on whether they can be sustainable in the long run [20]. Palit [15] highlighted, based on specific examples from north eastern region of India, that lack of availability of adequate maintenance facilities and inadequate capacity building of the technicians acted as a barrier. On the other hand, credit risk tends to be a serious concern for both financiers and dealers and makes credit sales particularly challenging. The key issue which calls for immediate attention is rationalizing of the interest rate for micro-lending to cover poor households and wider coverage through reduces transaction cost. For example, India Post can channelize micro-lending in rural India through its extensive network of branches and provide a wide range of small-scale finance that banks normally are unwilling to do or mobile banking can be extensively used to reduce the transaction cost and thereby the interest rate for micro financing. Instead of direct subsidy by the government, flexible financial instruments, such as interest rate buy down, viability gap funding, output based aid, for both the end-users and/or energy service entrepreneurs and appropriate risk mitigation measures for the rural lending sector will be more effective in ensuring not only the dissemination of solar products but also their sustainability. In addition, as it said before, the rate of success is directly dependent on the government's commitment in creating an enabling environment such as clear cut policy framework and milestones, systems for defining and enforcing appropriate technical standards, standardized operational metrics and financial support mechanism.

Chapter 2: Description of Katgaon and farmers needs

The aim of this chapter is to describe the village of Katgaon. From the 20th of October until the 20th of December 2014, we made a mission in India to study the context and to evaluate the availability and consumption of energy resources in Katgaon. A previous mission of few days was carried out in the month of August 2014 by two other members of Engineering Without Borders and we used their feedbacks to plan our mission. We based in the city of Pune, where our main local partner ProCluster has its headquarters and where we had the opportunity to study the general context of Maharashtra, the structure of the electricity market and where we prepared the material for our field studies. The description of Katgaon is based on data collected during two field visits. On those occasions we submitted a questionnaire to a group of selected farmers and conducted surveys in the local hospital, in public offices and schools. Surveys and measurements aimed to evaluate the actual energy loads and the presence of sources of energy which can represent an alternative to the national electric grid.

In the first part of this chapter the village of Katgaon is presented. The chapter then continues with the description of the submitted questionnaires, the methodology used to prepare the surveys and the practical execution of the surveys on site. It ends with the presentation of the main characteristics of the interviewed farmers and a focus on agriculture (products, farming and irrigation techniques, market), the sector which is most interested by our project.

2.1 Katgaon

2.1.1 General information

Katgaon is a small village of the district of Osmanabad in the State of Maharashtra. The closest city is Solapur, 40 minutes away by car, connected to Katgaon only by a dirt road. Katgaon has a population of 7,800 individuals, of which 60% and 40% are males and females, respectively. The share of children under 16 years is 18% of the total population. Most of the households live on agriculture (about 70% of workers are farmers), but the poor conditions of farmers in this region cause an high rate of migration toward the big cities of Maharashtra (in the last five years about 500 farmers have moved to the cities of Solapur, Pune and Mumbai).

2.1.2 Structure of the village

The total area of the village, including lots and uncultivated lands, is about 5,126 hectares. In the village there are a hospital, an animal health treatment centre, a telephone office, 5 nursery schools, a primary school, a secondary school, a bank, a post office and the local government office (Grampanchayat). There are approximately 100 shops, mainly small restaurants, mini markets, and grinding mills.

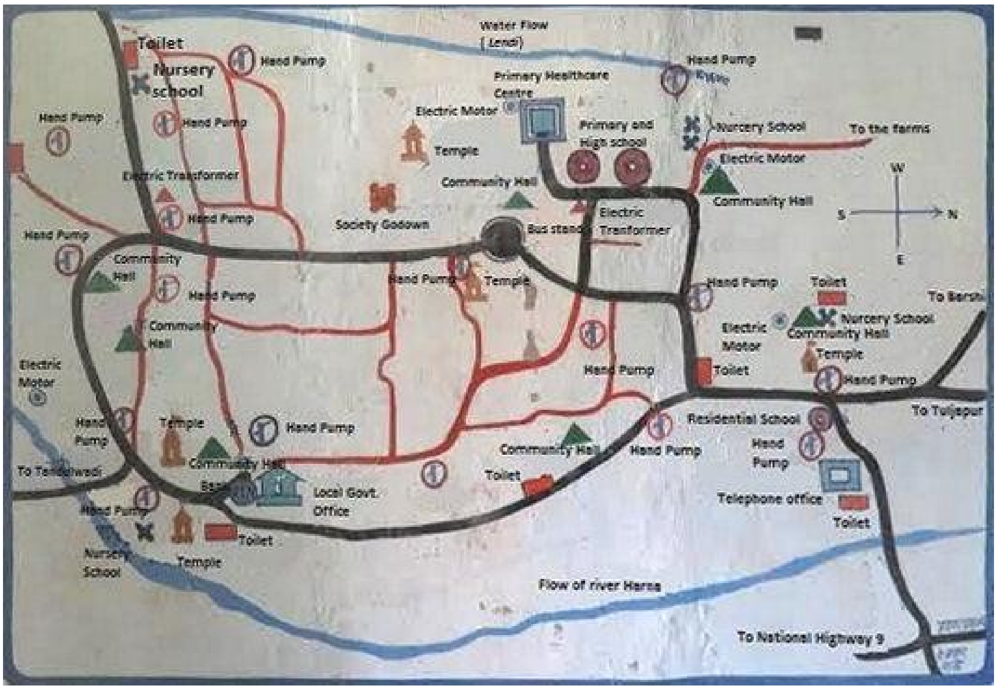


Fig. 2.1: Schematic map of Katgaon village drawn on the wall of Grampanchayat Office

Fig. 2.1 presents a schematic map of the village, supplied by the local office. During our staying, we visited some of these structures, evaluating their energy consumption, in particular the hospital (where there is a solar PV system and a solar thermal system installed by the Maharashtra Government), the primary and the high school and the Grampanchayat (Local Government Office).

Fig. 2.2: Solar PV system and solar collectors installed on the roof of Katgaon hospital

Around the village we can see an area electrified with the national grid, with a good availability of groundwater, and an area un-electrified and without ground water resources. The village has 455 hectares of cultivated land (bagayati) with water availability, about 140 hectares of land are used for grazing (gayran) and about 15 hectares are used for community purposes, as community land of the village (gavthan). Fields are cultivated by local farmers, who own their land; there are no large landlords. Land is distributed among family clans, that means that members of the same family cultivate neighbouring lots of land. For this reason most of the respondents have the same surname, as we limited our survey to a small area.

2.1.3 Water management

Water needs of the village are satisfied with groundwater resources: there is no running water, but there are two big tanks served by two electric motors, in which drinking water is stored, and 20 hand pumps distributed across the village. In the village there are no wastewater disposal systems.

Fig. 2.3: Water tank for the supply of drinking water to the village.
Fig. 2.4: Hand pump

2.1.4 Electricity supply

The village is connected to the national electric grid (Maharashtra State Electricity Board); there are two different grids, one for the village and one for the land. Electricity supply is not continuous, as the Electricity regulator, Maharashtra State Electricity Distribution Co. Ltd (MSEDCL), determines scheduled blackouts to balance out the infrastructural weakness of the grid and to reduce energy consumption. Blackout scheduling varies weekly and is communicated to Katgaon households by an agent of MSEDCL. In particular for the domestic supply there are 16 hours of electricity per day, for agriculture there are 8 hours of electricity per day and the supply time slot varies according to the following scheme:

1st week: 00.00-8.00

2nd week: 8.00-16.00

3rd week: 16.00-00.00

This power supply planning is not sufficient to guarantee system reliability. There are a lot of unscheduled blackouts during the day. We tried to measure the frequency and the duration of these blackouts in the fields and we came to the conclusion that there are only few blackouts in one day but they last for several hours. We used a simple software which detects if the computer is powered by the electric grid or if it uses the battery and registers these data. In the first visit to the village we connected the computer to the land grid during the period of planned electricity supply and we evaluated the reliability of the grid. The results of some measurements are shown in Table 2.1.

	N° BLACKOUTS	DURATION
06/11/2014	2	01:27:33
		00:02:50
07/11/2014	1	01:49:48
08/11/2014	No electricity at least from 8 AM to 12 AM	

Table 2.1: Measurement of frequency and duration of blackouts of national land grid taken with a specific software

Another problem that farmers have to face is the low voltage of the grid. This problem might have various causes: the excessive length of the grid, the inadequacy of the grid to the power needs of users and the under-sizing of transformers. The effect of this problem is that even when there is electricity from the grid, the pumps necessary for irrigation do not start because voltage is too low or, in case of sudden brown-out, the electric pump is damaged and need to be replaced.

2.2 Local data analysis

In order to obtain an accurate evaluation of the actual needs and the available resources of Katgaon, a careful assessment of the local situation was needed.

The purpose of our questionnaire (see Appendix A) was to gain information about the current needs of farmers in Katgaon and to build the basis for the Sanjeevani project.

The information collected through this questionnaire leads not only to an understanding of the factors that influence variations in the energy use pattern, but also becomes instrumental in assigning priorities for alternative uses of resources for energy and non-energy applications. [21]

2.2.1 Methodology

To draw up the questionnaire we wanted to submit to the farmers in Katgaon, we took some basic models found in literature and we adapted them to the Indian context. We organized face-to-face interviews because in literature it is evident that this is the method which delivers the most representative results.

In order to allow the investigator to collect the most accurate data from a target population, a questionnaire must be unbiased. Bias is a problem in the design and administration of the questionnaire. It is a result of an unanticipated communication gap between the investigator and respondents, which yields inaccurate results. It can arise from the way individual questions or questionnaire as a whole is designed and administered. To avoid these biases, [22], [23] and [24] suggest various steps while designing and administering the questionnaire. The words used in the questions should be simple, familiar and unambiguous to the target population. The length of the questionnaire should be short in order to avoid response fatigue and skipping questions tendencies. The investigator should be careful while designing and administering the questionnaire to avoid various types of biases. The investigator should pay attention towards the flow of questions. Questions on a same topic should be grouped together and transitional statements should be used to switch between different topics or sections. During the administration of questionnaire care should be taken to avoid respondents' conscious reaction (fake responses to seek sympathy), subconscious reaction (tendency of trying to be conservative), inaccurate recall, and cultural differences.

To obtain objective and quantitative data, we organized the questionnaire as multiple choice questions, while to make the questionnaire easily understandable by the Katgaon farmers we asked our local partners to translate the questionnaire in Marathi. The survey was conducted in local language (Marathi) for better understanding.

Prior to the survey, the questionnaire was pre-tested with subsets of the target population (few farmers from a representative village) to check aspects such as redundancy, missing information, relevancy as well as validity of the questions. The questionnaire was then modified on the base of pre-test results. The individuals included in pre-test were omitted from the sample considered in this study. [25]

2.2.2 Structure of the questionnaire

The questionnaire is divided in five parts and focuses on:

- Household characteristics: demographic information useful in assessing the family composition (number of members, responsible for the household) and economic aspects (income, main job);
- Characteristics of the area: information about cultivated land (size), livestock and water resources (availability, kind of resource, distance);
- Agricultural and livestock activities: information about products (productivity, season, size of area) and techniques (gmo seeds, installed pumps, irrigation system, presence of water storage, product conservation);
- Energy utilization for irrigation purposes: availability of electricity and other resources, assessment of energy needs;
- Energy utilization for domestic purposes: availability of electricity and other resources, assessment of energy needs for cooking, water heating and lighting;
- Market assessment: target market for agricultural products and profits from crops.

2.2.3 Submission

To select the interviewed households, we asked the local association Harnai to select a group of farmers cultivating nearby pieces of land in a defined area. During our field studies we succeeded in interviewing 15 farmers with the help of this association. The survey was conducted by getting directly in touch with the household; at least one of us was present during the interviews, and the interviews were conducted in local language (Marathi) by some members of Harnai. Whenever possible, we interviewed the person responsible for farming as he would best know the requested data; the interviewees had the possibility to confer with other family members in answering the questions.

Since we carried out our household survey while staying in the village, we could gain considerable insight in the habits, preferences, aspirations and lifestyle of the people; as a consequence we were able to draw some conclusions based on our own observations.

2.2.4 Description of the interviewed group

This paragraph presents a descriptive analysis of a selection of data collected through the questionnaire. The complete analysis of all the data is reported in Appendix B.

Due to the small size of our sample, this analysis is not intended to be a generalization of the global village conditions, but a simple evaluation of the target group in the pilot project. The names of the respondents are reported in Table 2.2. For convenience only, in the analysis of data every farmer is represented by a number.

Farmer n°	**Name**
1	Prakash Kumbhar
2	Pandurang Mali
3	Popat Mali
4	Mahadev Mali
5	Bhairavanath Maruti Mali
6	Dinesh Prabhu Hajare
7	Laxaman Nimba Hede
8	Mahadev Dagadu Mali
9	Matin Babu Patel
10	Tukaram Dashrath Mali
11	Padmini Mahavir Tivari
12	Suryakant Devrao Mehtre
13	Dattatray Balbheem Mali
14	Sudesh Prabhu Hajare
15	Arjun Uttan Mali

Table 2.2: Names of target farmers

Fig. 2.5: Position of the lands and of the wells of the target group. Picture reproduced from Google Earth

We localized the exact position of the land of each farmer using the GPS of our mobile phones and we asked the farmers to draw the boundaries of their land on a map. Then we compared the answers with the GPS position and the results are shown in Fig. 2.5. The red place marks on the map indicate the position of the wells of each farmer.

2.2.5 Household characteristics

In the first part of our analysis we tried to understand the demographic and economic characteristics of the households. Our local partner warned us of the low reliability of the economic data supplied by the farmers, who tend not to give exact figures for fear that they might have to pay government taxes.

The average household size is 7 members, with an equal presence of male and female. A household unit is considered to be composed of husband, wife, children and any other relatives or dependants residing within the household and eating from the same kitchen on a daily basis. Members of the family living away from the household for employment or any other reasons are not included.

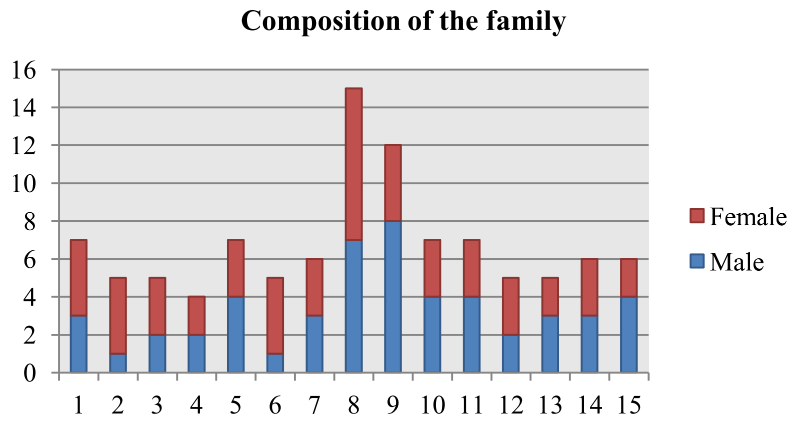


Fig. 2.6: Composition of the families of the target households

Only 3% of the respondents are not farmers and have a different job. The others base their livelihood on agriculture, working either in their own fields or as labourers for third farmers in case they do not own a piece of land or if the productivity of their land is too low for their sustenance. All the household members, except children, spend all the day in the field, from the morning till the evening, and carry out domestic activities early in the morning or late in the evening.

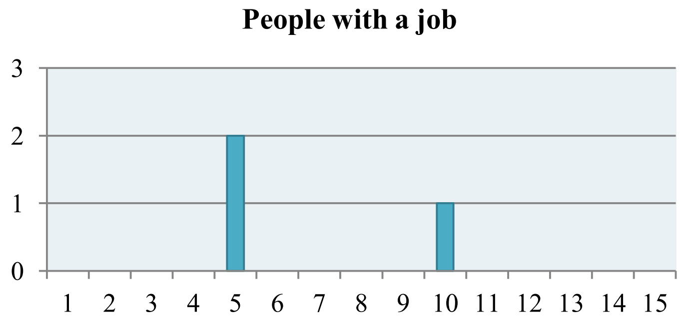


Fig. 2.7: Number of people with a job different from farming in the target group

As mentioned above, we cannot grant the accuracy of the economic data we collected. The average monthly household income results to be 26,000 Rs (about 300€), but there is a great variance among farmers: half of the respondents have an income lower than 100€ and one farmer has an income equal to six times the average. From later analysis we related these differences in the income to the different products cultivated by farmers: some particular products allow farmers to have good profits, as we will explain in the following section.

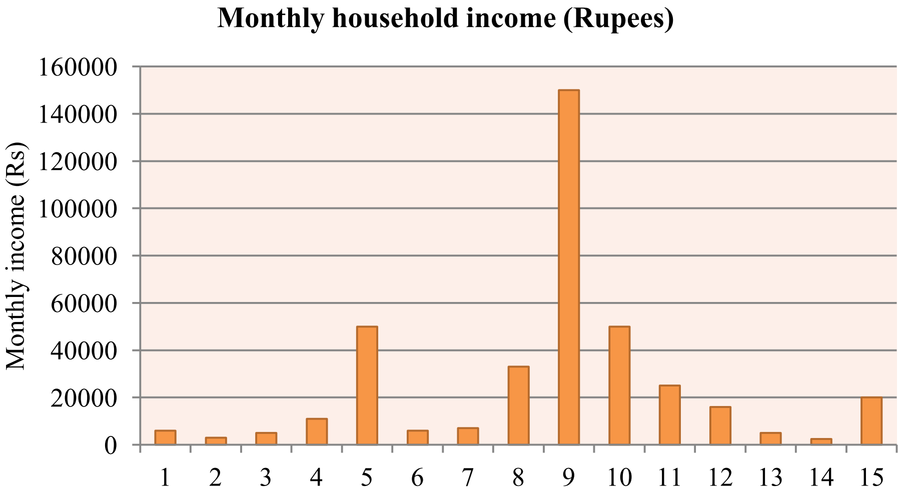


Fig. 2.8: Monthly household income of the selected household in Indian Rupees

2.2.6 Characteristics of the area and agricultural and livestock activities

In this part of the survey we investigated the size and the characteristics of cultivated land and we figured out some common aspects of agriculture in the village.

The size of each lot of land varies between 2 and 25 acres, with an average area of 9.5 acres. The differences are related to the wealth and to the history of the various families. Due to cultural practices and local traditions, land is divided among children from generation to generation. This leads to an increasing fragmentation, not compensated by an increase in productivity. The consequence is a lower income for each household. An important feature that comes out from the data collected is that some farmers are not even able to cultivate all the land they own because of their limited economic resources. Data clearly shows that for most of the farmers the areas cultivated changes according to the season. There are three different agricultural seasons: Rabi, Summer and Kharif. Rabi is the cool and dry season, lasting from October to March; Summer is the hot and dry season, lasting from March to June and not proper for agricultural activities; Kharif is the hot and wet season, characterized by the presence of frequent rainfalls and monsoons, lasting from

June to September. From one season to another farmers change the cultivated products and leave some lots uncultivated to preserve the quality of soil.

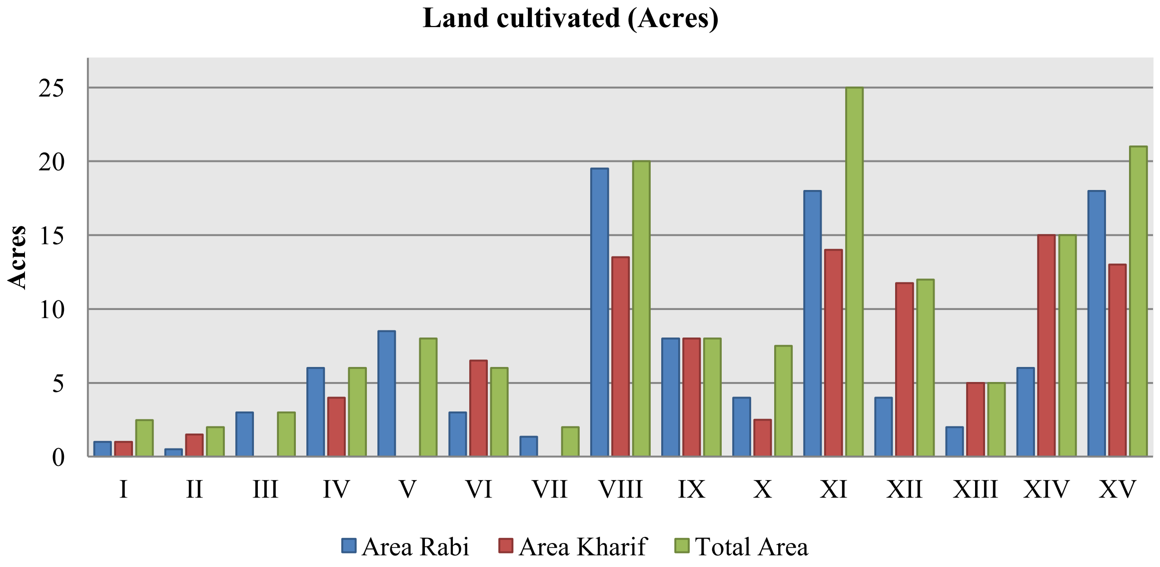


Fig. 2.9: Total area of the land owned by each farmer and areas cultivated during the Rabi and Kharif seasons

Livestock population of the group investigated is 62 units, of which 42% are buffalos, 29% are bulls, 13% are cows and the remaining are domestic animals such as cats and dogs. Farmers own on average 4 animals and only one of the respondents does not have any animal. In rural area livestock constitute a major component of traditional subsistence economy. [26] Buffalos and bulls are valued primarily for ploughing crop fields, cows for milk and their manure is utilized to produce fertilizers for the land or fuel for domestic usage. Milk production is only for self consumption and does not represent a cash income because the village of Katgaon, unlike many other Indian rural villages, does not have a dairy or a milk office. Livestock depend exclusively on grazing all over the year.

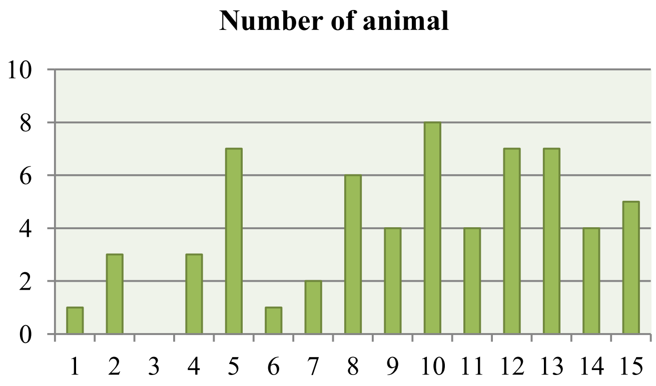


Fig. 2.10: Number of animals owned by each farmer

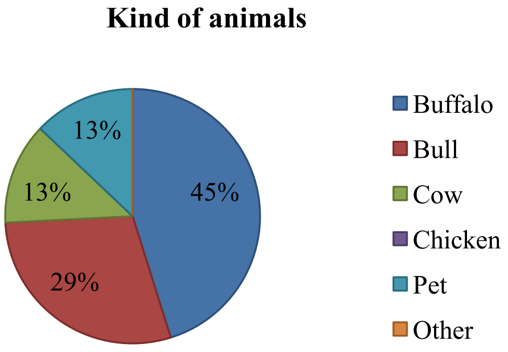


Fig. 2.11: Distribution of the kind of livestock

2.2.7 Description of the energy uses

The principal energy services utilized by households residing in rural agriculture-based settings in developing countries can be categorized into lighting, power for mobile phone recharging, other media and information technologies such as radio and television, cooking, heating, agro-processing and pumping. [27] A large part of the questionnaire was dedicated to energy usage. In particular we considered energy needs for agriculture and for domestic purposes because the fields and the village are served by two different electric grids.

All plots covered by our survey are connected to the national grid. In agriculture, electricity is mainly used to power the electric pumps used to irrigate the fields. In the Maharashtra State, the electricity tariff for agriculture is calculated on the basis of the total power installed in the land and not on the basis of the actual consumption. Electricity supply is limited to 8 hours per day and the time slot of the supply varies weekly. In the questionnaire we asked how often in a month the electricity supply does not match the irrigation needs: this happens at least on 15 days in a month. Farmers reported also that for different reasons (blackouts, low voltage, ...) the electric supply is not enough to satisfy their needs, particularly in the dry Rabi season. This has a great impact on land productivity and on the capability of having good profits from crops. Other energy uses in the agricultural sector are then related to the usage of diesel pumps, instead of electric, and on the usage of diesel as fuel to feed tractors to plough and till the land. Anyway energy consume for these processes is marginal.

A more detailed analysis of the energy needs for agriculture can be found in Chapter 4, since, according to Sanjeevani project objective, the solutions studied in our work are tailored for irrigation needs of the farmers, as it will be discussed in Chapter 3. Now we analyze in more detail the domestic needs.

Focus on domestic needs

At domestic level we considered different types of energy usage which are as follows:

- Cooking;
- Water heating;
- Lighting;
- Other appliances.

We neglected domestic space heating, which is not necessary because of comfortable climatic conditions. Before reporting the data obtained for different domestic uses, we report two relevant aspects.

All farmers interviewed, except one, are connected to the national electric grid. This figure is not surprising because during our visit we saw an extensive electric grid that covers much of the village. Despite of this, according to our information, a considerable group of people in Katgaon are not connected to the grid and some of them illegally take electricity from the grid.

Another interesting aspect is that even if the local government schedules 16 hours a day of electric supply, only one of the selected households has a system of batteries which allows them to store electricity and to use it also during the scheduled blackouts. In the 8 hours (at least) of blackout, all other farmers have to find out alternative solutions to compensate for the lack of electricity.

Electricity is mainly used to charge phones, watch TV, ventilate rooms with ceiling fans, refrigerate food and lighting. As for all other domestic energy needs, rural households in India have to rely on locally available biomass resources, consisting mainly of wood fuels, agricultural residues and cattle dung. Despite modern fuels like kerosene, diesel and electricity are also used in the village, their usage is limited and depends on their availability and on the household's ability to buy or gather them. [28]

Cooking

In Katgaon farmers use different types of fuel for cooking, according to their economic possibilities and to the technologies at their disposal: wood for the totality of farmers, LPG for 67%, cow dung for 47% and kerosene for 40%. The detailed results are reported in Table 2.3.

Main fuel for cooking		
Type	**number of household**	**%**
LPG	10	67%
Electricity	1	7%
Wood	15	100%
Paraffin	0	0%
Charcoal	0	0%
Gas	0	0%
Dung	7	47%
Kerosene	6	40%

Table 2.3: Share of fuels for cooking purpose used by the selected households

The common use of dung or kerosene is related to the fact that they catch fire easily. Dung is first sun-dried and subsequently used, such as kerosene, to start and accelerate the process of combustion of wood.

Only 18% of fuel wood is purchased. It is sold at the local market during the monsoon season, when dry wood is not available. We asked farmers the amount of wood they use on monthly basis, but not all the farmers were able to answer this question. From collected data it results that, on average, farmers consume about 1.3 ton of wood per year for cooking purposes. The wood price at the local market results to be 2,000 Rs/ton.

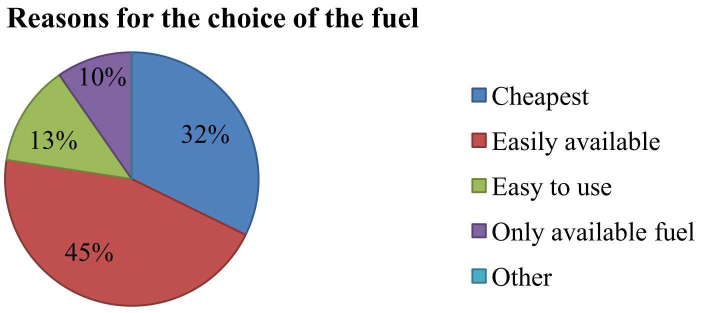


Fig. 2.12: Reasons behind the different choices of the fuel used for cooking purpose

We also investigated the reasons behind the fuel choice and we obtained the results of Fig. 2.12.

Most of the farmers base their choice on the easily availability or affordability of the fuel (more than 75%). Instead for 10% of our group there is no fuel choice. Only for 13% of the group the choice is related to the fact that it is easy to use.

Another factor taken into consideration is the cooking method. It has an impact on both energy efficiency and on the health of people who cook or are in the surrounding. Most households in the village do not have access to modern technologies for cooking and rely on traditional biomass appliances. Biomass cook stoves are common in households throughout the developing world but they have significant health, safety, and environmental consequences. [29]

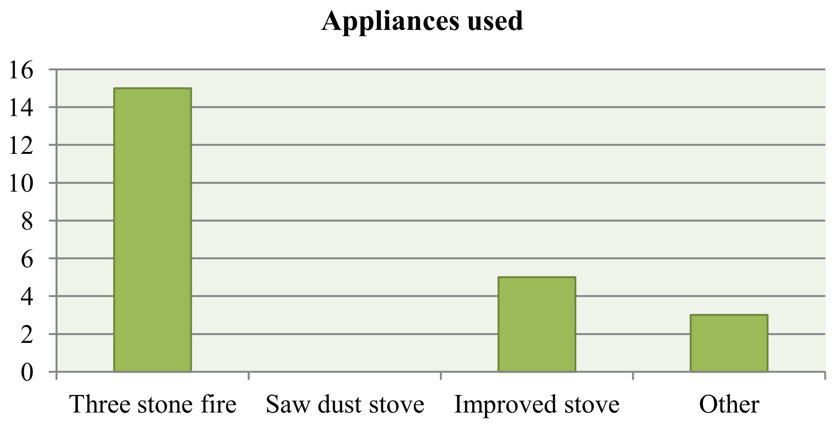


Fig. 2.13: Cooking appliances used in the target group

The most widespread appliance in the village is the three stone fire and only 30% of farmers owns improved stoves working with LPG or kerosene. Even if many studies demonstrate that cooking with biomass using a traditional three-stone fire is a major cause of indoor air pollution and respiratory problems and farmers are aware of these effects [27] often this is the only available choice for the households.

Water heating

Concerning water heating, we analyzed the same data that we evaluated for cooking. This includes the type of fuel used, the quantity and also the number of people in the family that use hot water to wash.

About the type of fuel used, wood is nearly the only type of fuel used and only few farmers rely on resistors. Data obtained are shown in Fig. 2.14

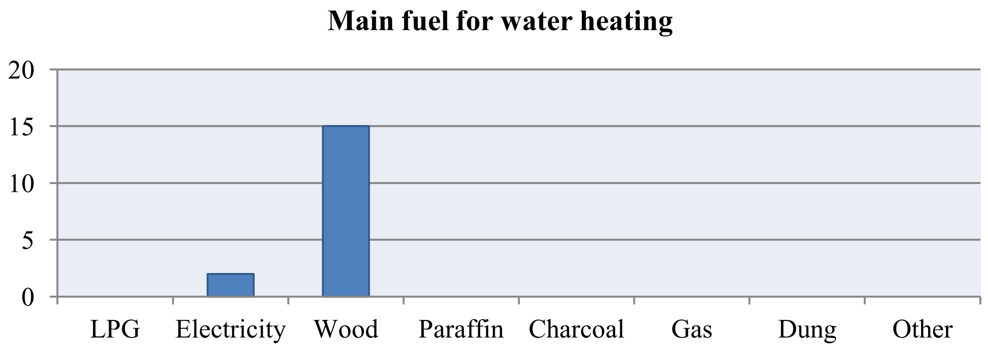


Fig. 2.14: Fuels used for water heating

The reasons for the fuel choice are reported in Fig. 2.15. They are similar to the previous case.

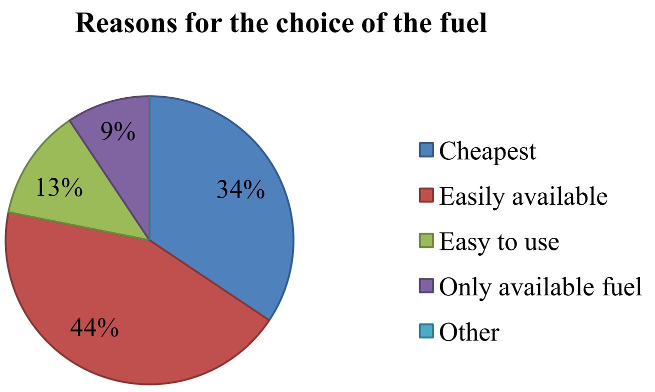


Fig. 2.15: Reasons behind the different choices of the fuel used for water heating

As mentioned above, we also obtained data about the number of people using hot water. The results are presented in Fig. 2.16.

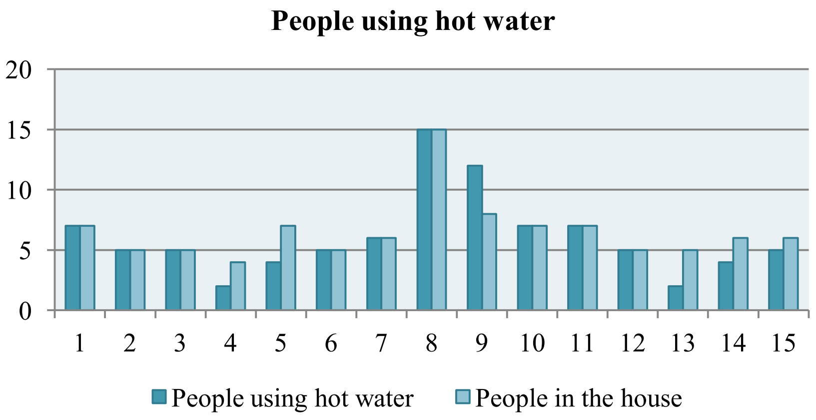


Fig. 2.16: Number of family members which use hot water for washing

In one third of the families the number of people using hot water does not exceed 60%, reaching in some cases a value of 40%. In the family of the farmer 9, instead, it is the opposite because they allow also labourers of the farm to use hot water for washing.

Lighting

Also for the lighting the same analysis was carried out. About the type of fuel used, these are the results:

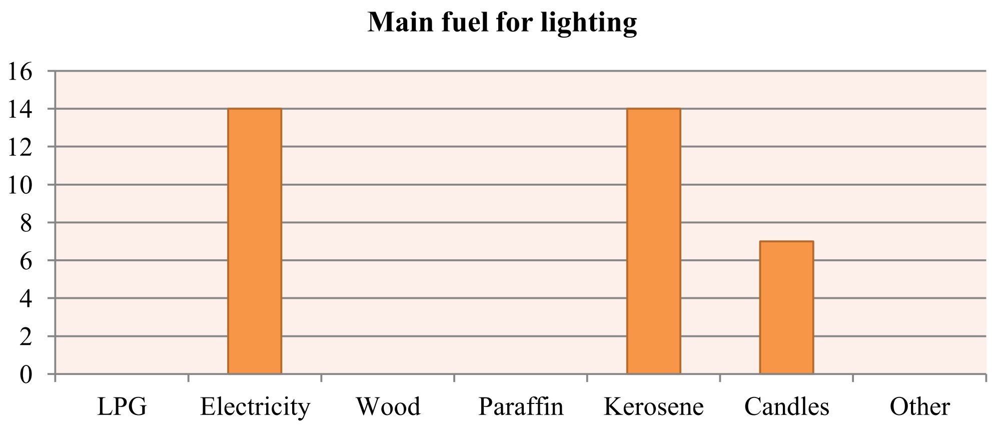


Fig. 2.17: Main fuels used for lighting purpose

As seen from the graph in Fig. 2.17, candles, kerosene and electricity from the grid are used for lighting. The numbers confirm what we saw during our experience at the village: when it is available, farmers use electricity, while during blackout periods most households (91%) use kerosene for domestic lighting. This is due to local government energy policies, according to which each household has right to 2 litres of free kerosene per month.

Other appliances

For a full analysis, we surveyed the target group to see whether they have domestic appliances and evaluate their demand of electricity for domestic purposes.

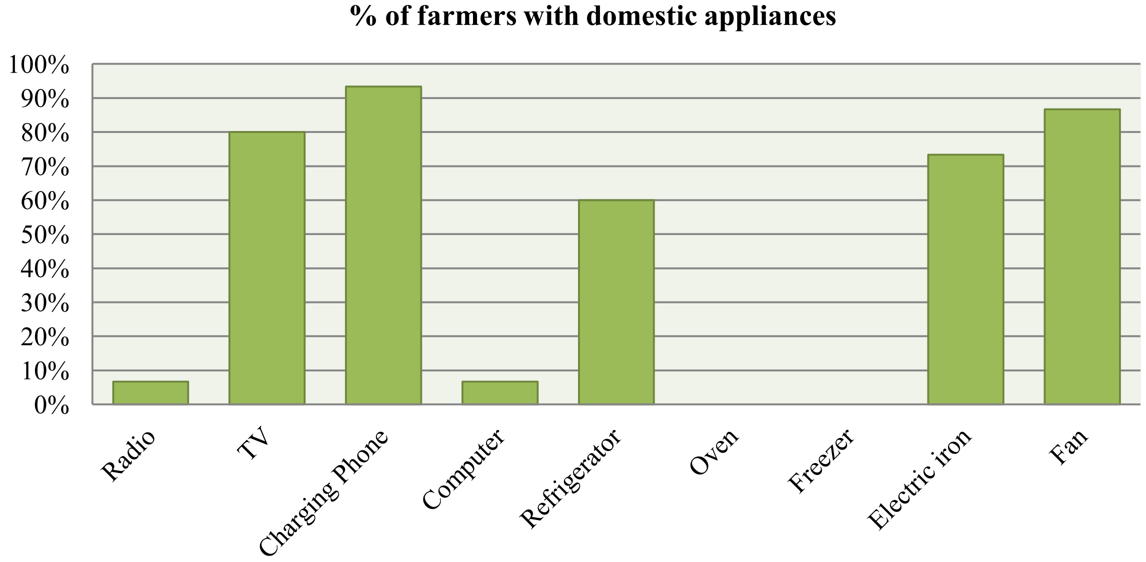


Fig. 2.18: Percentage of farmers which own each domestic appliance

Most farmers own TV (80%), mobile phones (93%), electric irons (73%) and fans. 60% of them owns a refrigerator, which is the appliance with the strongest impact on energy consumption. The oven is not used mainly because Indian cuisine does not entail the use of the oven. Instead, the freezer is not necessary because households live on agriculture and they consume fresh food freshly picked. Because of the high temperatures present throughout the year, 87% of households surveyed has in the house at least one fan.

2.3 Agricultural characteristics in Katgaon

This paragraph focuses on the agricultural pattern employed in Katgaon. Its purpose is to evaluate the energy needs for agricultural usage, in particular pumping and irrigating, as they remain largely unsatisfied. Sustainable agricultural development and food security remains a key focus area for India, considering that nearly 70% of population live in rural areas. Farmland is fast shrinking in size, but given the fact that the largest share of employment still continues to be in the agricultural sector, this negative trend has major repercussions from the viewpoints of poverty and inequality. Agriculture is the mainstay of livelihood in this area, but usage of traditional methods, lack of proper irrigation facilities and use of GM seeds, lead to lower yields, causing a “forced” migration to the nearby urban centres. Small farms are typically characterized by smaller applications of capital and land augmenting techniques. They also need to put in more human labour and to cut as much as possible the costs to become competitive to larger farmers and to succeed in sustaining their family. [30]

2.3.1 Main products

Agriculture is the main activity in the state of Maharashtra. Both food crops and cash crops grow in this state and the different regions are characterized by a particular product. The main food crops are mangoes, grapes, bananas, oranges, wheat, rice, jowar, bajra and pulses. Cash crops include groundnut, cotton, sugarcane, turmeric and tobacco. The region of Katgaon is characterized by large sugarcane fields. In Maharashtra the year is divided in two main agricultural seasons: Kharif (hot wet season), lasting from June to October, and Rabi (cool dry season) from October to March. The hottest season is called Summer and in this season fields are not cultivated.

Katagon's agriculture is characterized by small landholdings and the majority of the farmers practice subsistence agriculture. Farmers live in very poor conditions and cannot afford the cost of adopting new technologies and irrigation systems nor increase their production. Further, since rain-fed varieties grow only once in a year, the agricultural production is limited only to half the capacity. A positive aspect of agriculture in Katgaon is that farmers try to differentiate their production: they tend to cultivate different products both for selling and for self consumption. According to the collected data every farmer cultivates on average 5 different products.

Cultivated crops can be divided in two groups: the yearly crops and the seasonal crops. Yearly crops, mainly sugarcane and grapes, are intended for sale, while seasonal crops, more various, are intended for self consumption and for sale. The pie chart in Fig. 2.19 shows that sugarcane accounts for 89% of the total productivity: this crop allows good earnings, but requires also a big amount of water. Another yearly crop which allows good profits is grape, but it is more difficult to cultivate and its diffusion is limited. Other common crops are onions, soya and jowar. They present some advantages, among which easy storage and long-life after harvest.

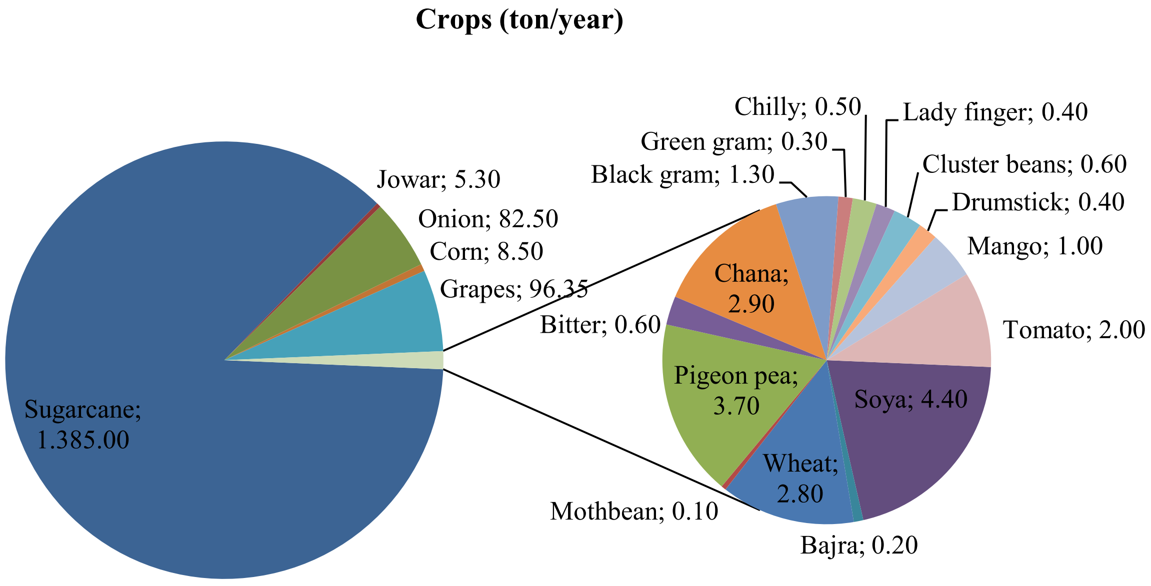


Fig. 2.19: Productivity of crops of the target group in ton/yr

Being the cultivable area limited, the focus should be on enhancing the crop yield or productivity. However, it has been observed that the productivity is high only for large and medium landholdings with access to irrigation facilities, remaining low for small and marginal ones. A study conducted by the World Bank [31] suggests that there are multiple reasons behind the low productivity in agricultural sector. One of the main reasons is the large number of agricultural subsidies that has in fact reduced the productivity, enhancing investments. The technologies for improved and sustained food production are used to a limited extent. A widespread knowledge of such technologies is also missing. The main reasons for these impediments are high costs, illiteracy, slow progress in implementing land reforms, inadequate or inefficient finance and marketing services for farm produce, and impracticality in the case of small landholdings. [32]

2.3.2 Water pumping and irrigation systems

Groundwater is a major source for irrigation and drinking water supply in India. The present contribution of groundwater to irrigation is about 50% in terms of area whereas 80% of the rural domestic water supply is met with groundwater. At present, the level of groundwater exploitation is about 30% of the existing potential. For irrigation purposes, 40% of the water is lifted by traditional means (i.e. human/animal power) and the rest is lifted by diesel and electric pump sets. Irrigation water pumping is then an important direct commercial energy end use in Indian agriculture, jointly with land. Diesel and electricity are commonly used for meeting irrigation energy demand in the country. [33]

In Katgaon, an important source of water for irrigations is the surface water, which is usually the cheapest option. Farmers with access to sufficient surface water for irrigation may not choose any other option.

All the farmers selected have water resources in their land or nearby and are able to use them. In particular both surface water (open well) and groundwater at various depth (bore well) are available. There is also a canal, along the borders of the fields, where water flows in the period of the year when the level of the nearby lake is sufficiently high.

Fig. 2.20: Examples of open well and channel for irrigation

Whilst in the Kharif season there is enough water to irrigate the cultivated fields, in the Rabi season plenty of farmers (most of them rely on surface water) complain about the lack of water due to climatic conditions. Water is lifted out of wells mainly with electric pumps connected to the national grid; only two farmers own a diesel pump and the share of power of diesel pumps is 10% of the total power installed for irrigation. Diesel pumps are powered up only in the period with blackouts of the national grid, but their presence has a significant impact on productivity: they allow to irrigate the land whenever needed and to obtain more abundant crops of superior quality. This impact on quality and productivity is not reflected in the same way on profits, because the expenses for fuel and maintenance of the diesel generator are significant. Crop productivity and the amount of energy required for irrigation depend also on the irrigation techniques used by farmers. All the farmers use traditional methods for irrigation, canals or pipes, which require a big amount of water and relevant energy consumption. Some farmers, in addition to this, use also modern techniques to irrigate in particular drip irrigation (37.5%) and sprinklers (19%). These techniques require a relevant initial investment, but bring to an increase in yield, to a reduction of the size of the prime mover and to smaller energy consumption. [34]

Fig. 2.21: In these photos the difference in the quality of crops irrigated with continuity thanks to a diesel pump (photo on the left) and in an intermittent way with a pump connected to the electric grid (photo on the right) is evident

2.3.3 Market assessment

Generally farmers do not have a direct access to the markets. As a matter of fact, except a small local weekly market, markets take place in the big cities (Solapur, Pune) which are not easily and quickly accessible for farmers. In addition, in the market of Katgaon there are not local farmers as sellers, but people coming from Solapur with products which are not cultivated in the village. Due to the absence of direct sales channel, farmers rely on commercial intermediaries (middlemen) which buy their products in the village at a price significantly lower than the effective market price, and bring them to the big markets. In this way a large share of farm profits is taken by these middlemen, and farmers cannot improve their condition and get out of poverty.

Sugarcane has a separate market and ensures certain profit to farmers: in 1954 the Indian state encouraged the establishment of sugar factories in the Maharashtra state through a policy of subsidies and tax deductions. This is the reason for which sugarcane is the main cultivated product. For the harvesting and the transport there is a dedicated state-owned union, which collects the product directly on the fields and transports it to the nearby sugar factories.

Chapter 3: Problem analysis and strategy selection

In this chapter we want to explain with a schematic process the methodology we used for the project preparation and which brought to the definition of the project goals. Before the formulation of the operational technical project it is necessary to understand the context, to know the involved stakeholders and to analyze all the problems and the possible solutions.

For this purpose, we used the Process Cycle Management (PCM), which is a useful way to describe schematically the context and to achieve sustainable solutions. PCM provides an overall analytical framework which involves management activities and decision making procedures used during the life-cycle of a project.

3.1 Stakeholder analysis

The stakeholder analysis is fundamental to identify and specify the stakeholders involved in the project. Through the stakeholder analysis it is possible to analyze their interests and the power relationships between them, to anticipate the influence, positive or negative, these groups will have, to develop strategies to get the most effective support and to reduce any obstacle to successful implementation. Only when stakeholders' real interest is identified, they can be sufficiently empowered during the project. [35]

Beneficiaries

The target group of the pilot project is composed of the 15 interviewed farmers. They are characterized by different income, family composition and farming methods, but all of them base their livelihood on agriculture and face the same problems: the difficulty in cultivating due to the inadequacy of the electric national grid and the low revenues from crops. The lack of electricity due to scheduled and unscheduled blackouts and to low voltage problems does not allow a proper irrigation of the crops with bad effects on the productivity and on the quality of the products.

Aim of the project is to create a sustainable economical and financial productive system, providing a reliable electric supply to these farmers and preventing them from getting into debts and committing suicide. For this reason, they have a great interest in this project but, as seen in paragraph 2.3.1, most of them do not have the financial ability to bear the costs of an alternative energy supply. Keeping them informed on the progress and involving them in some activities of the decision making phase is fundamental for the long-term sustainability of the project.

Local community

The local community includes all the households of Katgaon. Most of them are farmers which rely only on agricultural activities and are in the same situation as the selected farmers. Also they are affected by electric and economic problems, which prevent them to escape from poverty. They are not directly affected by the project at this stage, but their exclusion could result in lack of interest and low participation. To avoid this effect, it is important to make them understand the importance of a first testing phase which allows a better understanding of the impact of the project and a further improvement of the selected solution.

Harnai

Harnai is an association composed of farmers or sons of farmers in the village of Katgaon. Some Harnai members coincide with the interviewed farmers or are related to them in some way. This association is our local partner and helps us during all the phases of our project. Since they live in the village, they are aware of farmers' problems and condition experiencing directly the difficulties faced by farmers and their families. Only few members of Harnai can speak and understand English and for this reason communication with this partner could be difficult. Harnai members have no technical skills, but their role is fundamental to get in touch with local households and gain their confidence, because they already belong to the local community and know the local language. Moreover they have great knowledge about agriculture and traditional farming techniques. They are willing to give also an economic contribution to the project, according to their possibilities. The success of the project will improve their reputation and the importance of the association in the village.

ProCluster Business Association

ProCluster Business Association is our local partner in the city of Pune. ProCluster is a business association serving the nation by contributing to technological, economical and industrial growth and promoting entrepreneurship [36]. It is a no profit association socially active for the support of projects which aim to improve Indian farmers' condition. They hosted us during our mission and gave us all the needed support. The Managing director is an Indian, coming from a rural village in Maharashtra, who studied in Italy for 4 years, started the project in Milan and then went back to India. He has a strong personal interest in the success of the project, both for personal and human reasons, and for the interest of his company.

Maharashtra State Electricity Distribution Co. Ltd (MSEDCL)

This company is responsible for the distribution of electricity in the state of Maharashtra, except for Mumbai area. The policy of the company is to balance the structural weakness of the national grid and the fast increasing energy consumption introducing a scheduled timing for power supply in different regions and for different purposes. However, this measure is not sufficient to guarantee a reliable power supply. Farmers experience daily unscheduled blackouts and repeated low voltage problems. Another problem that this company has to face is the problem of illegal connection to the grid, which means that farmers who cannot afford the cost of electric bill connect to the grid with artisanal systems (see Fig. 3.1). This represents a great risk for the safety of farmers and causes further problems to the already overloaded national grid. During a meeting with Sudhakar Mali, the manager of the electric office of the district, he underlined that about 10% of the households are connected to the grid illegally and this share rises to 50% in the lands.

Fig. 3.1: Example of illegal connection to the electric grid

Our project could affect their interests both in a positive and in a negative way. The power supply through other energy sources, different from the national grid, will cause a reduction of illegal connections and of the load that the grid has to satisfy but, at the same time, it could cause also a reduction of the company's revenue if farmers adopt a stand-alone plant. It is however very likely that this big company would not be affected by this small scale project.

Indian government

The problem of farmers' suicides is a big issue for the Indian government, in particular because of the increasing dimension of this phenomenon. It causes great concern about public image. In the past, the government tried to implement some solutions to face the problem, but often these solutions did not have effect or had a negative one [2]. Also nowadays the government is adopting some measures to stop the suicides, in particular measures of economic support, which do not face the real roots of the problem and provide only a temporary relief to farmers' households. There is also a great disillusion from farmers with the role of the government and with its willingness to support them. We could stress the importance of our project for the prevention of suicides problem and consider the government as a possible donor. A participation of the government in the project would put it in a good light and increase the trust of farmers in the public authorities.

Possible donors

Finding financial resources is fundamental for the implementation and the success of the project. For this reason we should consider also the role of potential donors in our project. We could distinguish two categories of donors: public institutions and private donors. Public institutions (i.e. World Bank) could be interested in the project for its social relevance. To access to the funding from these agencies often it is necessary to participate to a public call. Private donors could be interested in the advantages, from the point of view of image, which could derive by their participation in the project and in possible revenues. They usually have a business approach, but if we succeed in catching their interest, it is easier to obtain funding.

Engineering Without Borders Milano

Engineers Without Borders Milano (Ingegneria senza frontiere Milano) is a no profit association based on the intergenerational partnership among professionals and young people with a scientific background with the aim to promote the realization of a sustainable development. EWB collaborates to Sanjeevani project from the beginning, in particular making the scientific and technological knowledge available to the local partner and looking for possible donors for the project.

Stakeholder map

We now summarize the understanding we have gained on the stakeholder map. We group all the stakeholders in a map which represents their priorities and their relative power and capacity to take part in the project. Not all the stakeholders have the power either to block or advance the project, some may be interested in what we are doing, while others may not care at all. We should take the appropriate actions to promote stakeholders' ownership and participation at all the levels of the project as well as to ensure that resources are appropriately targeted to meet fair objectives and the needs of priority groups.

We can recognize four different groups of stakeholders and represent them as in Fig. 3.2:

- High power, interested people: these people should be fully engaged in the project and their interests have to be satisfied.

- High power, less interested people: they should be kept satisfied, but we should not insist with them so much that they become bored with our project.
- Low power, interested people: these people should be adequately informed and we should talk to them to ensure that no major issues are arising. These people can often be very helpful with the detail of the project.
- Low power, less interested people: we should monitor these people, but not bore them with excessive communication.

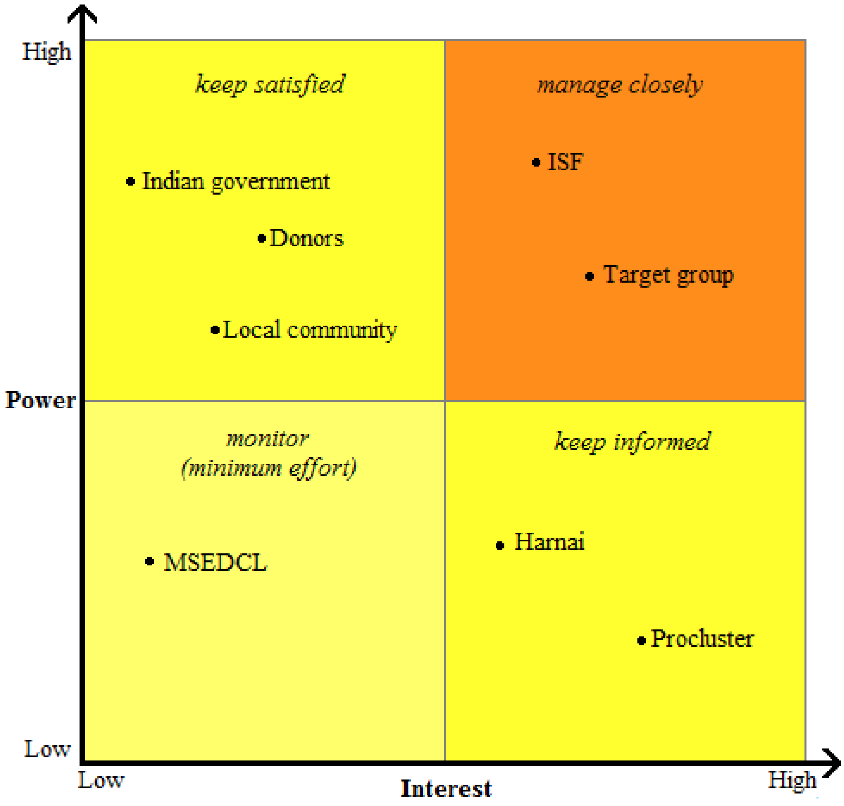


Fig. 3.2: Stakeholder map

3.2 Problem tree

During our first visit to Katgaon we analysed the main problems in the village with the aim to understand where and how to intervene to improve the farmers conditions. We established the cause and effect relationships between the identified problems and represented our results in a problem tree. The tree in Fig. 3.3 has the purpose of describing the aforesaid.

As highlighted in the tree, during our visits to Katgaon we identified the difficult living conditions of farmers as the starting problem. This problem affects the life of farmers in multiple ways: because of poverty malnutrition is common in Katgaon households and the mortality is high. Often these conditions lead to depression and/or psychological problems that could culminate in suicide. In looking for a better life, many farmers decide to migrate to the cities with the hope to find an employment that would allow them to support the family financially and to improve their conditions.

We recognized three main causes for the difficult living condition of farmers. The first cause is related to the domestic aspect. Farmers' houses are characterized by the presence of traditional cooking appliances which are not efficient, producing smoke and ashes with concern for the health of family members. Finding animals, like goats and stray dogs, in the house is common, especially during meals. In the village there is neither running water nor a system of wastewater disposal. These aspects bring to inadequate sanitary conditions. Another aspect which makes the domestic condition worse is the lack of electricity, or its discontinuous supply, due to the poverty of farmers or to the inadequacy of electric grid.

The economic straits that farmers have to face are the second cause for their difficult living conditions. Often profits from crops sale are too low to support the financial cycle of the family. Low profits are due to a low productivity of the land, but also to low prices at the market. Farmers usually do not sell directly their products to the market and rely on the intermediation of middleman. Since farmers do not have information about the current prices of crops, they have to accept the middlemen offers, which are really lower than the real prices. When farmers cannot sustain their expenses they have to ask banks or friends for credit, but frequently they are not able to obtain the money (especially from banks). Even if profits from crops are good, they are just sufficient to cover the costs for family sustenance or to solve debts and cannot be invested in other remunerative ways.

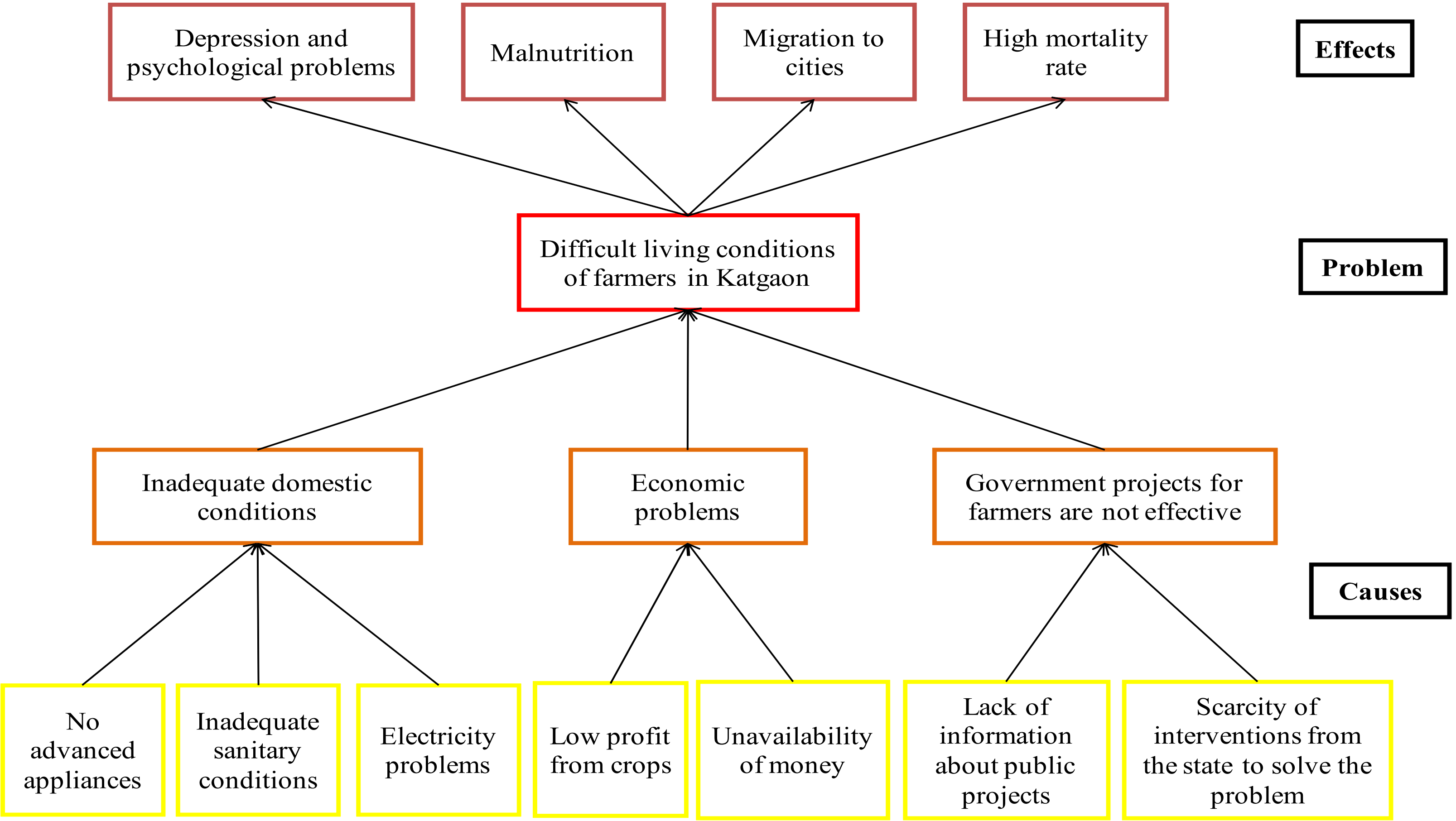


Fig. 3.3: Problem tree which represents the main problem (in red) related to the other problem with cause-effects relationships. The causes of the problem are represented below the main problem and the effects are represented above.

Indian government has been implementing some projects for the improvement of farmers' conditions since some years. Despite this, projects are often not effective and we recognize this as a third cause for the difficult living condition of farmers. The not effectiveness of these projects is due to two main reasons: there is a lack of awareness of these projects in the rural area (to which the projects are addressed) and the available resources for these projects and the real willingness of intervention are too small for the real dimension of the problem at a national level.

From this problem tree, an objective tree has been developed, that mirrors the problems described above.

3.3 Objective tree

Starting from the problem tree, we use the methodological approach of objectives analysis to describe the situation once identified problems have been solved. Converting the negative situations of the problem tree into positive achievement to obtain, a means-end relationship between the project objectives is highlighted. We obtained the objective tree represented in Fig. 3.4 which allowed us to identify the main objectives for the resolution of the above problems.

The achievement of an improvement in the living conditions of farmers in Katgaon can be obtained operating on the three dimensions above mentioned: the domestic one, the economic one and the effectiveness of governmental projects in rural areas.

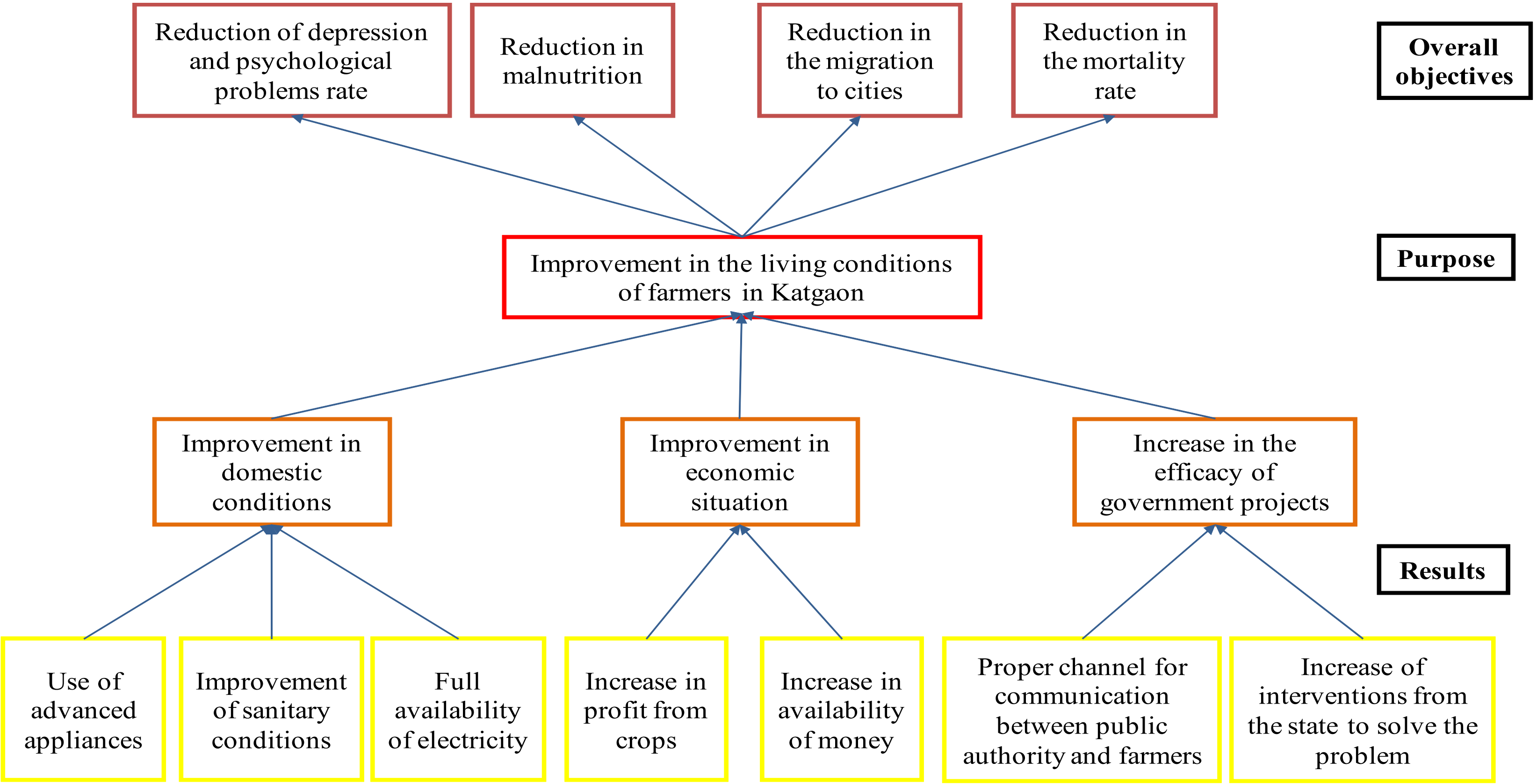


Fig. 3.4: Objective tree obtained turning the problem tree into the positive effects we want to achieve.
The purpose can be obtained through the achievement of the results below and it will contribute to the achievement of the overall objectives.

Acting on the domestic conditions means to ensure the access to modern cooking technologies for the farmers' households, to achieve an improvement in the sanitary conditions and to succeed in the supply of continuous electricity to farmers houses. Despite of this, an intervention only on the domestic conditions will not allow to achieve in a proper way the purpose. If farmers are not able to sustain their families financially, they probably cannot maintain the improvement of the domestic conditions. The effectiveness of governmental projects is a result that could help for the achieving of the other results, granting the governmental support to our actions.

The achievement of all these objectives would lead to the resolution of the main problems of the village. Despite of this it is utopian to think to solve all the problems of the village with a single action, because multidisciplinary knowledge and a huge economic cost are required.

3.4 Strategy analysis

For the aforesaid reason, our work intervenes only on the economic problems, as shown in Fig. 3.5, without considering the domestic conditions and the inefficiency of governmental projects.

This is the aspect that will impact most positively the needs of the farmers and that could offer good opportunities for a future improvement of the other not solved problems.

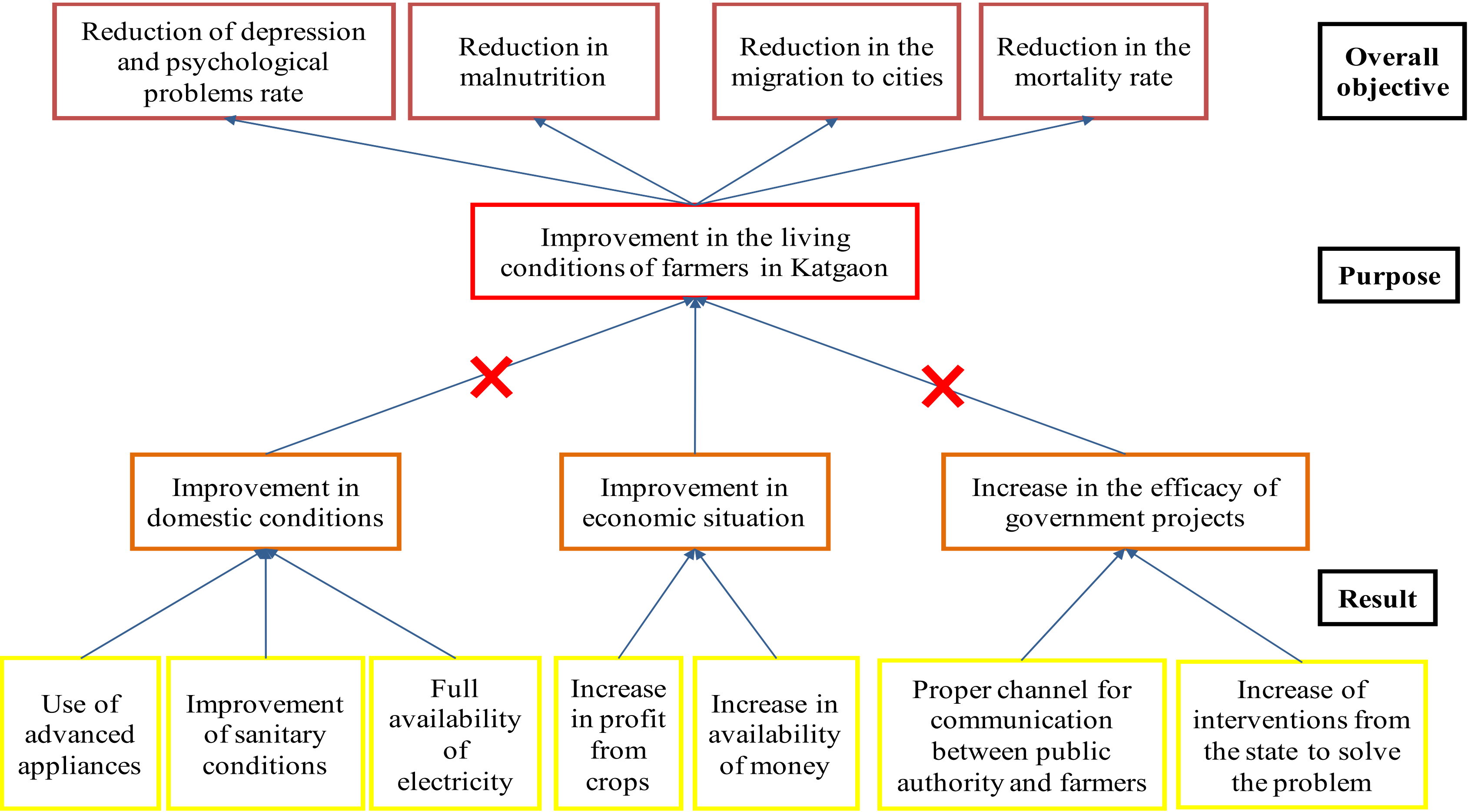


Fig. 3.5: Strategy analysis: the project focuses on the improvement of the economic situation without considering the domestic aspect and the efficacy of government projects

Within the project the contribution of this thesis is restricted to those results, which are related to our specific engineering skills, in particular to the solution of irrigation problems. For the planning of our project we focused only on some branches of the global objective tree; they are showed in Fig. 3.6. The purpose of our intervention became obtaining an improvement in the economic situation with two main results: an increase in profit from crops and in the availability of money. The related activities involve two different aspects: an energy aspect and an economic one.

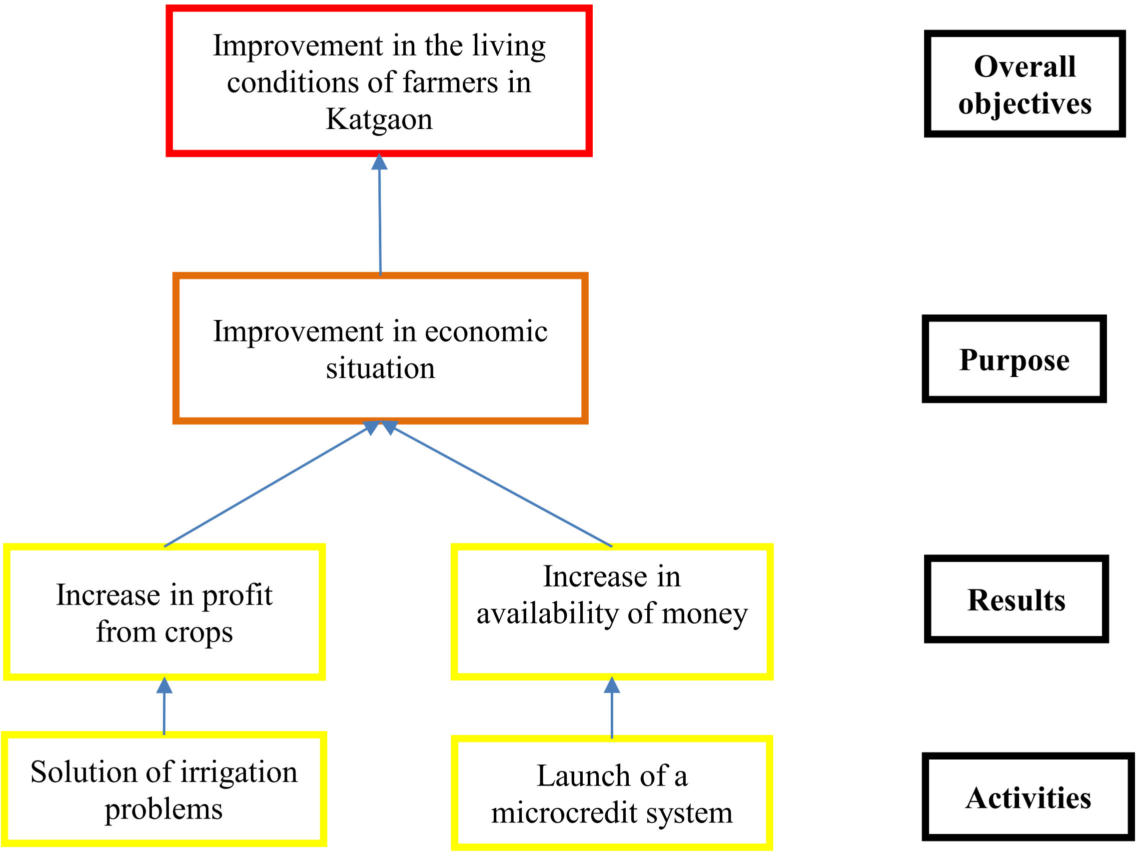


Fig. 3.6: Strategy selection: part of the global tree taken into account for the thesis

The results of the analysis of stakeholders, problems, objectives and strategy have been used for preparing the Logical Framework Matrix (LFM), which provides a summary of the project design. The LFM is reported in Table 3.1.

	Intervention logic	**Indicators**	**Sources of verification**	**Assumptions**
Overall objective	*Improve the living conditions of farmers in Katgaon*	-Annual rate of reduction of dissatisfied people -Annual rate of reduction of migration from village	-Data collected through periodic surveys conducted by Harnai -Data collected in the local office by Harnai	
Purpose	*Improve the economic situation of farmers. in Katgaon*	-Number of farmers who buy new appliances for domestic use -Number of farmers who invest money in agriculture	-Data collected through periodic surveys conducted by Harnai	-The economic improvement brings to improvement in the social and domestic conditions -The project has a great impact at village level
Results	*Increase profit from crops*	-Annual rate of variation of farmer profits	-Data collected through periodic surveys conducted by Harnai	-Farmers use profits in an effective way -The impact of electricity costs and taxes does not increase -There is crop demand in local markets
	Increase availability of money	-Annual rate of reduction of loan demand	-Data collected by Harnai from the local bank and from the Solapur bank	-Farmers use money for improvement in productive system -Since farmers have more money, they start to manage money in a proper way -The inflation rate does not increase

Activities	*Supply electricity for irrigation to farmers*			-Farmers use the power plant in a correct way -O&M operations are carried out as necessary -The power plant keeps working for all the period of the project -There are good rains, and there is no water shortage
	Develop a local microcredit system for farmers			-Local money lender do not oppose to the microcredit system -Farmers accept and use the microcredit system

Table 3.1: Logical framework matrix

The goal of our work, therefore, is to improve the economic conditions by focusing mainly on increasing the profit from the sale of products.

To get a deeper insight into the question, during our visit we analyzed in a more detailed way the above problem to be able to understand its causes. A focus of the problem tree for the irrigation problem helps to understand these causes.

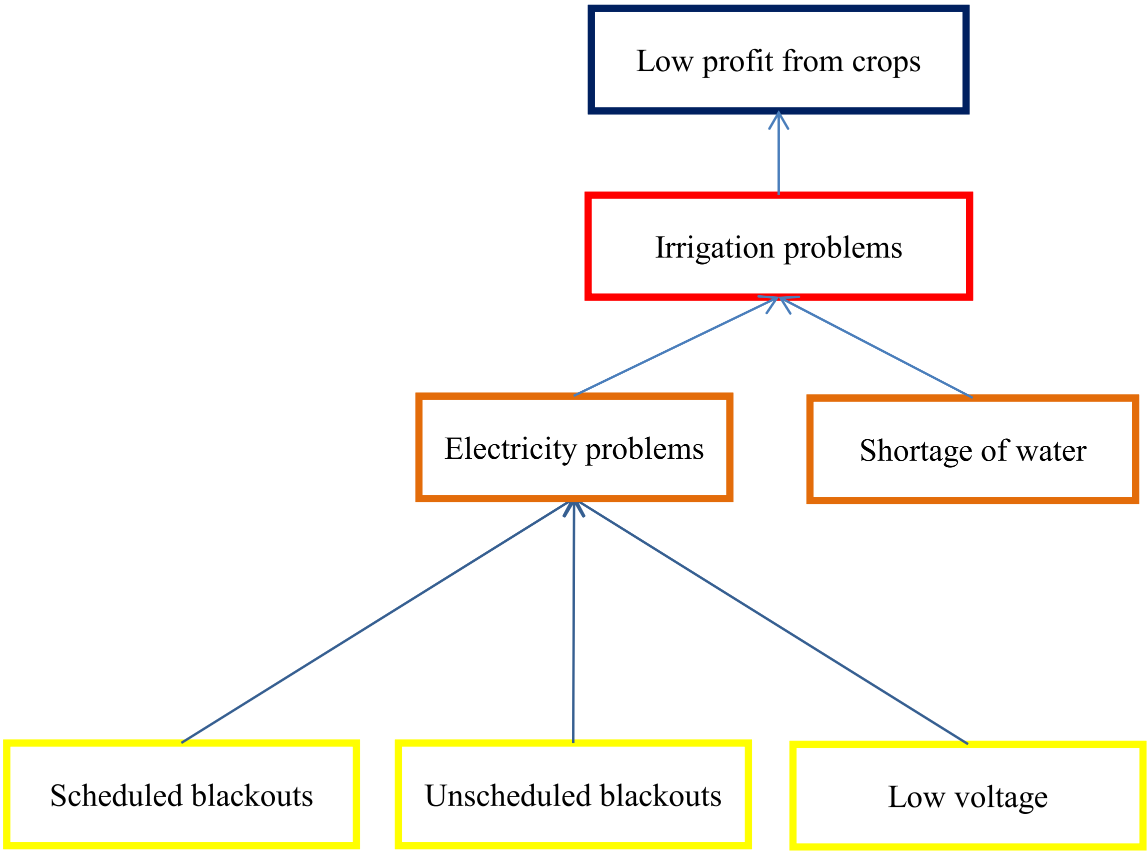


Fig. 3.7: Focus of the problem tree for irrigation problem

The problem of low profit from crops is related mainly to problems in irrigating fields, as stated by most of the farmers in the village. Difficulties in irrigation are due to problems in the electricity supply and to the shortage of water.

The electricity problem can be divided into three sub-problems: during the visits to Katgaon we identified the problem of scheduled blackouts, a high presence of unscheduled blackouts and low voltage problems.

In the second chapter, the phenomenon of the scheduled blackouts has already been described. They are planned by the electricity distribution company to balance out the weakness of the grid and to reduce the demand load. Farmers complain that scheduled blackouts prevent them to irrigate in the period required by the different crops and force them to change irrigation pattern every week and to wake up during the night to irrigate.

These blackouts, as evidenced by the logical scheme, do not serve their purpose, since there are other electrical problems in the village. They should instead be added to the other existing electrical problems in the village. With the use of a software programmed on purpose, we were able to calculate the number of unscheduled blackouts and their duration. This analysis was carried out only for the days spent in the village, since it was necessary to use our computer. From the analysis carried out, it was verified that the problem of unscheduled blackouts is present and of great magnitude: every day there were on average from 2 to 3 unscheduled blackouts each with duration of more than 30 minutes. The software needed to use a computer with power and calculated how many times the computer, in the absence of electricity, is fed to the battery. The last day it was not possible to calculate precisely the duration of the blackout as the PC's battery, because of the lack of electricity, ran out of power and therefore data were lost.

For the problem of low voltage, it was not possible to make any calculation because the computers at our disposal remained powered by electricity from the grid even at low voltage. This issue is certainly present, as all farmers have complained about it. Indeed, unlike our computer, the pumps could be damaged and do not work properly in presence of low voltage.

Only a group of farmers complained about the problem of shortage of water and this is likely due to the position of the land of each farmer. For farmers who own only open wells, a feasible solution could be the dig of a bore well for the irrigation of fields. From data reported by Harnai members, a share of Katgaon area is rich in groundwater and water for irrigation should be available.

We expect that an increase in irrigation quality would lead to an increase in field productivity and in profits from selling crops. The result we want to achieve is an increase in profits mainly through the supply of a reliable energy system. It was decided to act with a single action that involves the design of the appropriate energy system able to meet the energy needs of the farmers. To do this it was necessary, during our visits to the village, to analyze energy needs and assess the energy resources present, both exploited and exploitable.

The needs analysis was carried out with the aid of a questionnaire, created by us, objective and quantitative. The use of a dedicated questionnaire allowed us to understand the real needs of farmers for efficient irrigation of fields. The phase of resource assessment has been carried out not only with the use of the questionnaire, but with the aid of the NASA database.

Chapter 4: Energy assessment for agricultural uses

This chapter presents the results of a detailed assessment of the village energy load and resources in Katgaon. This analysis is instrumental in designing the energy system mentioned in our Strategy Analysis. The selected tool for the design of the system is HOMER Energy software.

As shown in Fig. 4.1 the use of this tool should come after a detailed analysis of the input data. After an initial general assessment of the context, the pre-HOMER analysis implies a detailed assessment of the site layout (described in Chapter 2), of the resources available in the village and of the energy load profile. This analysis is carried out outside HOMER Energy and the processing of collected data allows to figure out the necessary input for the tool. In the HOMER Energy analysis an energy system is designed according to a techno-economic analysis. It compares a wide range of equipment with different constraints and sensitivities to optimize the system design. The feasible systems are ranked according to their Net Present Cost. The best solution cannot be found only on the base of an economic optimization since there are other factors which influence the project delivery and have an impact on the long term sustainability: environmental sustainability, community involvement, proper O&M, business model, current policies. The post HOMER analysis allows to consider these aspects and to go beyond a restricted techno-economic analysis.

Regarding the resource assessment we based our analysis on data collected mainly on online databases.

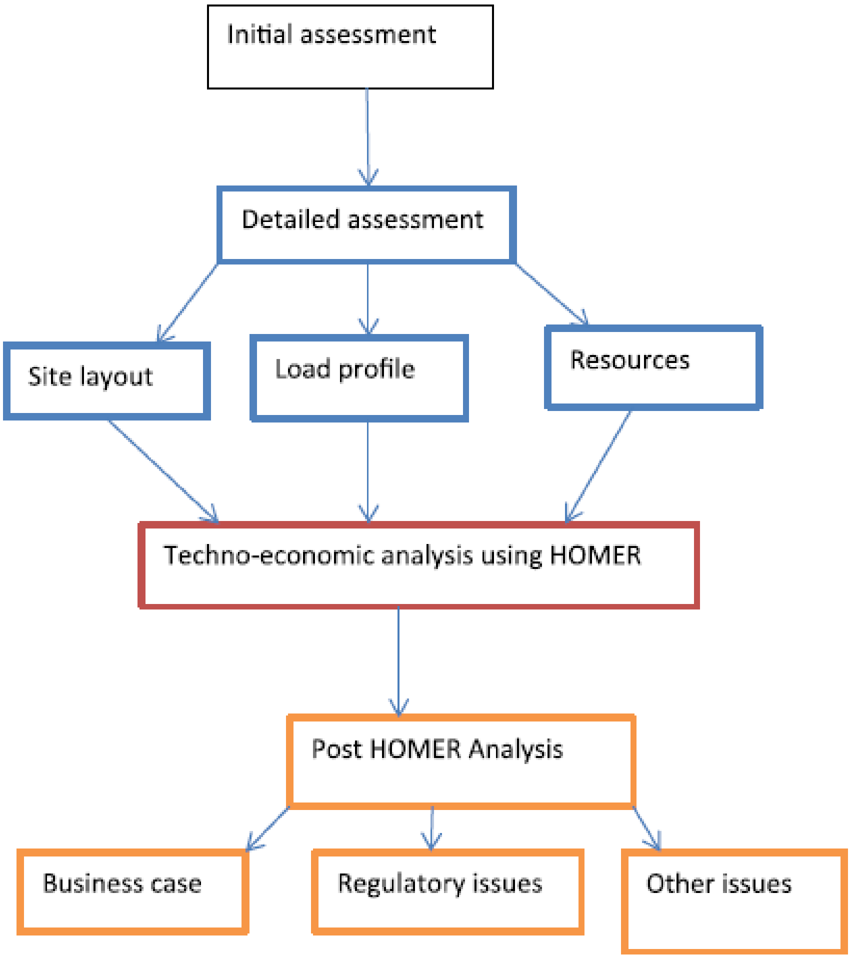


Fig. 4.1: Framework of analysis

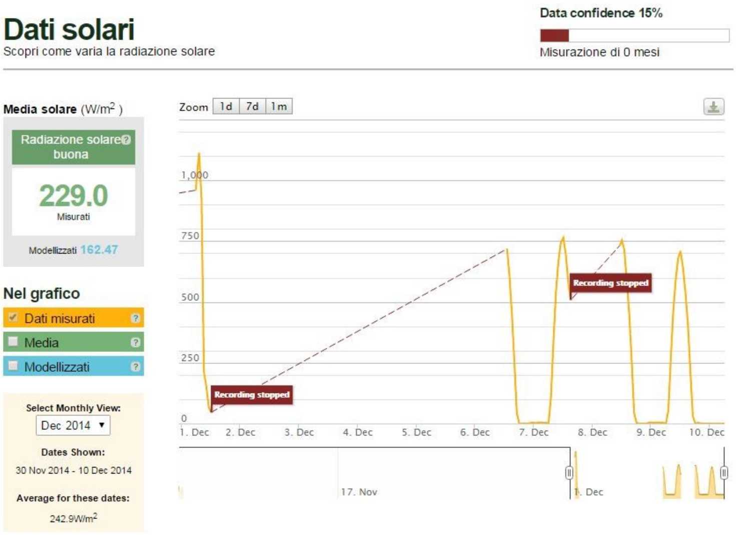
4.1 Energy resources

We have considered solar, wind, and biomass resources in our analysis. The solar and wind data used for Katgaon energy assessment have been taken from the NASA Surface Meteorology and Solar Energy website. The coordinates are 17.796 N latitude and 76.087 E longitude.

In the second visit to Katgaon we installed a kit for the wind and solar resource assessment for micro cogeneration sites, Power Predictor 2.0 (Fig. 4.2).

Fig. 4.2: Power Predictor installed in Katgaon

It is composed of a three cup pulse anemometer for the measurement of wind speed, a balanced wind vane for the measurement of wind direction and a PV sensor for the measurement of solar radiation. Data are collected at fixed sampling and averaging intervals: the sampling interval is 10 seconds, the averaging interval is 10 minutes. Data are stored on a removable memory card and analyzed by a specific web software. We installed the kit on a must at 6 m height in the field of a farmer. Our purpose was to compare the data registered since December with data available on NASA Database to evaluate the accuracy of NASA data for our site. Unfortunately the kit did not work in a proper way and we could not carry out this comparison. An example of data collected with the kit is reported in Fig. 4.3 and Fig. 4.4.



Dati solari

Scopri come varia la radiazione solare

Data confidence 15%

Misurazione di 0 mesi

Media solare (W/m^2)

Radiazione solare buona

229.0

Misurati

Modellizzati 162.47

Nel grafico

☑ Dati misurati

☐ Media

☐ Modellizzati

Select Monthly View: Dec 2014

Dates Shown: 30 Nov 2014 - 10 Dec 2014

Average for these dates: 242.9W/m^2

Fig. 4.3: Measures of solar radiation collected with the kit

Dati sul vento

Controlla la ventosità del tuo sito

Data confidence 15%

Misurazione di 0 mesi

Velocità media (m/s)

Velocità del vento bassa

1.2

Misurati

Modellizzato 2.3

Nel grafico

☑ Dati misurati

☐ Media dei dati

☐ Dati modellizzati

☐ Altezza modificata

Altezza 10m

Select Monthly View: -------------

Dates Shown: 30 Nov 2014 - 10 Dec 2014

Average for these dates: 1.3m/s

Fig. 4.4: Measures of wind speed collected with the kit

Data on the biomass availability have been collected through the questionnaire submitted to farmers.

4.1.1 Solar resource

Solar resource data indicate the amount of global horizontal solar irradiation (beam radiation coming directly from the sun, plus diffuse irradiance coming from all parts of the sky and ground-reflected radiation) that strikes Earth’s surface in a typical year. The data can be in one of three forms: hourly average global solar radiation on the horizontal surface (kW/m^2), monthly average global solar radiation on the horizontal surface (kWh/m^2/day), or monthly average clearness index. The clearness index is a measure of the clearness of the atmosphere. It is the ratio of the solar radiation striking the Earth surface to the solar radiation striking the top of the atmosphere. It is a dimensionless number between 0 and 1. The clearness index has a high value under clear, sunny conditions, and a low value under cloudy conditions.

As regards Katgaon, the monthly average data are reported in Fig. 4.5. The annual average solar radiation was scaled to be 5.32 kWh/m^2/day and the average clearness index was found to be 0.567. The solar radiation is available throughout the year; therefore a considerable amount of PV power output can be obtained.

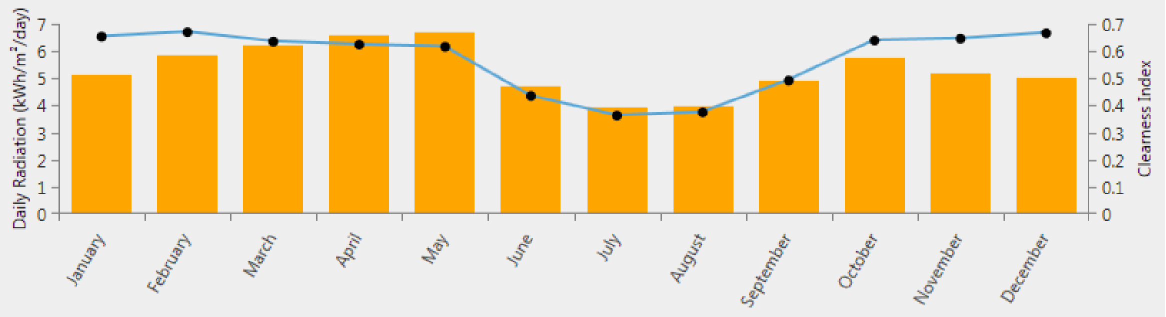


Fig. 4.5: Monthly average solar global horizontal radiation:
daily radiation (kWh/m^2/day) and clearness index

From the data shown in Fig. 4.5, it is evident that during the monsoon season (June-September) the availability of solar radiation decreases in a significant way: this does not cause problems to the energy supply because it is associated also to a decrease in the energy demand for irrigation related to the presence of frequent rainfall.

4.1.2 Wind resource

For the village of Katgaon, the monthly average wind resource data on an average of ten years was taken from the NASA resource website [37] based on the longitude and the latitude of the village location. The annual average wind speed for the location is 3.29 m/s with the anemometer height at 50 m (see Fig. 4.6). We set the logarithmic law to calculate the variation of wind speed with height with the surface roughness length typical for crops

(0.05 m). It is interesting to note the great variability in the wind speed between the monsoon season and the rest of the year.

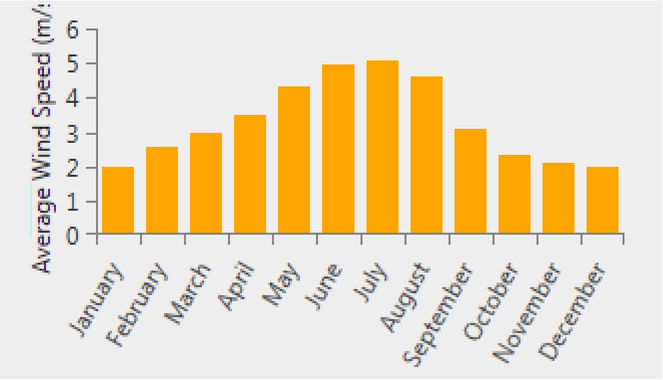


Fig. 4.6: Monthly average wind speed (m/s)

4.1.3 Biomass resource

Biomass is a resource well distributed on the territory and often available in all the contexts. It can be converted into energy with different technologies based on its chemical and physical characteristics. In particular we consider as biomass the livestock manure and, when available, the waste from crops. The animal-derived biomass can be converted into biogas mainly through anaerobic digestion, while plant-derived biomass can be converted into syngas through biomass gasification.

Biogas and syngas can be used in small size systems for the production of electricity and heat. These systems should be simple to use and reliable, to guarantee their application also in rural context. In our analysis we do not consider the waste from sugarcane crops because farmers declared that they use them in the fields to protect the water channels from the solar radiation and they do not want to use them for other purposes.

We evaluated the presence of livestock biomass through the survey we conducted in the village. In particular we started from the livestock data to assess the availability of biomass and the biogas production. We report the data in Table 4.1. We took the data for our calculation from [38]

Biomass	Cattle
Production (t/yr)	8 ÷15
Average production (t/yr)	11.5
% dry matter	7 ÷15
% volatile solids	65 ÷85
Specific biogas yield	200 ÷400
Biogas yield (Nm^3/t)	9 ÷51
Average yield (Nm^3/t)	25
Number of animals	54
Annual production (Nm^3/yr)	621

Table 4.1:Annual biogas production (Nm^3/yr)

Given the Low Heating Value of biogas (18855-27235 kJ/Nm^3), we evaluate the energy content of biogas and the electricity generated with a internal combustion engine. If we use this energy to power the electric pump for irrigation, it results in a number of equivalent hours equal to 11 (see Table 4.2). So the quantity of available biomass is really small compared with the energy needs of the village and we do not consider this energy source further in our analysis.

LHV biogas	18855 ÷27235	kJ/Nm^3
E_{in}	14310.945	MJ
E_{el}	4293.2835	MJ/yr
	1192.57875	kWh/yr
P_{pumps}	105.51655	kW
H_{eq}	11.30229097	h/yr

Table 4.2: Data for the calculation of equivalent hours of a biogas system

Moreover in the previous analysis we considered biomass as if it were unused by the community. Actually the households already use biomass for two main purposes: as fuel for cooking and as fertilizer for the fields. In particular, they use cow dung for cooking during the phase of fire lighting up because it is easy to burn and they prefer preparing organic fertilizer instead of buying chemicals. Being biomass already used for these purposes, we believe that using biomass for electricity generation is not a viable solution for the village of Katgaon.

4.1.4 Considerations

Therefore for the design of the energy system we considered the solar and the wind resources. Instead we did not consider the biomass resource for the reasons explained above.

4.2 Energy in the agricultural sector

The agricultural sector obtains energy in the form of human labour, animal power and farmyard manure from different sources, such as household, livestock and rural transport. It receives energy from outside in the form of electricity, diesel, and chemical fertilizers, but also produces energy in the form of food, non-food, crop residues, fodder, timber, logs fuel wood which have different usages, and thus supplies energy inputs to other subsystems. During our visits we evaluated the energy consumption in the different agricultural activities: land preparation and irrigation. Harvesting was omitted because farmers use only human labour for this purpose.

4.2.1 Land preparation

Farmers in Katgaon rely on two methods for land preparation. The first method is the traditional rural method based on animal labour, the second one is the use of tractors. Often farmers rely on both methods. Despite tractors' performances are better than animals, they are too expensive for farmers who rent tractors only for the first ploughing and use animals during the rest of the year. From data collected, we obtained that 33% of the target group rely only on tractors, 20% rely only on animal-drawn plough and the remaining relies on both methods. Only one of the farmers owns a tractor, while the others should face prices between 1000 and 1600 Rs/acre for the rent.

Energy consumption in this activity is related to the usage of diesel for tractors. For a complete assessment of energy consumption we should find out the amount of fuel used for land preparation. However, we did not consider it in our analysis because energy consumption for land preparation is negligible compared to energy consumption for irrigation.

4.2.2 Irrigation

Irrigation is the most energy consuming activity in the village of Katgaon. For this reason, and being the solution of the irrigation problem the aim of the project, we focused our attention on this activity.

Farmers use mainly electric pumps to irrigate fields. Each farmer owns on average 2 pumps to lift water out of open wells or bore wells. The total power installed amounts to 156.5 HP and is distributed among farmers according to the histogram shown in Fig. 4.7. The histogram shows that there is not a uniform distribution of the power installed in each field: the power of the pumps depends on the size of the land and other factors, such as the irrigation method, the shape of the land and the position of the well. The variance of these data leads to different energy demands among farmers. This plays an important role in the sizing of our system because if we define an "average farmer", we might run the risk of building an improper model.

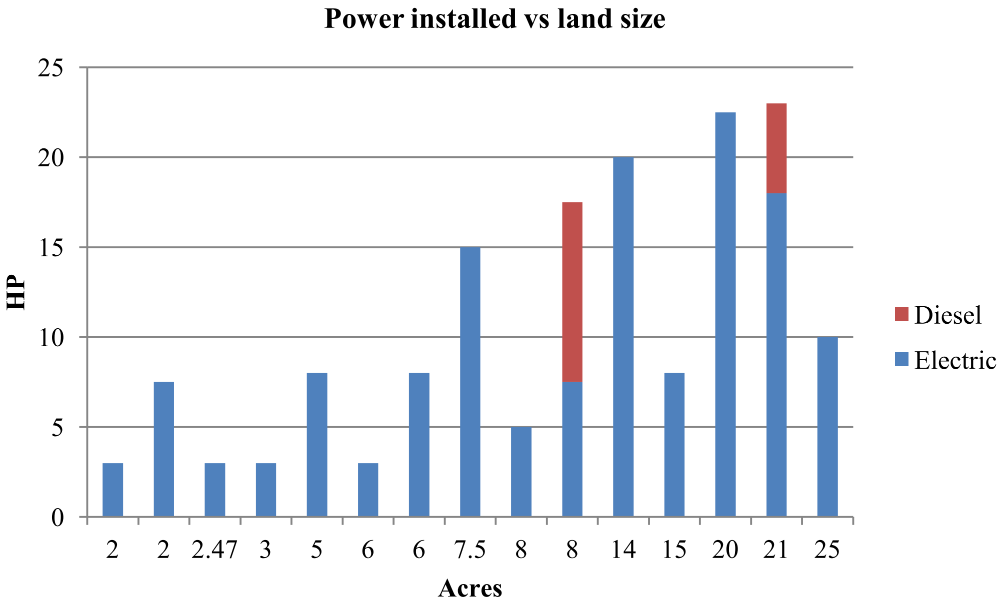


Fig. 4.7: Distribution of power of pumps installed related to the size of the land of each farmer

4.2.3 Energy load profiles

Since a correct evaluation of the energy needs is important for the sizing of the system, we designed a specific section of the questionnaire for this purpose. We did not evaluate the current energy consumption, but we asked farmers to imagine a hypothetical monthly irrigation schedule during the Rabi season, in case of full availability of electricity for 24 hours. We chose to size the energy system depending on the Rabi demand, because this is the season with the highest requirements of water and energy for irrigation. From data collected, we designed an energy load profile for each farmer.

We made the following assumptions:

- In the Kharif season we considered an energy load profile equal to the 50% of the Rabi profile. This assumption is needed to avoid an over-sizing of the system. During Kharif there is a reduction of the availability of solar radiation which would bring to an increase in the size of PV power installed. Despite of this, there is also a reduction of the crop water requirement due to the frequent rainfalls which reduce the energy requested for irrigation.
- We set the day-to-day variability and the time-step variability of the load at 10%, taking into consideration that the energy loads given by farmers should not deviate from the effective profiles. This means a low variability. On the other hand the tool requires in input an average daily profile per month and this leads to the loss of information related to the different profiles available for each day of the month. Calculating the standard deviation of the considered profiles, we get results in accordance with the selected value of variability.

We report how the variability of load profiles is calculated using these factors. The random variability inputs allow to add randomness to the load data to make them more realistic. Day-to-day variability causes the *size* of the load profile to vary randomly from day to day, although the *shape* remains unchanged. Time-step-to-time-step variability disturbs the *shape* of the load profile without affecting its *size*.

The mechanism for adding day-to-day and time-step-to-time-step variability is the following. First the year-long array of load data are assembled from the daily profiles that we specify. Then an algorithm steps through that time series and in each time step it multiplies the value in that time step by a perturbation factor α:

$$\alpha = 1 + \delta_d + \delta_{ts}$$

where:

δ_d = daily perturbation value

δ_{ts} = time step perturbation value

The daily perturbation value is randomly drawn *once per day* from a normal distribution with a mean of zero and a standard deviation equal to the "daily variability" input value. The time step perturbation value is randomly drawn every time step from a normal distribution with a mean of zero and a standard deviation equal to the "time-step-to-time-step variability" input value.

For farmers in Katgaon we obtained 15 different energy load profiles. The shape of the profile and the power installed by each farmer are the two main factors accounting for the differences among the load profiles. The power installed varies from 0.3 to 12 kW. Regarding the shape of profiles, it is possible to recognize two frequent distribution: in the first one, the load is concentrated in one single block around noon, in the other one, farmers use pumps in two different time slots (one in the morning and one in the afternoon/evening hours). Two examples are reported in Fig. 4.8 and Fig. 4.9.

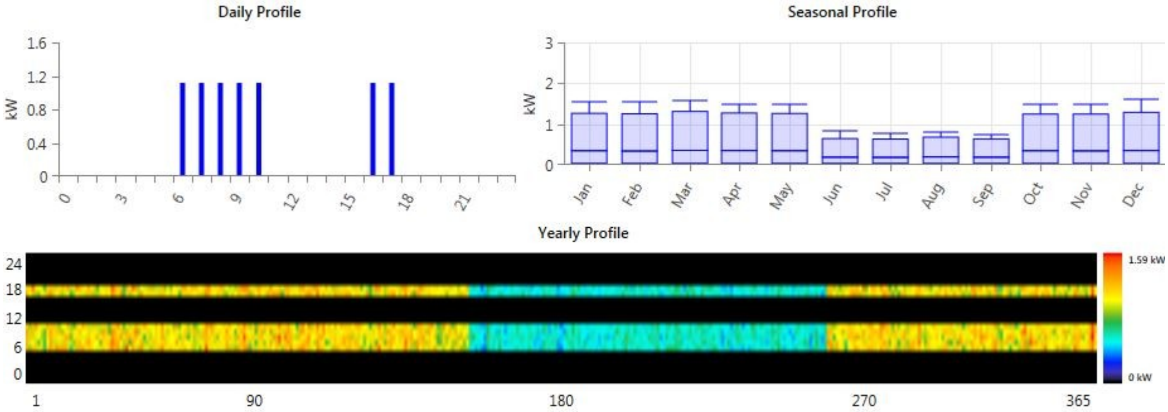


Fig. 4.8: Load profile for farmer IV simulated with HOMER Energy

The daily profile shows how the electric load is distributed during the average day. Farmer IV irrigates his field in the morning (from 6 to 11 AM) and in the afternoon (from 4 to 5 PM). With the current electricity supply scheduling, he could never follow this irrigation pattern which he considers the best for his crops. The average load is 6.53 kWh/day with a peak load of 1.59 kW which is one of the lowest in the target group. In the monthly profile, the hypothesis made on the load reduction during the monsoon month is evident. The monthly profile is represented through monthly box plots which allow to identify the median load, the interquartile range and the maximum load of the month. The median remains the same in months of the same type because of the method used for the addition of variability to the load. The yearly profile shows the load magnitude for each day of the year because thanks to the variability added every day is different from the other.

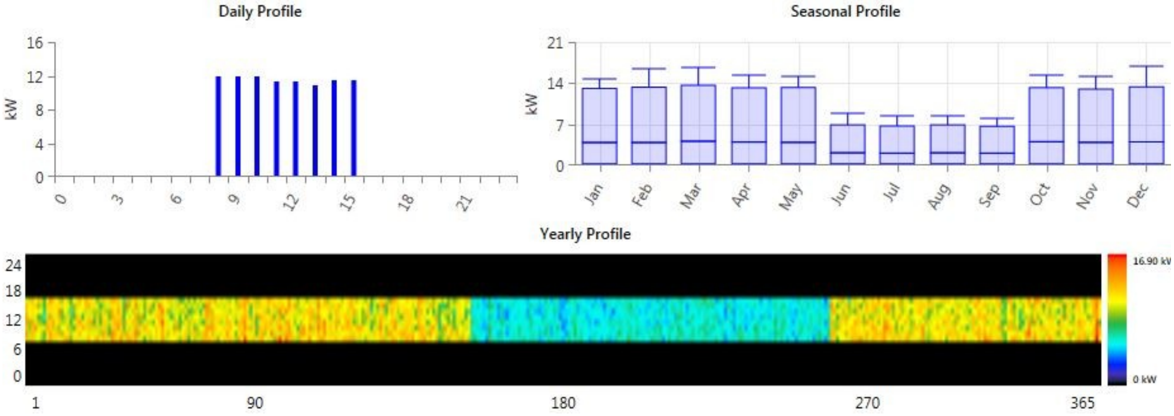


Fig. 4.9: Load profile for farmer XIV simulated with HOMER Energy software

The load profile of farmer XIV represents the second typical profile pattern that characterizes the target group. Farmer XIV would like to irrigate fields from 8 AM to 4 PM in a single time slot, longer than the previous one. The load of this farmer is higher, with an average daily load of 76.63 kWh/day and a peak load of 16.90 kW. The considerations about the variability of the load are the same as for Farmer IV.

Chapter 5: Simulations and results

In this chapter we present the results of our simulations. We start with a description of the three different configurations that we have analysed, with all the scenarios considered. Then we make a brief description of the components used for our systems and the mode of operation of HOMER Energy. We go on presenting in detail the results obtained. At the end of the chapter we show the post HOMER Energy analysis which takes into account other factors in addition to the economic aspect.

5.1 Scenarios

We considered three different system configurations for the development of this project, which involve different groups of farmers and lead to solutions of different sizes and with a different impact at village level. For each configuration, we studied the possibility of connecting the system to the existent national grid or of designing a stand-alone system as schematically reported in Fig. 5.1.

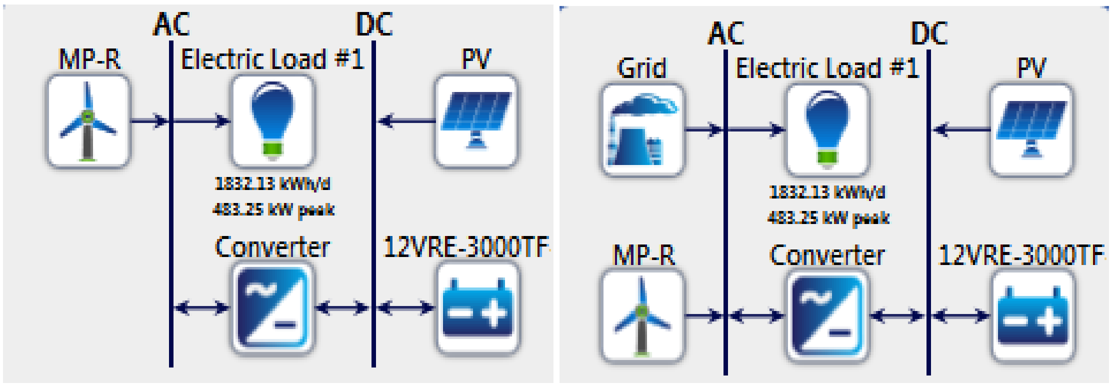


Fig. 5.1: Schematic design of the stand-alone (on the left) and of the grid-connected (on the right) systems

In Table 5.1 we report the configurations and the scenarios considered in our analysis. A more detailed description of each scenario is reported in this Chapter.

		CONFIGURATION		
		A (total area)	B (15 farmers)	C (3 clusters)
SCENARIO	Stand-alone	A1	B1	C1
	Grid-connected (day)	A2	B2	C2
	Grid-connected (night)	A3	B3	C3
	Grid-connected (day-random blackout)			C4
	Water storage			C5

Table 5.1: Schematic description of configurations and scenarios of our analysis

Moreover, for one of these configurations we modelled the water storage and the unscheduled blackouts in order to understand the impact of them on the system results.

For the design of a power system, HOMER Energy requires an average daily load profile. An energy load profile represents the variation of electric load over time, that is the amount of kilowatts for each hour of the year. We can specify a single 24-hour profile that applies throughout the year, or can specify different profiles for different months and different profiles for weekdays and weekends. To synthesize load data and obtain a unique load pattern for each day, a user-specified amount of randomness is added according to the methodology explained in Chapter 4.

The analyzed configurations have different energy load profiles. In this section we explain the methodology used to design these profiles starting from data collected.

5.1.1 Configuration A

In this configuration, the system satisfies the energy needs for irrigation of all the farmers present in the area highlighted in Fig. 5.2.

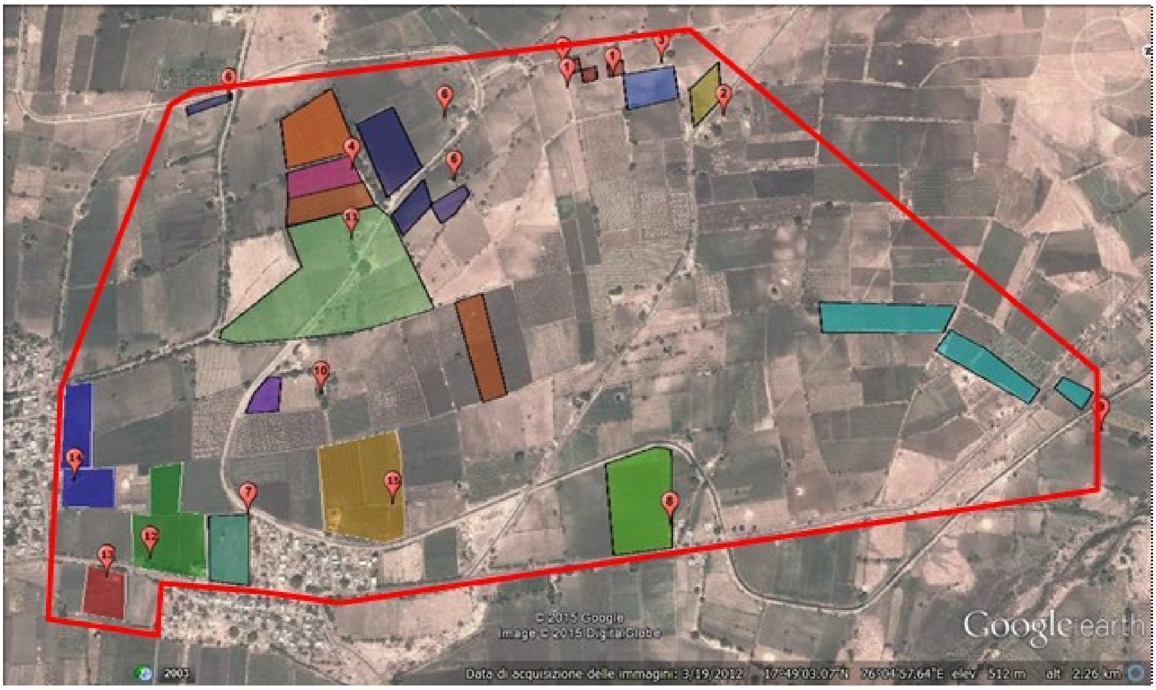


Fig. 5.2: Display of Configuration A on map

As described in Chapter 4:, from our survey we know the energy load only for the 15 farmers interviewed during our mission. To assess the energy needs of all the farmers in the area, we calculated an energy need specific per acre and we estimated the total energy load profile of this configuration multiplying the specific energy need by the total area. We used this method instead of estimating the average energy needs for farmer for two reasons. The first one is that we do not know the exact number of farmers in the area. The second reason is that the differences in the energy needs from one farmer to another depend mainly on the dimension of the land (see Fig. 4.7). The use of an energy need specific per acre allows to consider this relationship. The sum of the hourly energy load of the 15 farmers is reported in the column “Average load profile” of Table 5.2. In the next column the load is divided by the total area of the farmers in order to obtain an energy load profile specific for acre. In the last column this value is multiplied by the total area of Configuration A to obtain the total energy load profile of Configuration A.

Area 15 farmers		145 acres	
Total area		320 acres	
	Average Load Profile	**Load Profile per acre**	**Load Profile Conf A**
Hours	kW	kW	kW
5	9.25	0.17	53.85
6	25.02	0.45	145.58
7	31.45	0.57	183.00
8	47.45	0.86	276.04
9	46.91	0.85	272.95
10	45.25	0.82	263.26
11	31.32	0.57	182.22
12	23.93	0.44	139.22
13	22.26	0.40	129.54
14	22.53	0.41	131.09
15	20.29	0.37	118.07
16	8.76	0.16	50.98
17	19.28	0.35	112.18
18	8.39	0.15	48.81
19	8.92	0.16	51.91
20	4.39	0.08	25.57
21	1.07	0.02	6.20
22	1.60	0.03	9.30

Table 5.2: Evaluation of load profile for Configuration A

We provide the resulting load profile as input into HOMER Energy. We set up a day-to-day variability of 20% and a time step variability of 10% because we used an average profile instead of the real profile that is unknown. Fig. 5.3 is the electric load processed by the software. The highest daily load is 276 kW in the morning. The added variability brings to a peak load of 483.25 kW in the month of December with an average load of 76.34 kW. The daily average electric load is 1,832.1 kWh/day.

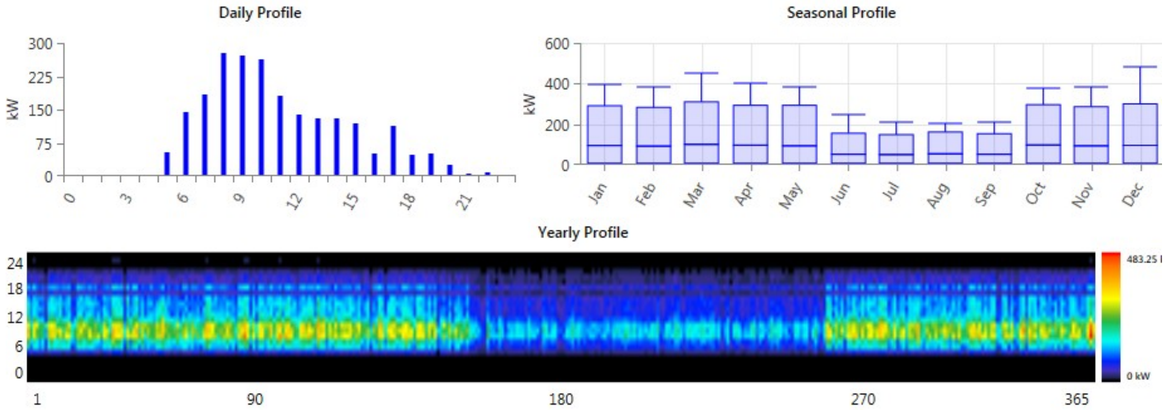


Fig. 5.3: Energy load profile of Configuration A

5.1.2 Configuration B

In this configuration we give electricity to the 15 farmers separately, that means one power plant for each farmer. Fig. 5.4 shows the farmers' land position.

To evaluate this configuration we had to run 15 simulations each one with a different energy load specific to the single farmers. All the energy loads are reported in Appendix C and they have been derived from the questionnaire. To have a more realistic electric load profile we used a day-to-day variability of 10% and a time step variability of 10% for the reasons reported in paragraph 4.2.3.

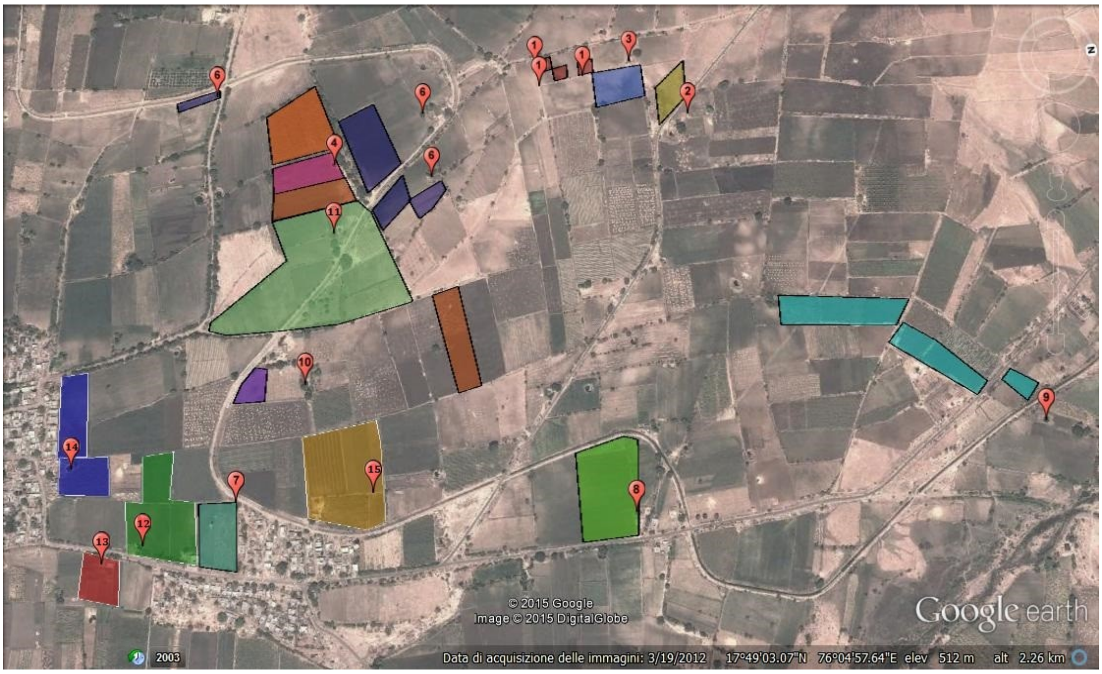


Fig. 5.4: Display of Configuration B on map

5.1.3 Configuration C

In the last configuration we separated farmers into three different clusters according to their position (see Fig. 5.5).

We can define the following clusters:

- Cluster I composed of farmers 1, 2 and 3. This cluster is composed of farmers with small lands of similar extensions. They belong to the same family.
- Cluster II composed of farmers 4,5,6,10 and 11. Farmers with land of different size belong to this cluster, in particular there are the farmer with the biggest area and the farmer with one of the smallest area. This cluster is composed of members of two different families.
- Cluster III composed of farmers 7, 12, 13 and 14. This cluster is composed of farmers which own land of average size. This cluster is located close to the village and three out of five farmers have their house in the field.

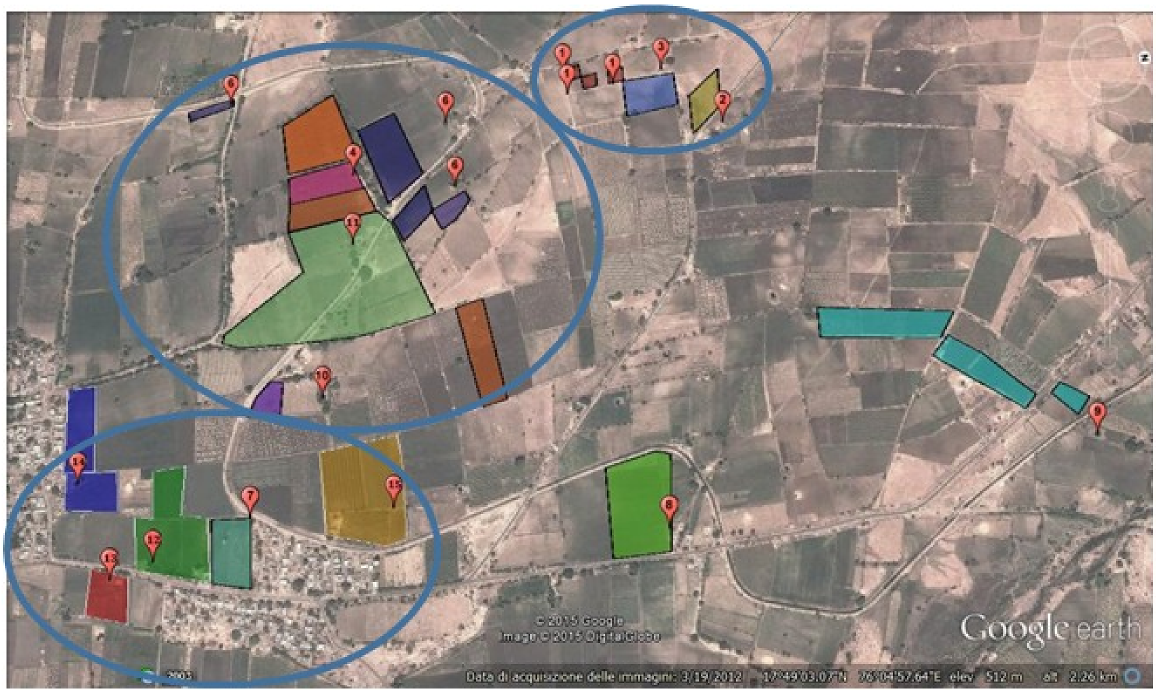


Fig. 5.5: Display of Configuration C on map

Farmers 8 and 9 are not involved in this configuration because of their distance from the others.

Each cluster is characterized by a different number of farmers with different size of land and this brings to different energy loads. Energy load profiles were obtained as the sum of the profiles of single farmers. The three profiles are reported in Fig. 5.6, Fig. 5.7 and Fig. 5.8.

	FM 1	**FM 2**	**FM 3**	**C I**	**FM 4**	**FM 5**	**FM 6**	**FM 10**	**FM 11**	**C II**	**FM 7**	**FM 12**	**FM 14**	**FM 15**	**C III**
h	kW	kW	kW	kW	kW	kW	kW	kW	kW	kW	kW	kW	kW	kW	kW
5	0.0	0.0	0.0	0.0	0.0	0.0	2.1	3.4	0.0	5.5	0.0	3.7	0.0	0.0	3.7
6	1.3	0.3	0.0	1.6	1.1	2.0	2.1	3.4	7.5	16.1	1.1	3.7	0.0	1.2	6.0
7	1.3	0.3	0.0	1.6	1.1	2.0	2.1	3.4	7.5	16.1	1.1	3.7	0.0	6.0	10.8
8	1.3	0.0	1.7	3.0	1.1	2.0	2.1	2.2	0.5	8.0	0.0	3.7	11.9	6.0	21.5
9	1.3	0.0	1.7	3.0	1.1	2.0	2.1	2.2	0.0	7.4	0.0	3.7	11.9	6.0	21.5
10	1.3	0.0	1.7	3.0	1.1	0.0	2.1	0.6	7.5	11.3	0.5	4.0	11.9	6.0	22.3
11	1.3	0.2	1.7	3.2	0.0	0.0	0.0	0.6	0.0	0.6	0.8	0.8	11.3	6.0	18.9
12	0.3	0.2	1.7	2.3	0.0	0.0	0.0	0.4	0.3	0.7	0.3	0.8	11.3	0.0	12.4
13	0.3	0.2	1.7	2.3	0.0	0.0	0.0	0.4	0.3	0.7	0.0	0.8	10.9	0.0	11.7
14	0.3	0.2	1.7	2.3	0.0	0.0	0.0	0.4	0.3	0.7	0.0	0.5	11.5	0.0	12.0
15	0.3	0.0	1.7	2.1	0.0	0.0	0.0	0.4	0.3	0.7	0.0	0.5	11.5	0.0	12.0
16	0.3	0.0	1.7	2.1	1.1	0.0	1.1	0.0	0.3	2.5	0.5	0.0	0.0	3.7	4.3
17	0.3	0.0	1.7	2.1	1.1	3.3	1.1	0.0	7.5	13.0	0.5	0.0	0.0	3.7	4.3
18	0.0	0.0	0.0	0.0	0.0	3.3	1.1	0.0	0.0	4.4	0.0	0.3	0.0	3.7	4.0
19	0.0	0.0	0.0	0.0	0.0	3.3	1.1	0.0	0.0	4.4	0.5	0.3	0.0	3.7	4.5
20	0.0	0.0	0.0	0.0	0.0	3.3	0.0	0.0	0.0	3.3	0.8	0.3	0.0	0.0	1.1
21	0.0	0.0	0.0	0.0	0.0	1.1	0.0	0.0	0.0	1.1	0.0	0.0	0.0	0.0	0.0
22	0.0	0.0	0.0	0.0	0.0	1.1	0.0	0.0	0.0	1.1	0.5	0.0	0.0	0.0	0.5

Table 5.3: Evaluation of energy load profiles for the clusters of Configuration C

For this configuration we used a day-to-day variability of 20% and a time step variability of 10% as we did for Configuration A for the reasons already explained.

Cluster I has a quite uniform load from 6 AM to 6 PM. The peak load is from 11 AM to midday and it amounts to 5.71 kW. The daily average energy load results to be

23.73 kWh/day. This is the cluster with the smallest energy load, equal to less than one quarter of the others.

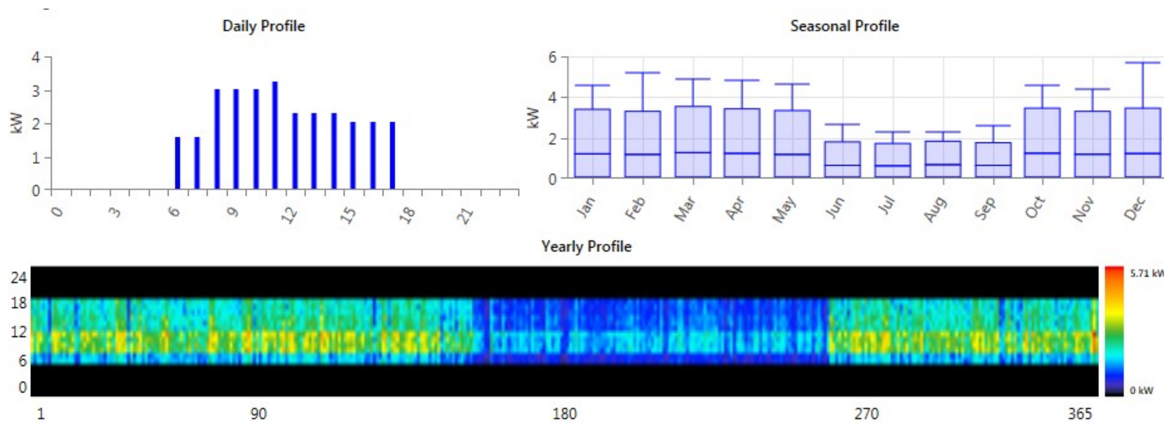


Fig. 5.6: Energy load profile of Cluster I

The electrical load profile of Cluster II presents two periods with a high demand and an intermediate period with a really low demand (less than 1 kW). The peak load is between 6 AM and 8 AM and is equal to 26.21 kW. The daily average energy load is 81.11 kWh/day.

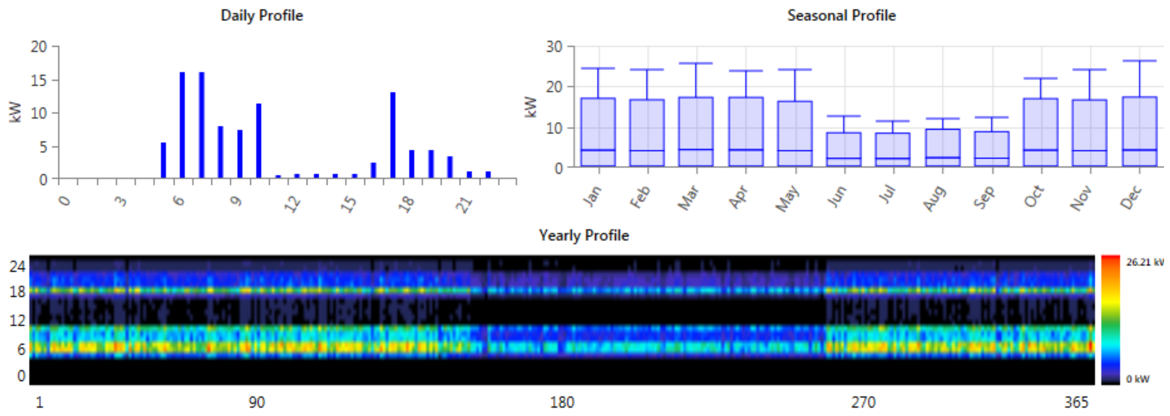


Fig. 5.7: Energy load profile of Cluster II

Cluster III presents an increasing load in the morning, which reaches the peak from 10 AM to 11 AM and gradually decreases until 11 PM. The peak load value is 37.85 kW, which is the highest of the three clusters, and the daily average energy load is 142.85 kWh/day. This cluster has the highest energy load.

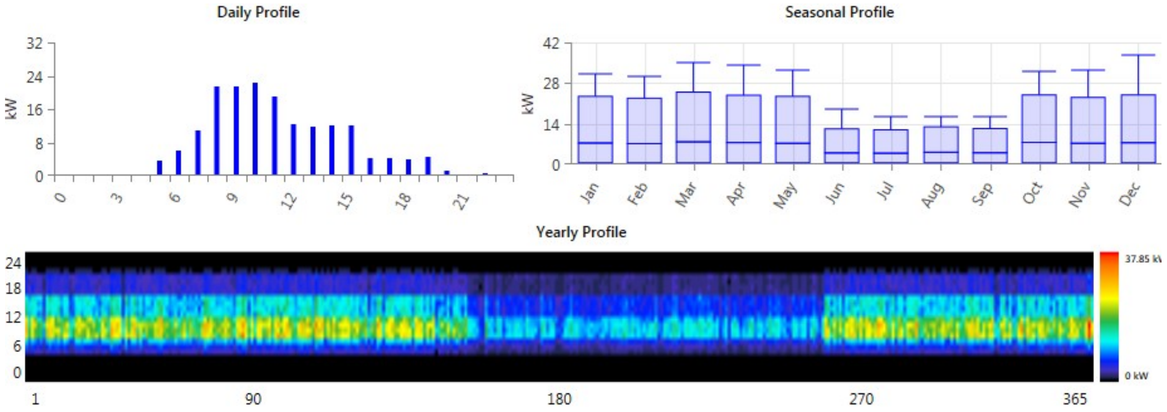


Fig. 5.8: Energy load profile of Cluster III

In addition to the standard simulations, for this case we added two more scenarios. One with the presence of water storage and one with random blackouts. The aim of the first scenario is to evaluate the feasibility of the usage of water storage in this context as replacement for the batteries, the aim of the second one is to evaluate how the local grid unreliability might influence the design of the system.

5.2 HOMER Energy input

In this section we describe the components used in our simulations in HOMER Energy. We present the characteristics of these components and the parameters required by HOMER Energy for their modelling. We give also a brief description of the software operating mode.

We present all the components used for our simulations: solar PV, wind turbines, batteries, water tanks, converter and grid.

5.2.1 Solar PV model

HOMER Energy models the PV array as a device that produces DC electricity in direct proportion to the global solar radiation incident upon it, independent of its temperature and the voltage to which it is exposed. The power output of the PV array is calculated using the following equation:

$$P_{PV} = f_{PV} Y_{PV} \frac{I_T}{I_S}$$

Where, f_{PV} is the PV derating factor, Y_{PV} the rated capacity of the PVarray (kW), I_T the global solar radiation (beam plus diffuse) incident on the surface of the PV array (kW/m^2), and I_S is 1 kW/m^2, which is the standard amount of radiation used to rate the capacity of the PV array. In the following paragraphs we describe these variables in more detail.

The rated capacity (sometimes called the peak capacity) of a PV array is the amount of power it would produce under standard test conditions of 1 kW/m^2 irradiance and a panel temperature of 25°C. In HOMER Energy, the size of a PV array is always specified in terms of rated capacity. The rated capacity accounts for both the area and the efficiency of the PV module, so neither of those parameters appears explicitly.

Each hour of the year, the global solar radiation incident on the PV array is calculated using the HDKR model, explained in Section 2.16 of Duffie and Beckmann [39]. This model takes into account the current value of the solar resource (the global solar radiation incident on a horizontal surface), the orientation of the PV array, the location on the Earth surface, the time of year, and the time of day, using the following formula [40]:

$$\bar{H}_T = (\bar{H}_b + \bar{H}_d A)\bar{R}_b + \bar{H}_{\rho_g}\left(\frac{1 - cos\beta}{2}\right) + \bar{H}_d\left\{(1 - A)\left(\frac{1 + cos\beta}{2}\right)\left[1 + \sin^3\left(\frac{\beta}{2}\right)\right]\right\}$$

where $\bar{H}_T$ is the monthly total incident radiation on a tilted surface, $\bar{H}_b$ is the monthly mean daily beam radiation on a horizontal surface, $\bar{H}_d$ is the monthly mean daily diffuse radiation, A is anisotropy index, which is the function of transmittance of the atmosphere for beam radiation, $\bar{R}_b$ is the ratio of mean daily beam radiation on the tilted surface to that on a horizontal surface, $\bar{H}_{\rho_g}$ is the monthly mean daily radiation due to ground reflectance and β is the slope of PV array.

The orientation of the array may be fixed or may vary according to one of several tracking schemes.

The derating factor is a scaling factor meant to account for the effects of dust on the panel, wire losses, elevated temperature, or anything else that would cause the output of the PV array to deviate from that expected under ideal conditions. HOMER Energy does not account for the fact that the power output of a PV array decreases with increasing panel temperature, but we can reduce the derating factor to correct for this effect when modelling systems for hot climates.

In reality, the output of a PV array depends strongly and nonlinearly on the voltage to which it is exposed. The maximum power point (the voltage at which the power output is maximized) depends on the solar radiation and on the temperature. If the PV array is connected directly to a DC load or a battery bank, it will often be exposed to a voltage different from the maximum power point, and performance will suffer. A maximum power point tracker (MPPT) is a solid-state device placed between the PV array and the rest of the DC components of the system that decouples the array voltage from that of the rest of the system, and ensures that the array voltage is always equal to the maximum power point. By ignoring the effect of the voltage to which the PV array is exposed, it is effectively assumed that a maximum power point tracker is present in the system.

To describe the cost of the PV array, we need to specify its initial capital cost, replacement cost, and operating and maintenance (O&M) cost per year. The replacement cost is the cost of replacing the PV array at the end of its useful lifetime, which we specify in years. By default, the replacement cost is equal to the capital cost, but the two can differ: for example, a donor organization may cover some or all of the initial capital cost but none of the replacement cost.

Input values for modelling solar PV

After this explanation of the input parameters, we present the values used in our simulations.

The alternatives offered by HOMER Energy are “Generic Flat Plate PV” and “Concentrating PV”. We chose the Flat Plate PV technology because this is the most appropriate for the context: it is the most simple, the most common and the less expensive technology and it requires less maintenance.

The lifetime is set to 25 years, which is a standard value for solar PV panels and coincide with project life time. We chose a derating factor of 80%, which is lower than the default value proposed by HOMER Energy, to consider the high temperature typical of the context and the effect of dust as suggested by [41]. As regards the orientation, we set a slope value of 26° and an azimuth value of 0°. These are the values already used for the solar panels installed on the local hospital roof by the Indian government. For the ground reflectance we set up a value of 25%, that is the standard value used for agricultural land. For maintenance and economic reasons we chose a system without tracking.

For the costs we referred to a document of the Central Electric Regulatory Commission New Delhi [42]. We set up the capital cost to 995 $/kW, the O&M cost to 20 $/kW/yr and the replacement cost to 830 $/kW. The currency used by HOMER Energy is Euro, so we used an exchange rate of 1.15 $/€.

We report all the input data in a synthetic table:

Lifetime	25 years
Derating factor	80%
Ground reflectance	25%
Slope	26°
Azimuth	0°
Capital cost	995 $/kW
O&M cost	20 $/kW/yr
Replacement cost	830 $/kW

Table 5.4: Input for Solar PV component

5.2.2 Wind turbine models

HOMER Energy models a wind turbine as a device that converts the kinetic energy of the wind into AC or DC electricity according to a particular power curve, which is a graph of power output versus wind speed at hub height.

To model a system comprising one or more wind turbines we need wind resource data indicating the wind speeds the turbines would experience in a typical year. We could provide measured hourly wind speed data if available. Otherwise, synthetic hourly data can be generated with 12 monthly average wind speeds and four additional statistical parameters: the Weibull shape factor, the autocorrelation factor, the diurnal pattern strength, and the hour of peak wind speed. The Weibull shape factor is a measure of the distribution of wind speeds over the year. The autocorrelation factor is a measure of how strongly the wind speed in one hour tends to depend on the wind speed in the preceding hour. The diurnal pattern strength and the hour of peak wind speed indicate the magnitude and the phase, respectively, of the average daily pattern in the wind speed.

We need to indicate the anemometer height, meaning the height above ground at which the wind speed data were measured or for which they were estimated. If the wind turbine hub height is different from the anemometer height, the wind speed at the turbine hub height can be calculated using either the logarithmic law, which assumes that the wind speed is proportional to the logarithm of the height above ground, or the power law, which assumes that the wind speed varies exponentially with height. To use the logarithmic law, we have to enter the surface roughness length, which is a parameter characterizing the roughness of the surrounding terrain.

Each hour, the power output of the wind turbine is calculated in a four-step process. First, the average wind speed is determined for the hour at the anemometer height by referring to the wind resource data. Second, the corresponding wind speed at the turbine's hub height is calculated. Third, referring to the turbine's power curve the power output at that wind speed is calculated assuming standard air density. Fourth, the power output value is multiplied by the air density ratio, which is the ratio of the actual air density to the standard air density.

In addition to the turbine's power curve and the hub height, we need to specify the expected lifetime of the turbine in years, its initial capital cost, its replacement cost, and its annual O&M cost per year.

Input values for modelling wind turbines

As regards the wind resource, the data needed for the simulation are carried out by the analysis in Chapter 4.

We chose two different wind turbines to simulate all the different scenarios. Indeed, costs and power curves of wind turbines are not linear with the power installed and make it necessary to change the kind of turbine depending on the size of our system. In our configurations, we set up the following turbines available in HOMER Energy library:

- Generic 3 kW turbine

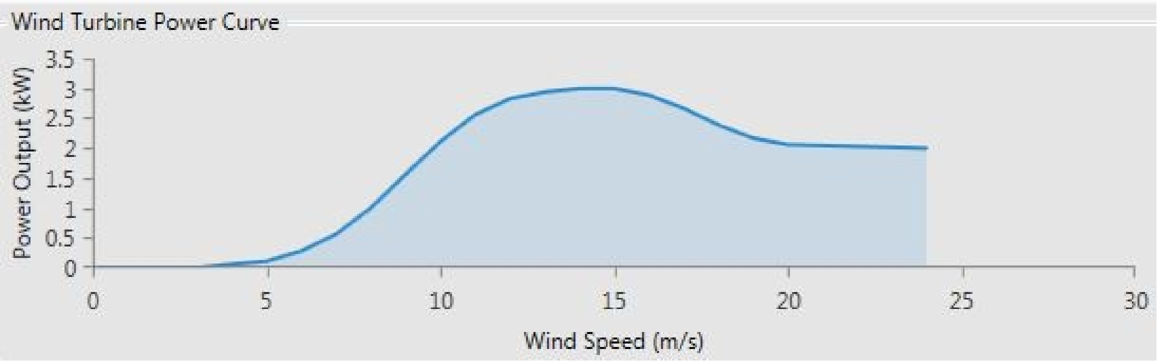


Fig. 5.9: Power curve of Generic 3 kW turbine

- Vergnet GEV MP-R (275 kW)

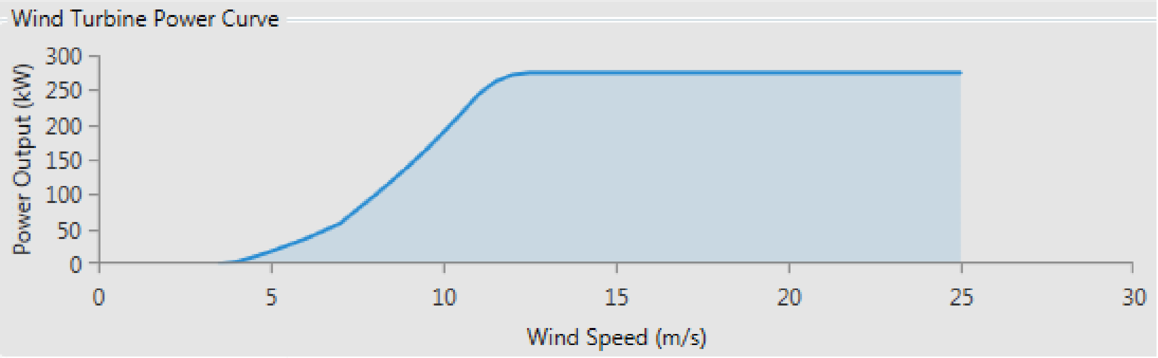


Fig. 5.10: Power curve of Vergnet GEV MP-R

We report the features of these turbines in Table 5.5 for an easy comparison. The economic data are obtained from a document of the Indian Energy Regulatory Commission [42].

	Generic 3 kW	Vergnet GEV MP-R
Power (kW)	3	275
Lifetime (years)	25	25
Hub height (m)	17	32
Capital cost (€)	10,000	233,000
O&M cost (€/yr)	500	3,900
Replacement cost (€)	10,000	186,000

Table 5.5: Input parameters for wind components

5.2.3 Batteries model

The battery bank is a collection of one or more individual batteries. HOMER Energy models a single battery as a device capable of storing a certain amount of DC electricity at a fixed round-trip energy efficiency, with limits as to how quickly it can be charged or discharged, how deeply it can be discharged without causing damage, and how much energy can cycle through it before it needs replacement. The properties of the batteries are assumed constant throughout the lifetime and are not affected by external factors such as temperature.

The key physical properties of the battery are its nominal voltage, capacity curve, lifetime curve, minimum state of charge, and round-trip efficiency. The capacity curve shows the discharge capacity of the battery in ampere-hours versus the discharge current in amperes. Capacity typically decreases with increasing discharge current. The lifetime curve shows the number of discharge–charge cycles the battery can withstand versus the cycle depth. The number of cycles to failure typically decreases with increasing cycle depth. The minimum state of charge is the state of charge below which the battery must not fall to avoid permanent damage. The round-trip efficiency indicates the percentage of the energy going into the battery that can be drawn back out.

To calculate the battery's maximum allowable rate of charge or discharge, the kinetic battery model, which treats the battery as a two tank system, is used. Part of the battery's energy storage capacity is immediately available for charging or discharging, but the rest is chemically bound. The rate of conversion between available energy and bound energy depends on the difference in ''height'' between the two tanks. Three parameters describe the battery. The maximum capacity of the battery is the combined size of the available and bound tanks. The capacity ratio is the ratio of the size of the available tank to the combined size of the two tanks. The rate constant is analogous to the size of the pipe between the tanks.

Modelling the battery as a two-tank system rather than a single-tank system has two effects. First, it means the battery cannot be fully charged or discharged all at once; a complete charge requires an infinite amount of time at a charge current that asymptotically approaches zero. Second, it means that the battery's ability to charge and discharge depends not only on its current state of charge, but also on its recent charge and discharge history. A battery rapidly charged to 80% state of charge will be capable of a higher discharge rate than the same battery rapidly discharged to 80%, since it will have a higher level in its available tank.

We specify the battery bank's capital and replacement costs and the O&M cost per year. Since the battery bank is a dispatchable power source, its fixed and marginal cost of energy are calculated for comparison with other dispatchable sources.

Input values for modelling batteries

Among the batteries available in HOMER Energy library, we chose the Discover 12VRE-3000TF-L lead acid batteries with a nominal voltage of 12 V, a nominal capacity of 215 Ah and a round trip efficiency of 85%.

Lead acid batteries are the most suitable technology for solar PV storage systems because of their high round-trip efficacy and for the ratio between price and performance. Moreover, lead acid batteries are an easily available and affordable solution in our context. According to the voltage range of the converter, we limited the number of batteries per string to 4 in order to reach a maximum voltage of 48V. The number of parallel strings depends on the energy load and on the global system and is calculated as output by the software. For the other parameters we keep the standard values given by HOMER Energy which are reported in Table 5.6.

We set up the costs of the battery bank referring to a paper written by Sen and Bhattacharyya [43].

Nominal voltage (V)	12
Nominal capacity (Ah)	215
Round trip efficiency (%)	85
Max batteries per string	4
Maximum capacity (Ah)	244.971
Initial state of charge (%)	100
Minimum state of charge (%)	20
Lifetime throughput (kWh)	3550
Capital cost (€)	220

O&M cost (€/yr)	10
Replacement cost (€)	176

Table 5.6: Input parameters for batteries

5.2.4 Water tanks model

In our analysis we evaluated also the possibility to install water tanks. This solution could be seen as an alternative to the storage of electricity into the batteries, bringing to the reduction of the battery bank size.

In HOMER Energy there are not components modelling water storage. For this reason we used the battery component to model also this kind of storage, with the following assumptions:

- We considered a round trip efficiency of 100% because water storage does not present charge and discharge losses.
- We increased the lifetime of batteries to the standard value, for water storage, of 40 years.
- For costs we had to calculate a conversion factor (m^3/kWh) to be able to define a cost of storage in €/l. We specify the method used in the following paragraph.

Calculation of conversion factor

Firstly we simulate the system without water storage and we calculated the amount of energy stored ($E_{storage}$) into the battery bank in the following way:

$$E_{storage} = n_{batteries} V_{battery} C_{battery} \qquad [kWh]$$

Where $n_{batteries}$ is the number of batteries, $V_{battery}$ is the nominal voltage of batteries and $C_{battery}$ is the nominal capacity of the batteries.

Then we calculated the average flow rate of a pump using the average depth of the well and the average power obtained thanks to our survey. We assumed an average pump efficiency of 0.9.

$$Q_{ave} = \frac{P_{ave} \eta_{pump}}{h_{ave} \rho g} \qquad \left[\frac{m^3}{s}\right]$$

Where Q_{ave} is the average flow rate of the pump, P_{ave} is the average power of the pump, η_{pump} is the efficiency of the pump, h_{ave} is the average depth of the well, ρ is the density of the water and g is the acceleration of gravity.

With these data we can estimate the equivalent volume of water that should be stored to replace batteries.

$$V_{storage} = \frac{E_{storage} Q_{ave} \eta_{roundtrip}}{P_{ave}} \qquad [m^3]$$

Where $V_{storage}$ is the volume of the water tank, $E_{storage}$ is the energy stored in the battery bank, Q_{ave} is the average flow rate of the pump, $\eta_{roundtrip}$ is the round-trip efficiency equal to 0.85 and P_{ave} is the average power of the pump installed.

The conversion factor is:

$$f = \frac{V_{storage}}{E_{storage}} \qquad \left[\frac{m^3}{kWh}\right]$$

For the definition of water storage costs, we referred to a document [44] which presents the quotes of three different local suppliers for a water tank. The value used is an average and is equal to 0.21 €/l.

5.2.5 Converter model

A converter is a device that converts electric power from DC to AC in a process called inversion, and/or from AC to DC in a process called rectification.

The converter size, which is a decision variable, refers to the inverter capacity, meaning the maximum amount of AC power that the device can produce by inverting DC power. We specify the rectifier capacity, which is the maximum amount of DC power that the device can produce by rectifying AC power, as a percentage of the inverter capacity. The rectifier capacity is therefore not a separate decision variable. The inverter and rectifier capacities are not assumed to be surge capacities that the device can withstand for only short periods of time, but rather, continuous capacities that the device can withstand for as long as necessary.

We need also to indicate whether the inverter can operate in parallel with another AC power source such as a generator or the grid. Doing so requires the inverter to synchronize to the AC frequency, an ability that some inverters do not have.

The final physical properties of the converter are its inversion and rectification efficiencies, which are assumed to be constant. The economic properties of the converter are its capital and replacement cost in dollars, its annual O&M cost in dollars per year, and its expected lifetime in years.

Input values for modelling the converter

In our simulation we used the default converter available in the library. To set up the parameters we used some papers [43], [42], [45], [46] and the standard data given by HOMER Energy. We present the data in Table 5.7.

Input	Value	Source
Lifetime (years)	15	[45]
Inverter efficiency (%)	90	[43]
Rectifier efficiency (%)	85	[43]
Relative rectifier capacity (%)	100	HOMER Energy
Capital cost (€)	80	[42]
O&M cost (€/yr)	5	[43]
Replacement cost (€)	56	[46]

Table 5.7: Input parameters for converter

5.2.6 Grid model

Grid is present in HOMER Energy as one of the components of the system. At the beginning of our analysis, we used this component, but we figured out that modelling the unscheduled blackouts which characterize the context was not possible. In order to solve this problem we decided to use a generator to model the grid, with the following assumptions:

- We created a new fuel called "grid power" where 1 kg is equivalent to 1 kWh. The energy content of the fuel is 3.6 MJ/kg and the density is 1,000 kg/cubic meter. In this way when HOMER Energy reports "grid power" consumption in kg we know that this is equal to kWh.

- In the fuel curve section, we set the Intercept coefficient to 0 and the Slope to 1. This makes our "grid" a 100% fuel efficient machine, meaning we get to use every kWh that the "grid" delivers, none of it is lost through combustion.

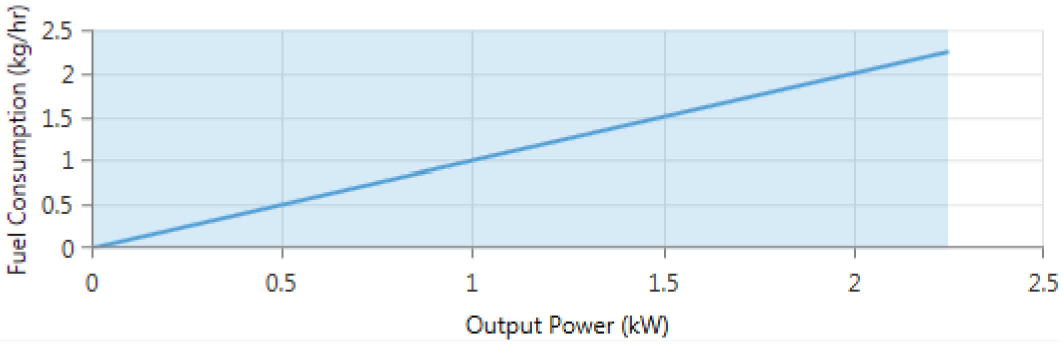


Fig. 5.11: Fuel curve for "grid" generator

- The "grid" can then be scheduled off using the Generator Scheduling capability. We determined the duration and frequency of outages in the schedule tab of the generator inputs window. This allows us to have a different "outage schedule" every month. The only limitations are that it is not random, and the schedule must be consistent during each month.
- We modelled the grid in a way that does not allow to sell electricity back to the grid.
- As explained in Chapter 2, farmers do not pay the effective energy consumption (\$/kWh), but they pay a fixed monthly tariff depending on the power of pumps present in the fields. For this reason we set the fuel price equal to 0 \$/kWh. Then we set the capital cost of the "grid" equal to the replacement cost and to the monthly tariff. We fixed the lifetime of the generator to a number of hours which guarantee the replacement of the generator each month.

5.2.7 Global modelling parameters

HOMER Energy requires also some global parameters for the project. We report these data in Table 5.8.

Annual nominal interest rate (%)	5-7
Expected inflation rate (%)	2
Project lifetime (years)	25
Goal	Economic minimization
Maximum annual capacity shortage (%)	10, 20, 30

Table 5.8: Input parameters for project set up

For the annual nominal interest rate we selected two different values depending on the system size, which involves different values of capital investment. Three different strategies for the definition of the best solution can be used: economic minimization, fuel minimization, weight minimization. We used the first one for our analysis. Moreover we analyzed how the solutions vary for different values of capacity shortage. In the Results section we reported only the solutions for a value of 30% capacity shortage, because we assumed that this value is the more realistic one for the implementation of project. The complete set of results is given in Appendix C.

5.3 Results

In this section we present the results of the simulations. We consider separately the three configurations and, at the end of the chapter, we compare them.

5.3.1 Configuration A

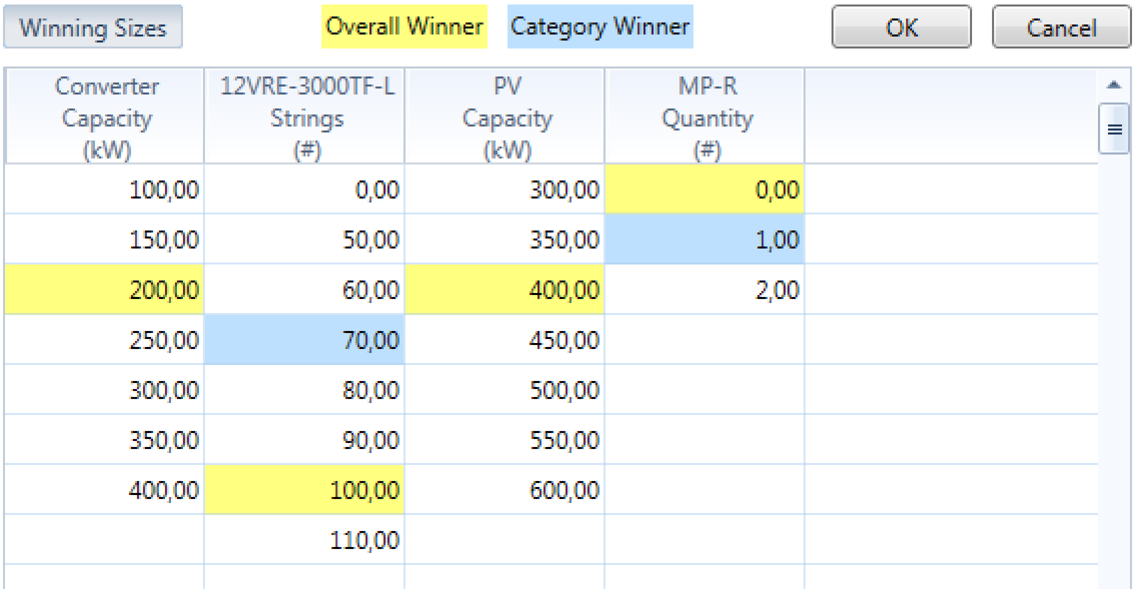
Starting from Configuration A, we considered the three following scenarios:

A1. A stand-alone system;
A2. A grid-connected system with electricity supply from 10 AM to 2 PM;
A3. A grid-connected system with electricity supply from 1 AM to 5 AM.

The grid-connected scenarios represent the two current situations that farmers have to face because of scheduled blackouts. In one case, we considered the supply time slot from 8 AM to 4 PM, in the other case we consider both the time slots from 4 PM to midnight and from midnight to 8 AM. We grouped these two time slots in one simulation because they are similar from an irrigation perspective: in both situations there is not electricity demand for most of the time in which electricity is supplied. We decided also to reduce the electricity supply from 8 to 4 hours to consider the unreliability of the national grid, since HOMER Energy does not allow the setup of random blackouts. We did not make simulations for the hypothetical situation of full reliability of the grid because we do not expect an improvement of this infrastructure during the project implementation.

Scenario A1: stand-alone system

For this scenario we chose the Vergnet GEV MP-R (275 kW) wind turbine because of the high electric load (peak load of 483.25 kW). For all the components we selected a reasonable range of sizes as shown in Fig. 5.12.

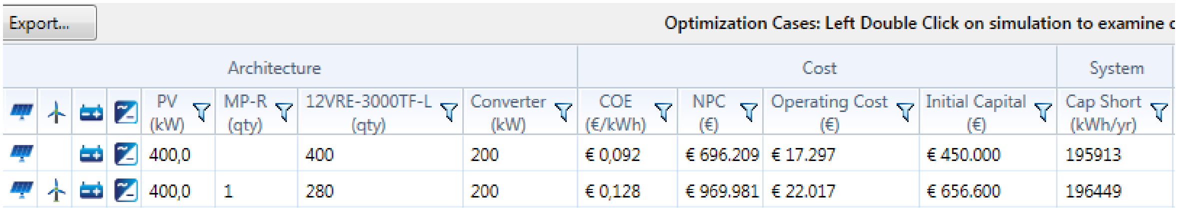


Converter Capacity (kW)	12VRE-3000TF-L Strings (#)	PV Capacity (kW)	MP-R Quantity (#)
100,00	0,00	300,00	0,00
150,00	50,00	350,00	1,00
200,00	60,00	400,00	2,00
250,00	70,00	450,00	
300,00	80,00	500,00	
350,00	90,00	550,00	
400,00	100,00	600,00	
	110,00		

Fig. 5.12: Picture taken from HOMER Energy representing the search space for the scenario A1 and the winning sizes

HOMER Energy uses these inputs to simulate different system configurations, or combinations of components, and generates results as a list of feasible configurations ranked by net present cost (NPC). For the range choice we did some attempts to verify the accuracy of our choice: for all the solutions the winning size should not be one of the end values of our range (except for value 0).

In this scenario the overall winner solution is highlighted in yellow in Fig. 5.12. HOMER Energy found two different solutions: one with all the components (wind turbine, PV and batteries) and one with only solar PV and batteries (without wind turbine), as reported in Fig. 5.13.

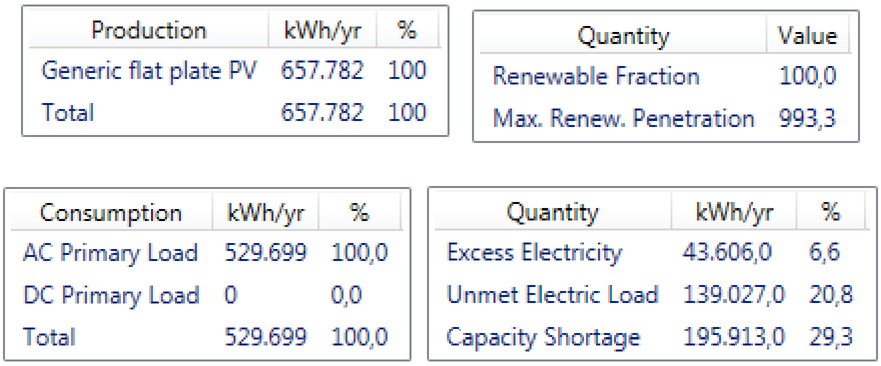


Optimization Cases: Left Double Click on simulation to examine c

Architecture								Cost					System
				PV (kW)	MP-R (qty)	12VRE-3000TF-L (qty)	Converter (kW)	COE (€/kWh)	NPC (€)	Operating Cost (€)	Initial Capital (€)		Cap Short (kWh/yr)
✓		✓	✓	400,0		400	200	€ 0,092	€ 696.209	€ 17.297	€ 450.000		195913
✓	✓	✓	✓	400,0	1	280	200	€ 0,128	€ 969.981	€ 22.017	€ 656.600		196449

Fig. 5.13: Optimized solutions in output from HOMER Energy for scenario A1

The best economic solution is the one with solar PV, converter and batteries with a NPC of 696,209 € instead of 969,981 €. The reason for this difference is the high capital cost of wind turbine which impacts on costs more than the reduction of batteries. The impact of the wind component on costs stands out also in the values of initial capital costs with a gap of more than 200,000 €.



Production	kWh/yr	%
Generic flat plate PV	657.782	100
Total	657.782	100

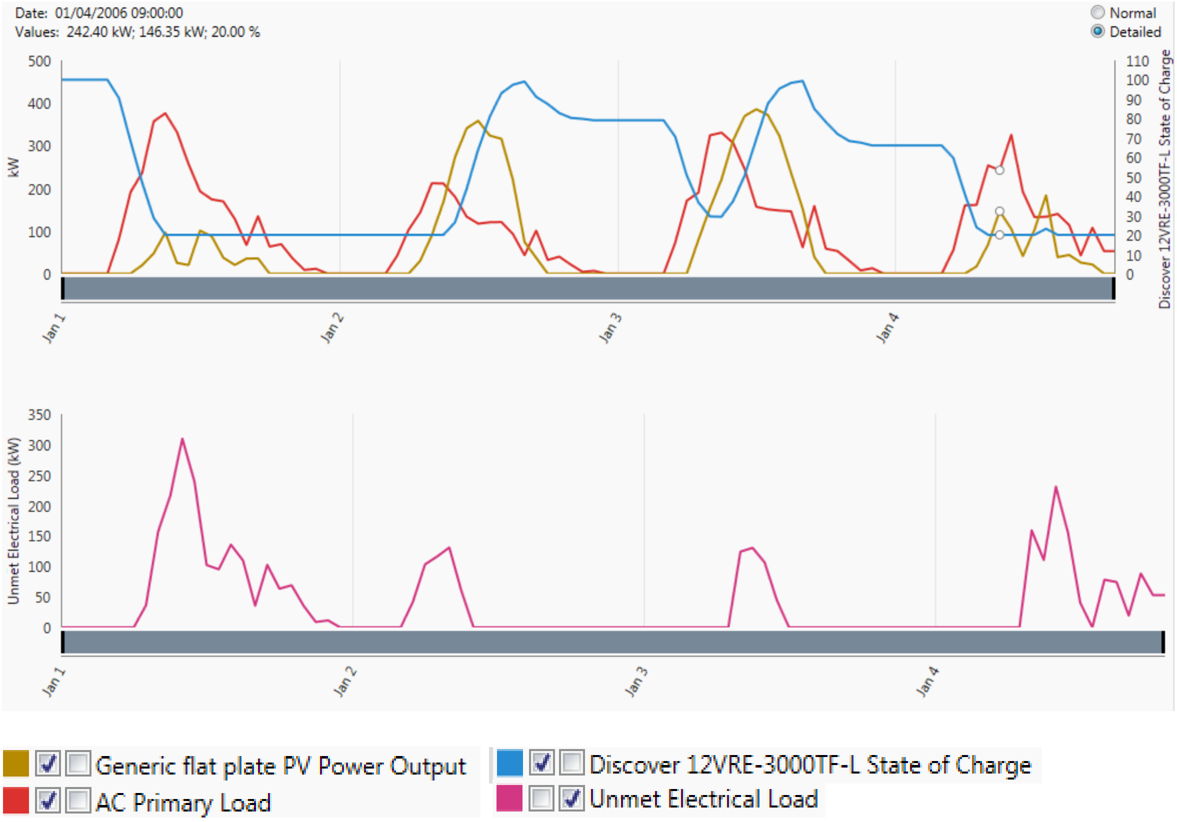
Quantity	Value
Renewable Fraction	100,0
Max. Renew. Penetration	993,3

Consumption	kWh/yr	%
AC Primary Load	529.699	100,0
DC Primary Load	0	0,0
Total	529.699	100,0

Quantity	kWh/yr	%
Excess Electricity	43.606,0	6,6
Unmet Electric Load	139.027,0	20,8
Capacity Shortage	195.913,0	29,3

Fig. 5.14: Electrical output of the best solution of scenario A1

With the best solution we obtained an excess of electricity of 6.6%, an unmet electric load of 20.8% and a capacity shortage of 29.3% (minus than the 30% limit imposed). Excess electricity is the surplus electrical energy that must be dumped. For this solution the excess electricity fraction is not high, that means that there is not a big surplus of power (by renewable sources) which cannot be used or absorbed by batteries. The amount of unmet load could represent a problem since 20.8% is a significant value. This is true for a system installed in a developed and fully electrified context, whereas in the village of Katgaon it represents a great improvement compared to the current situation.



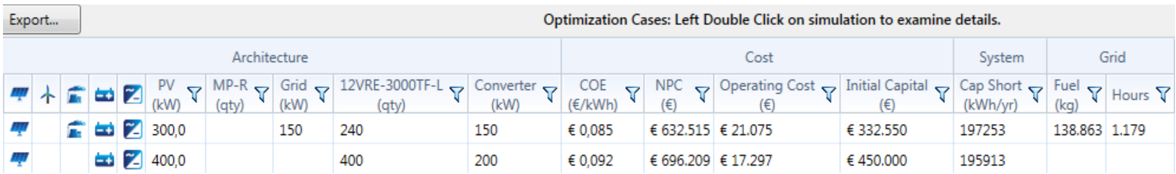
Date: 01/04/2006 09:00:00
Values: 242.40 kW; 146.35 kW; 20.00 %

Fig. 5.15: Detailed trend of energy load, solar PV output, batteries state of charge and unmet load

We report an extract of the daily load and power curves to understand how the system works. As Fig. 5.15 shows, during the year batteries charge and discharge according to the primary load and the solar available radiation, that means PV power output. We selected these days because they allow analysing how the power plant works under different conditions. In the first day the primary load is bigger than the power output of the solar system, that satisfies as much as possible the demand using also the energy stored in batteries, which are fully charged in the beginning. At the end of the day, batteries have reached the minimum allowed state of charge and the amount of unmet load is quite high. In the following days, the demand varies and the solar output increases and remains bigger than the load demand. This situation allows the charge of batteries which provide for electricity when the solar radiation is not enough. The last day the solar radiation decreases in a significant way (representing a cloudy day) with a following increase of unmet load. The system is therefore able to satisfy the electrical needs for agriculture during sunny days, while in the other days there is a higher share of unmet load. However, this could be not such a negative issue for our purpose: since we are analyzing the electrical requirements for irrigation, in cloudy days there is a lower evapotranspiration and a lower need of irrigation.

Scenario A2: grid-connected system (daily supply)

In this scenario we simulated a system composed of a power plant that interacts with the existent grid. From the simulations, we obtained the results shown in Fig. 5.16.

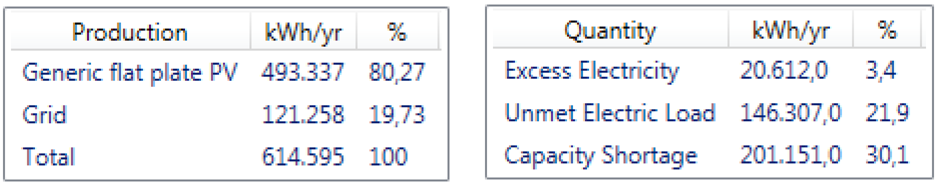


Optimization Cases: Left Double Click on simulation to examine details.

Architecture					Cost				System	Grid	
PV (kW)	MP-R (qty)	Grid (kW)	12VRE-3000TF-L (qty)	Converter (kW)	COE (€/kWh)	NPC (€)	Operating Cost (€)	Initial Capital (€)	Cap Short (kWh/yr)	Fuel (kg)	Hours
300,0		150	240	150	€ 0,085	€ 632.515	€ 21.075	€ 332.550	197253	138.863	1.179
400,0			400	200	€ 0,092	€ 696.209	€ 17.297	€ 450.000	195913		

Fig. 5.16: Optimized solutions in output from HOMER Energy for scenario A2

There are two possible solutions: one involves the supply of electricity from the national grid and the other is equivalent to a stand-alone system. The connection to the grid brings about a decrease in the installed solar power (from 400 kW to 300 kW) and a lower number of batteries (from 400 to 240). The second solution is equivalent to scenario A1 analyzed in the above paragraph. The NPC of the grid-connected solution is 636,014 €, that means about 60,000 € less than the stand-alone solution. For the initial capital cost, the economical convenience is evident, but the grid-connected solution implies higher operating costs (which include the bill for the electricity supply).



Production	kWh/yr	%
Generic flat plate PV	493.337	80,27
Grid	121.258	19,73
Total	614.595	100

Quantity	kWh/yr	%
Excess Electricity	20.612,0	3,4
Unmet Electric Load	146.307,0	21,9
Capacity Shortage	201.151,0	30,1

Fig. 5.17: Electrical output of scenario A2

The electrical analysis of the grid-connected solution in Fig. 5.17 reports that in this case the capacity shortage approaches the imposed 30% limit, the excess electricity is lower than the stand-alone solution (3.4%) and the unmet electricity load is about the same (21.9%). The load is satisfied for the 19.73% by the national grid, and for the remaining by our plant with a renewable fraction of 73.3%. It is important to stress that the unreliability of the grid (that we considered decreasing to 4 the hours of electricity supply) could be bigger and it could bring to a higher unmet electric load.

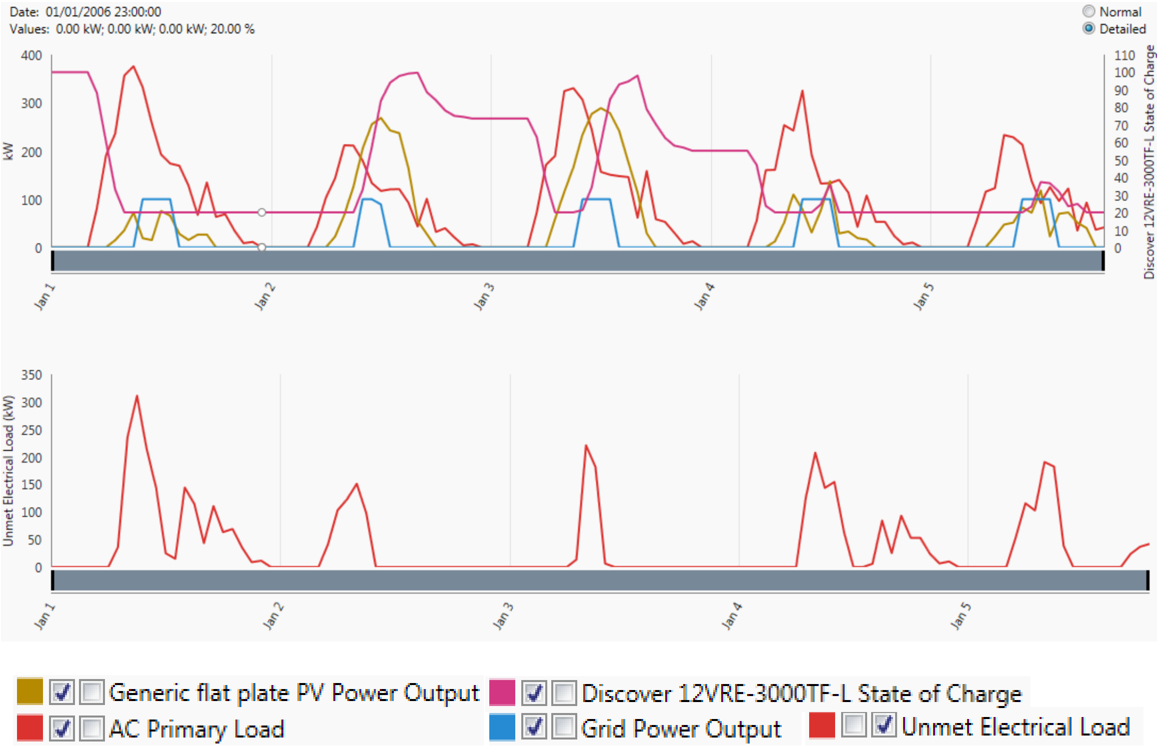
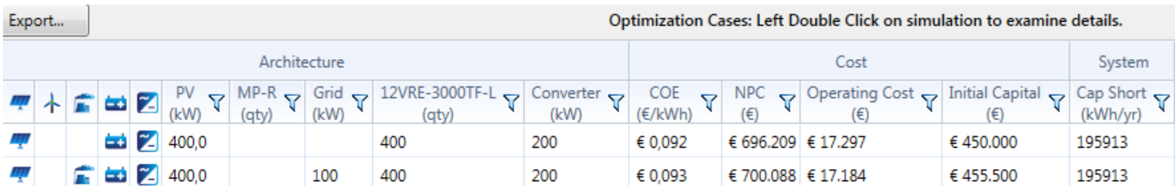


Fig. 5.18:Detailed trend of energy load, solar PV output, batteries state of charge, grid power output and unmet load

Also, for this scenario we report an extract of the daily load and power curves to understand how the system works. The logic behind the cycle of batteries charging and discharging is the same of scenario A1. The supply of electricity from the grid in the central hours of the day generates the decrease in size of solar PV, that produces a lower amount of energy.

Scenario A3: grid-connected system (nightly supply)

In this scenario, we simulate the electric supply during the night hours (when there is no demand for irrigation). In this situation, electricity could be used to charge batteries during the night and use the stored energy when there is demand. The result of simulations are shown in Fig. 5.19.



Optimization Cases: Left Double Click on simulation to examine details.

Architecture					Cost				System
PV (kW)	MP-R (qty)	Grid (kW)	12VRE-3000TF-L (qty)	Converter (kW)	COE (€/kWh)	NPC (€)	Operating Cost (€)	Initial Capital (€)	Cap Short (kWh/yr)
400,0			400	200	€ 0,092	€ 696.209	€ 17.297	€ 450.000	195913
400,0		100	400	200	€ 0,093	€ 700.088	€ 17.184	€ 455.500	195913

Fig. 5.19: Optimized solutions in output from HOMER Energy for scenario A3

The HOMER Energy output gives the stand-alone system (the same of scenario A1) as the most economic solution. If the electricity is supplied during the night, the system does not purchase electricity and relies only on self production. This means that using the grid at night to charge the battery bank is not convenient for farmers. Moreover, the grid-connected solution given as output does not purchase electricity from the grid. The difference in costs between the configurations in Fig. 5.19 is not to be ascribed to a real higher investment cost for the grid-connected solution, but rather to costs related to the purchase of electricity from grid by farmers in the grid-connected solution.

Configuration A: summary of results

In Table 5.9 we present the best solution for each scenario considered. Both the size of components of the energy systems and the costs of each solution are reported in the table.

	PV	**Grid**	**Battery**	**Inverter**	**COE**	**NPC**	**O&M Cost**	**Initial Capital**	**Capacity Shortage**
Scenario	kW	kW	Qty	kW	€/kWh	€	€/yr	€	kWh/yr
A1	400	0	400	200	0.092	696,209	17,297	450,000	195,913
A2	300	150	240	150	0.085	632,515	21,075	332,550	197,253
A3	400	0	400	200	0.092	696,209	17,297	450,000	195,913

Table 5.9: Configuration A: optimized solutions (size of components and costs)

The best scenario results to be the grid-connected power plant when electricity is supplied daily. This solution presents a lower NPC and lower initial investment costs, while the O&M costs are higher than the stand-alone solution because of the costs of electricity supply from the national grid. The grid-connected solution presents also a lower COE, which means that the cost of electricity for farmers is lower for this solution.

5.3.2 Configuration B

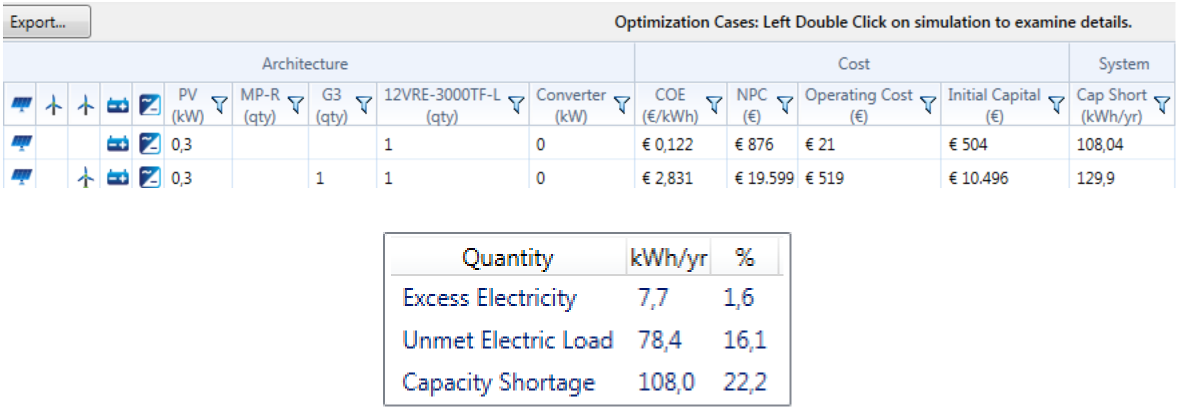
In Configuration B we considered 3 different scenarios for each farmer, for a total of 45 different scenarios. The different kind of scenarios are the same of Configuration A.

The results of all the scenarios are reported in Appendix C. We reported the results for two farmers: the one with the lowest energy load (Farmer II) and the one with the highest energy load (Farmer XIV).

As wind turbine component, we selected the generic 3 kW turbine because of the small dimension of the energy load (the maximum peak load is 16.90 kW).

Scenario B Farmer II-1: stand-alone system

Also in this scenario the best solution is the system composed of solar PV (0.3 kW) and batteries (1). The size of this system is really different from the previous scenarios and also the costs are of another order of magnitude. The solution has a NPC of 876 €, an excess electricity of 1.6%, an unmet electricity load of 16.1% and a capacity shortage of 22.2% (as reported in Fig. 5.20). For small size systems, the difference between the solar PV solution and the hybrid wind-solar PV solution is more evident. The difference in the NPC is about 18,000 €.



PV (kW)	MP-R (qty)	G3 (qty)	12VRE-3000TF-L (qty)	Converter (kW)	COE (€/kWh)	NPC (€)	Operating Cost (€)	Initial Capital (€)	Cap Short (kWh/yr)
0,3			1	0	€ 0,122	€ 876	€ 21	€ 504	108,04
0,3		1	1	0	€ 2,831	€ 19.599	€ 519	€ 10.496	129,9

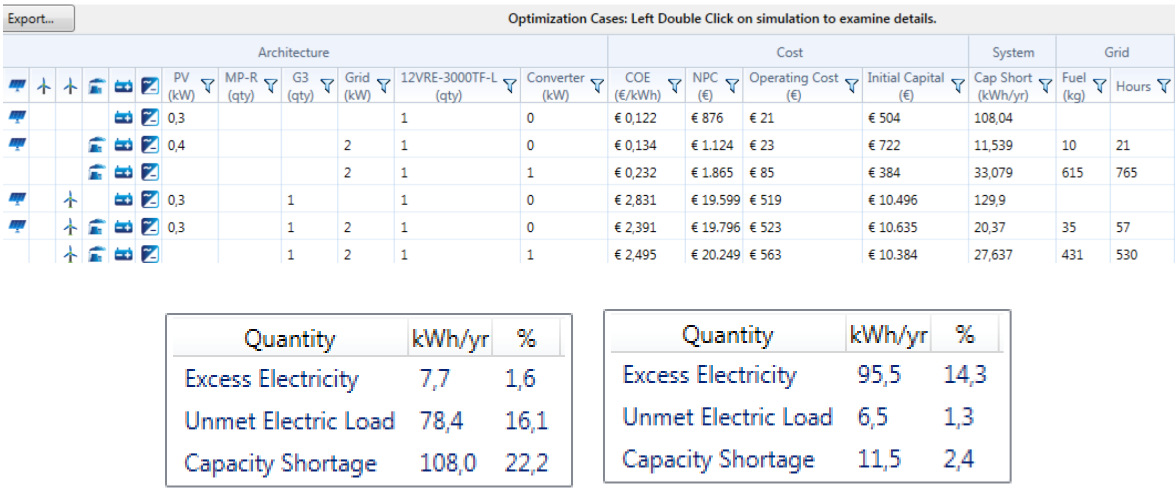
Quantity	kWh/yr	%
Excess Electricity	7,7	1,6
Unmet Electric Load	78,4	16,1
Capacity Shortage	108,0	22,2

Fig. 5.20: Optimized solutions and electrical output from HOMER Energy for scenario BII.1

Scenario B Farmer II-2: grid-connected system (daily supply)

In this scenario we allow the system to choose to buy electricity from grid or produce it with a stand-alone plant. The best economic solution is the stand-alone plant (already described in scenario BII-1) without connection to the national grid. However, we analyze also the grid-connected solution.

The grid-connected solution implies higher costs related to the purchase of electricity from grid and to the bigger size of converter and PV power installed. The increase in PV size involves low values for the unmet electricity load (1.3%) and for the capacity shortage (2.4%). The grid-connected system is more expensive, but also more efficient with a profile of power production which is about the same of the electric load profile. HOMER Energy does not give as output a system with the same PV size of the stand-alone plant and with less energy purchased from the grid. This solution should be cheaper with an higher capacity shortage.



Optimization Cases: Left Double Click on simulation to examine details.

Architecture												Cost				System	Grid	
						PV (kW)	MP-R (qty)	G3 (qty)	Grid (kW)	12VRE-3000TF-L (qty)	Converter (kW)	COE (€/kWh)	NPC (€)	Operating Cost (€)	Initial Capital (€)	Cap Short (kWh/yr)	Fuel (kg)	Hours
●				●	●	0,3				1	0	€ 0,122	€ 876	€ 21	€ 504	108,04		
●			●	●	●	0,4			2	1	0	€ 0,134	€ 1.124	€ 23	€ 722	11,539	10	21
			●	●	●				2	1	1	€ 0,232	€ 1.865	€ 85	€ 384	33,079	615	765
●		●		●	●	0,3		1		1	0	€ 2,831	€ 19.599	€ 519	€ 10.496	129,9		
●		●	●	●	●	0,3		1	2	1	0	€ 2,391	€ 19.796	€ 523	€ 10.635	20,37	35	57
		●	●	●	●			1	2	1	1	€ 2,495	€ 20.249	€ 563	€ 10.384	27,637	431	530

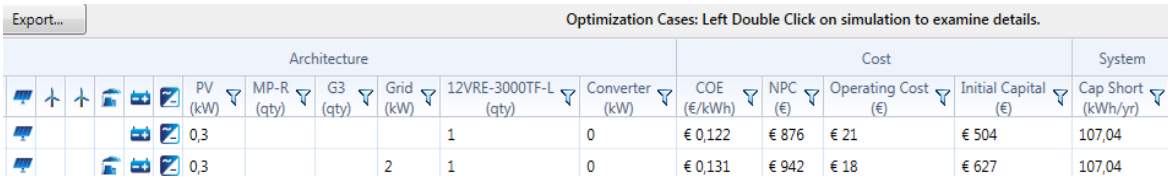
Quantity	kWh/yr	%
Excess Electricity	7,7	1,6
Unmet Electric Load	78,4	16,1
Capacity Shortage	108,0	22,2

Quantity	kWh/yr	%
Excess Electricity	95,5	14,3
Unmet Electric Load	6,5	1,3
Capacity Shortage	11,5	2,4

Fig. 5.21: Optimized solutions and electrical output from HOMER Energy for scenario BII.2

Scenario B Farmer II-3: grid-connected system (nightly supply)

In this scenario electricity is supplied during the night. HOMER Energy gives as output the stand-alone solution (found in scenario BII-1) and a grid-connected solution in which the electricity from grid is never used.



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Optimization Cases: Left Double Click on simulation to examine details.

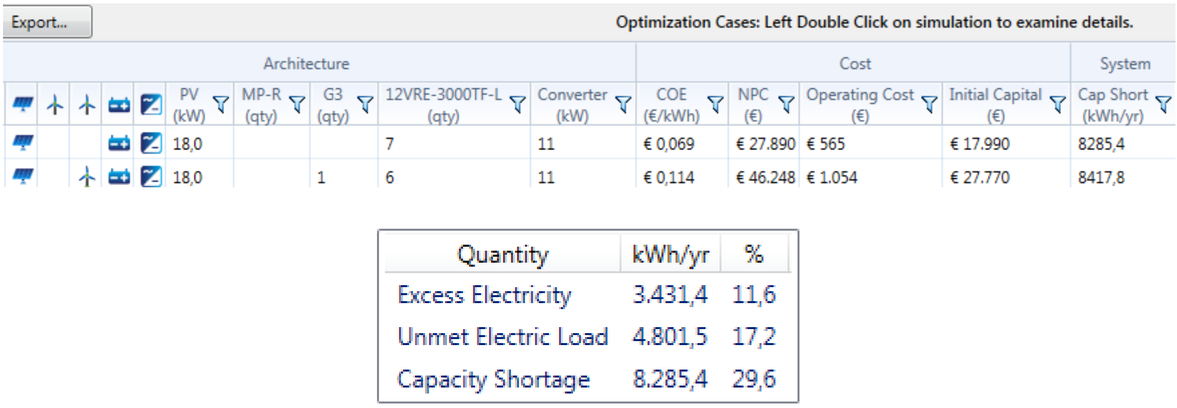
Architecture						Cost					System
PV (kW)	MP-R (qty)	G3 (qty)	Grid (kW)	12VRE-3000TF-L (qty)	Converter (kW)	COE (€/kWh)	NPC (€)	Operating Cost (€)	Initial Capital (€)		Cap Short (kWh/yr)
0,3				1	0	€ 0,122	€ 876	€ 21	€ 504		107,04
0,3			2	1	0	€ 0,131	€ 942	€ 18	€ 627		107,04

Fig. 5.22: Optimized solutions for scenario BII.3

Also for the other simulations, the scenarios involving the electricity supply during the night give as output the same solution of the corresponding stand-alone scenarios. For this reason in the next analysis we will not further consider this scenario.

Scenario B Farmer XIV-1: stand-alone system

As shown in Chapter 4, Farmer XIV has a high electricity load, concentrated in a single time slot. For the stand-alone plant, HOMER Energy displays two alternatives: a solar PV system or a hybrid wind-solar PV system. The best solution is the PV system with a power installed of 18 kW, 7 batteries and an 11 kW converter (Fig. 5.23). The excess electricity is 11.6%, the unmet electric load is 17.2% and the capacity shortage of the system is 29.6%.



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Optimization Cases: Left Double Click on simulation to examine details.

Architecture					Cost				System
PV (kW)	MP-R (qty)	G3 (qty)	12VRE-3000TF-L (qty)	Converter (kW)	COE (€/kWh)	NPC (€)	Operating Cost (€)	Initial Capital (€)	Cap Short (kWh/yr)
18,0			7	11	€ 0,069	€ 27.890	€ 565	€ 17.990	8285,4
18,0		1	6	11	€ 0,114	€ 46.248	€ 1.054	€ 27.770	8417,8

Quantity	kWh/yr	%
Excess Electricity	3.431,4	11,6
Unmet Electric Load	4.801,5	17,2
Capacity Shortage	8.285,4	29,6

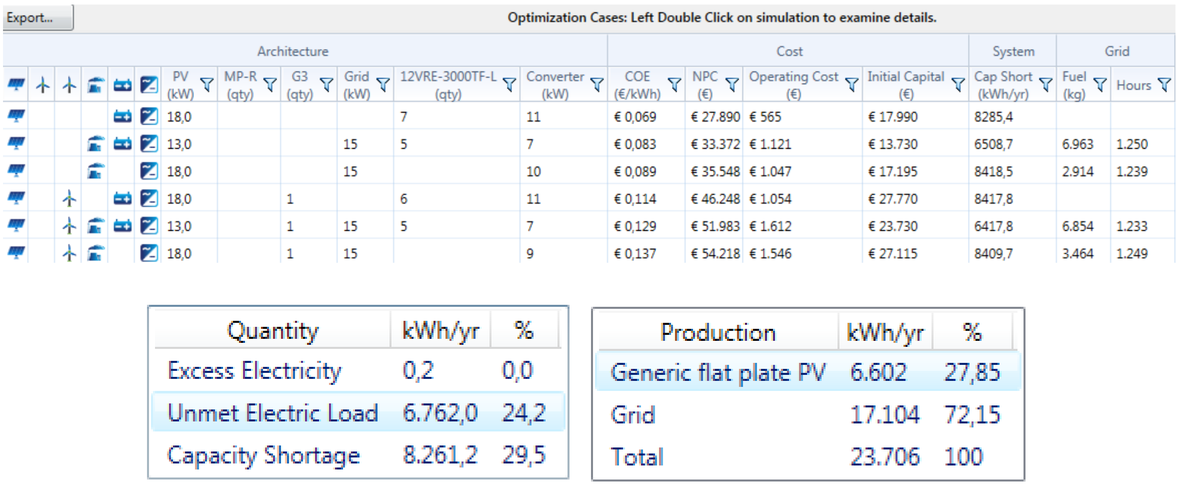
Fig. 5.23: Optimized solutions and electrical output from HOMER Energy for scenario BXIV.1

We report the detailed profiles of solar power output, primary load and inverter power output. Fig. 5.24 shows that the unmet electric load and the capacity shortage are related to the size of converter. Since the load is concentrated in the central hours of the day, solar power is sufficient to satisfy the total load in sunny days. Despite of this, HOMER Energy selects a small converter which allows to follow the clause on capacity shortage minimizing the NPC as requests by the optimization. Batteries are mainly used as back up for cloudy days.

Fig. 5.24: Trend of energy load, solar PV output and inverter power output

Scenario B Farmer XIV-2: grid-connected system

Even when the farmer is connected to the grid, the best solution remains the stand-alone plant. The grid-connected solution (in Fig. 5.25) presents a higher NPC which differs only by about 5000 € from the best solution. The initial capital cost instead is about 4000 € higher because the size of PV power installed is smaller. The grid-connected solution relies mainly on the national grid with a renewable fraction (which accounts for solar PV) of 27.85%. A third possible scenario is a system composed only of the grid and solar PV without any kind of storage. This system presents reliability and stability problems and for this reasons it is not considered in this analysis.



Optimization Cases: Left Double Click on simulation to examine details.

Architecture						Cost				System	Grid	
PV (kW)	MP-R (qty)	G3 (qty)	Grid (kW)	12VRE-3000TF-L (qty)	Converter (kW)	COE (€/kWh)	NPC (€)	Operating Cost (€)	Initial Capital (€)	Cap Short (kWh/yr)	Fuel (kg)	Hours
18,0				7	11	€ 0,069	€ 27.890	€ 565	€ 17.990	8285,4		
13,0			15	5	7	€ 0,083	€ 33.372	€ 1.121	€ 13.730	6508,7	6.963	1.250
18,0			15		10	€ 0,089	€ 35.548	€ 1.047	€ 17.195	8418,5	2.914	1.239
18,0		1		6	11	€ 0,114	€ 46.248	€ 1.054	€ 27.770	8417,8		
13,0		1	15	5	7	€ 0,129	€ 51.983	€ 1.612	€ 23.730	6417,8	6.854	1.233
18,0		1	15		9	€ 0,137	€ 54.218	€ 1.546	€ 27.115	8409,7	3.464	1.249

Quantity	kWh/yr	%
Excess Electricity	0,2	0,0
Unmet Electric Load	6.762,0	24,2
Capacity Shortage	8.261,2	29,5

Production	kWh/yr	%
Generic flat plate PV	6.602	27,85
Grid	17.104	72,15
Total	23.706	100

Fig. 5.25: Optimized solutions and electrical output from HOMER Energy for scenario BXIV.2

In this scenario electricity is supplied by the grid from 10 AM to 2 PM, while the load starts at 7 AM and ends at 4 PM. Fig. 5.26 represents how the components satisfy the electric demand. The electricity supply from grid, when present, is sufficient to satisfy the load, while during the period of scheduled blackouts the power is supplied by batteries, which are charged with the electricity produced in excess by solar panels and with electricity in excess from the grid. The unmet load is present only in the hours in which there is no electricity supply and it happens when batteries reach the minimum state of charge.

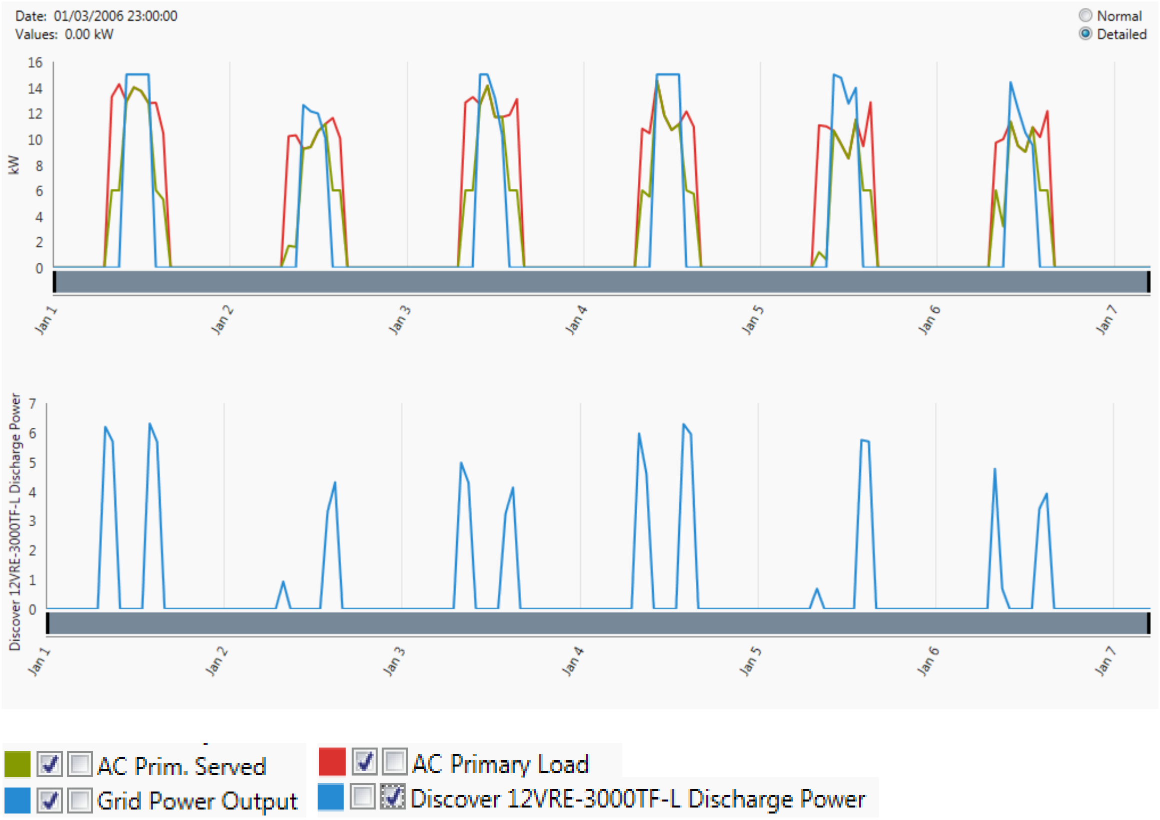


Fig. 5.26: Trend of energy load, energy load served, grid power output and batteries state of charge

Configuration B: summary of results

In Table 5.10 we report a summary of the solutions found for the fifteen farmers. We present the average energy system calculated as the average of the best solutions for each farmer, both for the stand-alone and the grid-connected scenario. Then we present, for both scenarios, the solutions with the highest and the lowest size of PV installed and the solutions with the highest and the lowest COE. For the grid-connected scenario, we present also the solution with the highest grid power installed.

The average solutions both for the grid-connected and the stand-alone scenarios present a different size of solar PV, but the NPC and the COE are the same. This means that, from an economic point of view, the solutions are equivalent and the choice between them should be based on other criteria.

From the analysis of the solutions, the scenarios with the highest PV power installed result to be also the scenarios with the highest NPC and the highest Initial Capital Cost. The solutions with the lowest PV power installed result to be the solutions with the lowest NPC and the lowest Initial Capital Cost. We can derive that the component with the highest impact on NPC and Initial Capital cost are the PV panels.

The solution which relies on the national grid is the solution with the highest O&M costs. As stated above, this is due to the costs that farmers have to sustain to purchase electricity from the grid.

The COE presents a great variability among the different solutions with values between 0.067 €/kWh and 0.132 €/kWh.

	PV	**Grid**	**Battery**	**Inverter**	**COE**	**NPC**	**O&M Cost**	**Initial Capital**	**Farmer**
Scenario	kW	kW	qty	kW	€/kWh	€	€/yr	€	
B1 average	5.0	0.0	4.9	3.7	0.096	10,055	253	5,682	
B2 average	4.4	0.9	4.9	3.4	0.096	10,012	275	5,196	
B1 max PV	18	0	7	11	0.069	27,890	565	17,990	XIV
B2 max PV	18	0	7	11	0.069	27,890	565	17,990	XIV
B2 max grid	3	7.5	10	4.5	0.126	16,256	610	5,568	XI
B1 min PV	0.3	0	1	0.3	0.122	876	21	504	II
B2 min PV	0.3	0	1	0.3	0.122	876	21	504	II
B1 max COE	4.5	0	9	4	0.132	12,819	378	6,193	V
B2 max COE	4.5	0	9	4	0.132	12,819	378	6,193	V
B1 min COE	3.5	0	1	2	0.067	5,260	106	3,408	III
B2 min COE	3.5	0	1	2	0.067	5,260	106	3,408	III

Table 5.10: Configuration B: summary of solutions (sizes of components and costs) for particular scenarios

5.3.3 Configuration C

In this configuration we have three different clusters. For each cluster we simulated

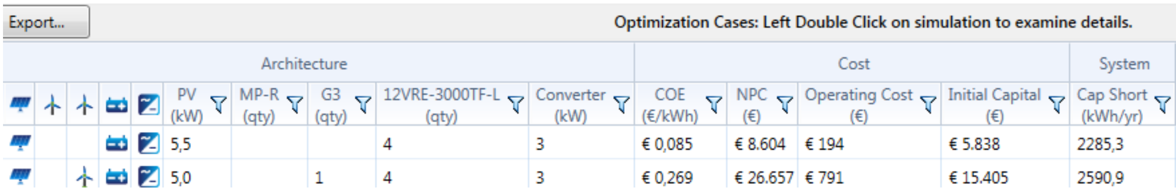
- The stand-alone scenario;
- The grid-connected scenario with electricity supply from 10 AM to 2 PM;
- The grid-connected scenario with electricity supply from 10 AM to 2 PM and random blackouts in this time slot;
- The stand-alone scenario with water storage.

For the scenario with water storage we present the results for only one cluster. In the other scenarios we compare different clusters.

As wind turbine component, we selected the generic 3 kW turbine because of the small dimension of the energy load.

Scenarios Cluster CI-1, Cluster CII-1, Cluster CIII-1: stand-alone systems

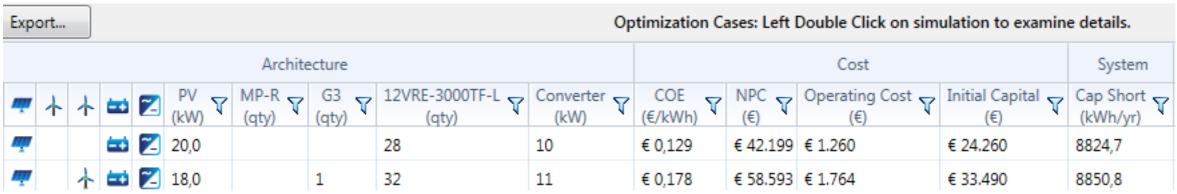
There are two possible designs for the stand-alone plant: a solar PV system and a hybrid wind-solar PV system. For all the scenarios, the best solution is the PV system because, as highlighted in the previous scenarios, wind turbines present high capital costs which are not balanced out by the cost reduction of the other components. The sizes of the system for the three clusters are various due to the different magnitude of the loads. Cluster I is the smaller one, composed only of farmers of small dimensions. The best solution is a 5.5 kW PV system with 4 batteries and a 3 kW converter. This plant is also smaller than the system found as solution for the big single farmers. Also the NPC of this system is lower than the other and this represents an advantage. Small farmers, if grouped together, could afford the construction of a power system to solve their problems. Cluster II and Cluster III have bigger loads, which bring to bigger sizes of the systems and higher NPC. Since the clusters have different dimensions to compare the three solution it could be useful to compare the values of the levelized cost of energy (COE). For Cluster I and III the COE is about the same: this means that the average cost per kWh of electricity produced by the systems is the same. For Cluster II the COE is higher, that means that the electricity produced with this system is more expensive.



Optimization Cases: Left Double Click on simulation to examine details.

Architecture					Cost				System
PV (kW)	MP-R (qty)	G3 (qty)	12VRE-3000TF-L (qty)	Converter (kW)	COE (€/kWh)	NPC (€)	Operating Cost (€)	Initial Capital (€)	Cap Short (kWh/yr)
5,5			4	3	€ 0,085	€ 8.604	€ 194	€ 5.838	2285,3
5,0		1	4	3	€ 0,269	€ 26.657	€ 791	€ 15.405	2590,9

Fig. 5.27: Optimized solutions for scenario CI.1



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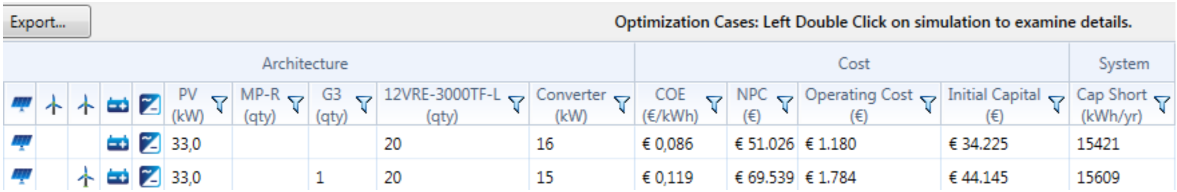
Optimization Cases: Left Double Click on simulation to examine details.

Architecture										Cost				System
					PV (kW)	MP-R (qty)	G3 (qty)	12VRE-3000TF-L (qty)	Converter (kW)	COE (€/kWh)	NPC (€)	Operating Cost (€)	Initial Capital (€)	Cap Short (kWh/yr)
●			●	●	20,0			28	10	€ 0,129	€ 42.199	€ 1.260	€ 24.260	8824,7
●		●	●	●	18,0		1	32	11	€ 0,178	€ 58.593	€ 1.764	€ 33.490	8850,8

Fig. 5.28: Optimized solutions for scenario CII.1



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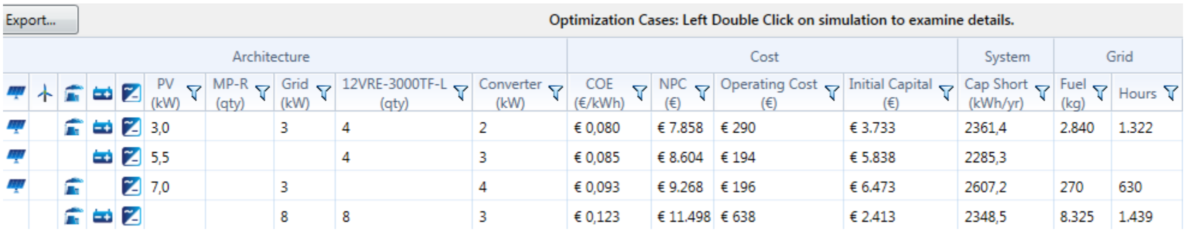
Optimization Cases: Left Double Click on simulation to examine details.

Architecture										Cost				System
					PV (kW)	MP-R (qty)	G3 (qty)	12VRE-3000TF-L (qty)	Converter (kW)	COE (€/kWh)	NPC (€)	Operating Cost (€)	Initial Capital (€)	Cap Short (kWh/yr)
●			●	●	33,0			20	16	€ 0,086	€ 51.026	€ 1.180	€ 34.225	15421
●		●	●	●	33,0		1	20	15	€ 0,119	€ 69.539	€ 1.784	€ 44.145	15609

Fig. 5.29: Optimized solutions for scenario CIII.1

Scenarios Cluster CI-2, Cluster CII-2, Cluster CIII-2: grid-connected systems

When clusters have the possibility to connect to the grid and when there is supply of electricity during the day the best solution always involves the purchase of electricity from the grid. Electricity from the grid allows small sizes of PV panels compared with stand-alone plants and the expenses for purchasing electricity do not exceed the saving in initial capital costs. Cluster I purchases more electricity from the grid and the renewable fraction of the system is lower than the other clusters. Despite of this, the COE of this cluster is competitive with the COE of Cluster III and also in this scenario Cluster II has the system with the highest COE.



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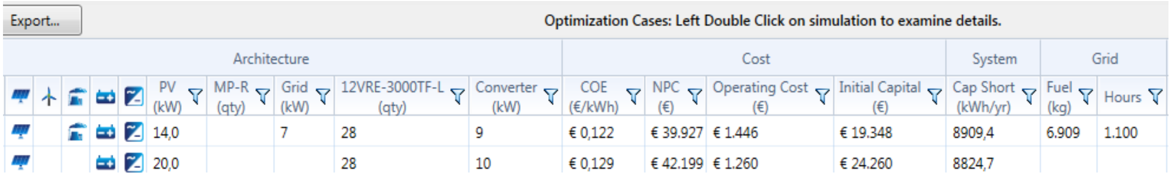
Optimization Cases: Left Double Click on simulation to examine details.

Architecture										Cost				System	Grid	
					PV (kW)	MP-R (qty)	Grid (kW)	12VRE-3000TF-L (qty)	Converter (kW)	COE (€/kWh)	NPC (€)	Operating Cost (€)	Initial Capital (€)	Cap Short (kWh/yr)	Fuel (kg)	Hours
●		●	●	●	3,0		3	4	2	€ 0,080	€ 7.858	€ 290	€ 3.733	2361,4	2.840	1.322
●			●	●	5,5			4	3	€ 0,085	€ 8.604	€ 194	€ 5.838	2285,3		
●		●		●	7,0		3		4	€ 0,093	€ 9.268	€ 196	€ 6.473	2607,2	270	630
		●	●	●			8	8	3	€ 0,123	€ 11.498	€ 638	€ 2.413	2348,5	8.325	1.439

Fig. 5.30: Optimized solutions for scenario CI.2



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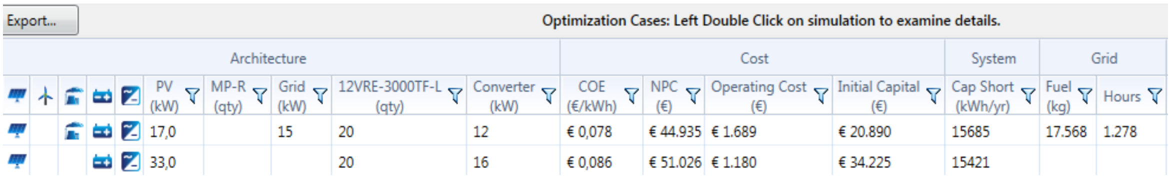
Optimization Cases: Left Double Click on simulation to examine details.

Architecture										Cost				System	Grid	
					PV (kW)	MP-R (qty)	Grid (kW)	12VRE-3000TF-L (qty)	Converter (kW)	COE (€/kWh)	NPC (€)	Operating Cost (€)	Initial Capital (€)	Cap Short (kWh/yr)	Fuel (kg)	Hours
●		●	●	●	14,0		7	28	9	€ 0,122	€ 39.927	€ 1.446	€ 19.348	8909,4	6.909	1.100
●			●	●	20,0			28	10	€ 0,129	€ 42.199	€ 1.260	€ 24.260	8824,7		

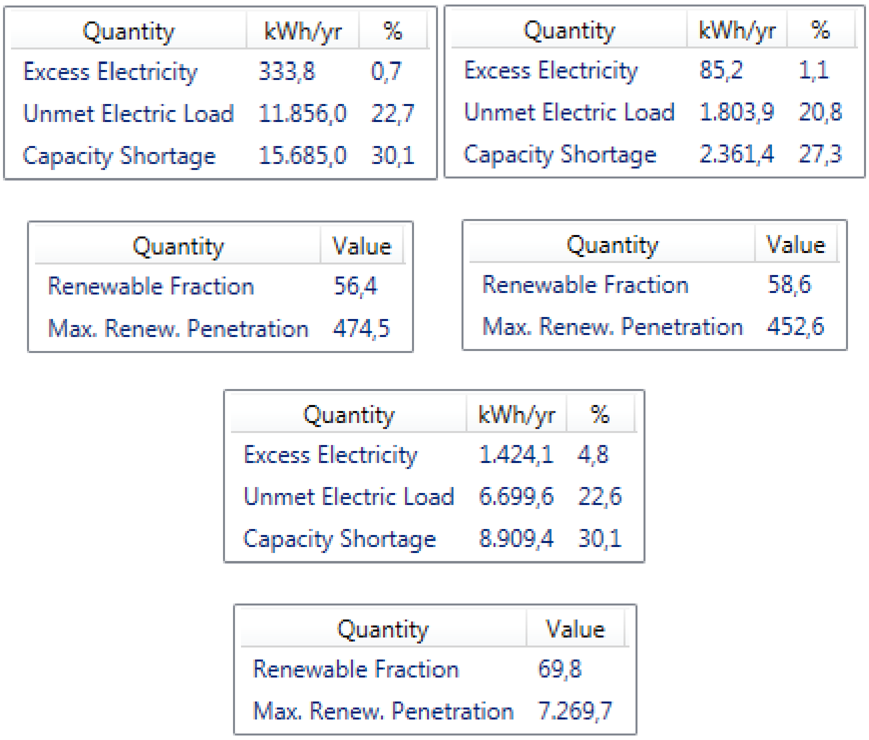
Fig. 5.31: Optimized solutions for scenario CII.2



Optimization Cases: Left Double Click on simulation to examine details.

Architecture					Cost				System	Grid	
PV (kW)	MP-R (qty)	Grid (kW)	12VRE-3000TF-L (qty)	Converter (kW)	COE (€/kWh)	NPC (€)	Operating Cost (€)	Initial Capital (€)	Cap Short (kWh/yr)	Fuel (kg)	Hours
17,0		15	20	12	€ 0,078	€ 44.935	€ 1.689	€ 20.890	15685	17.568	1.278
33,0			20	16	€ 0,086	€ 51.026	€ 1.180	€ 34.225	15421		

Fig. 5.32: Optimized solutions for scenario CIII.2



Quantity	kWh/yr	%
Excess Electricity	333,8	0,7
Unmet Electric Load	11.856,0	22,7
Capacity Shortage	15.685,0	30,1

Quantity	kWh/yr	%
Excess Electricity	85,2	1,1
Unmet Electric Load	1.803,9	20,8
Capacity Shortage	2.361,4	27,3

Quantity	Value
Renewable Fraction	56,4
Max. Renew. Penetration	474,5

Quantity	Value
Renewable Fraction	58,6
Max. Renew. Penetration	452,6

Quantity	kWh/yr	%
Excess Electricity	1.424,1	4,8
Unmet Electric Load	6.699,6	22,6
Capacity Shortage	8.909,4	30,1

Quantity	Value
Renewable Fraction	69,8
Max. Renew. Penetration	7.269,7

Fig. 5.33: Electrical output for scenarios CI.2 (top left), CII.2 (top right) and CIII.2 (bottom)

Scenarios Cluster CI-4,Cluster CII-4, Cluster CIII-4: grid-connected systems with random blackouts

The results of the previous scenarios do not reflect the reality of our context. The solutions would be correct if the supply of electricity from grid were reliable. Actually we do not expect an improvement in the electric service in the near future and we decide to evaluate how the results vary in case of unscheduled blackouts. For each scenario we introduced random blackouts in the generator schedule as shown in Fig. 5.34. Since HOMER Energy does not allow the introduction of random blackouts, we imposed three difference blackout schedules and we compared the results.

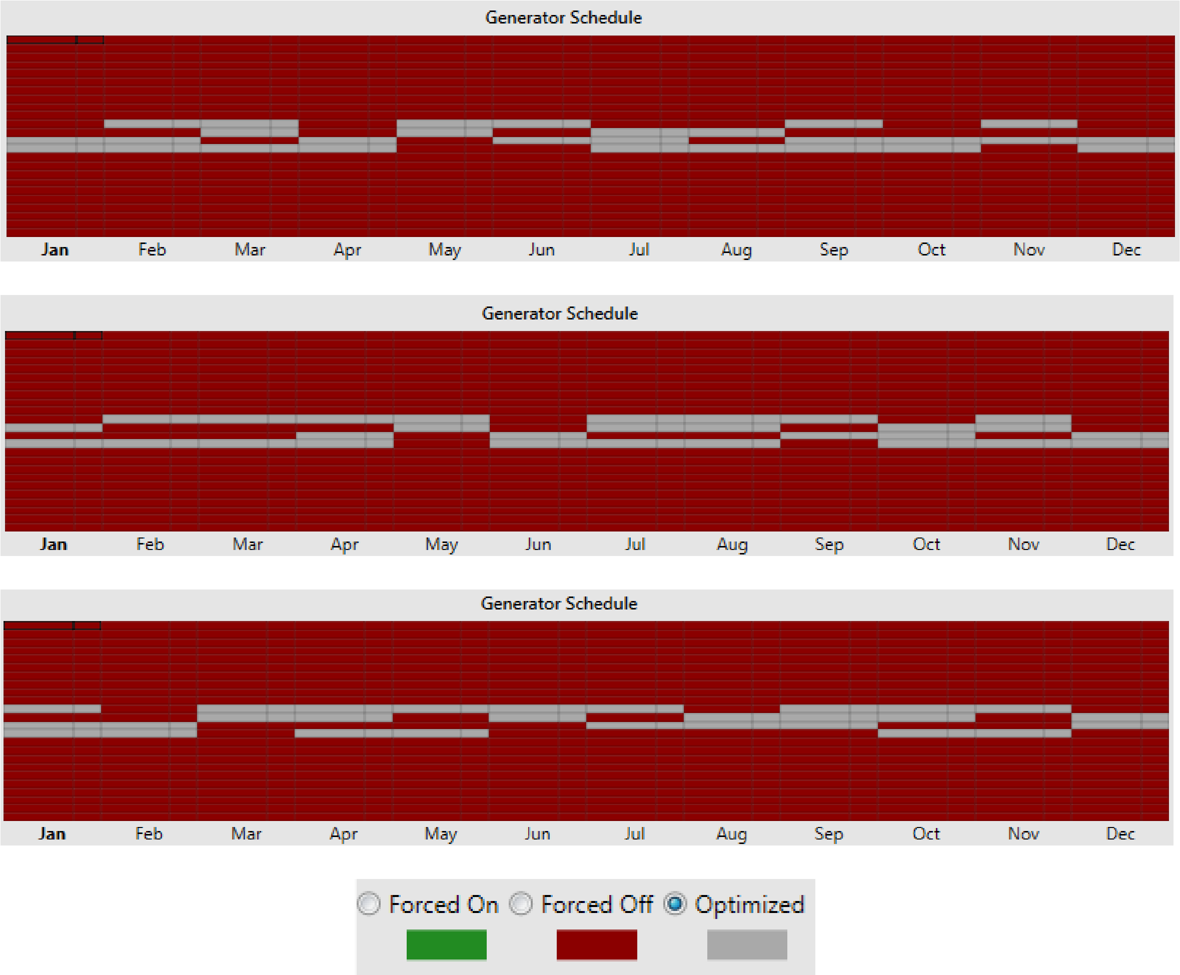


Fig. 5.34: Examples of random blackouts in generator schedule

We reduced the daily availability of electricity to 2 or 3 hours. We believe that this drastic reduction in the availability of electricity reflects the current situation of the village because of the inadequacy of local infrastructures. When we introduce the unscheduled blackouts, the gap in NPC between the stand-alone and the grid-connected solution decreases in a significant way, especially for Cluster II and III. This is due to the increase in the initial capital cost. To balance out the reduced supply of electricity from the grid, the power of installed PV increases with a consequent increase in capital costs. The amount of electricity purchased from the grid decreases and this can be seen in the operating cost reduction (which include the cost of the electricity bill).

Cluster I	COE (€/kWh)	NPC (€)	Operating Cost (€/yr)	Initial Capital (€)	Cap Short (kWh/yr)
Grid-connected	0.08	7,892	292	3,733	2,312.4
Random blackout	0.081	7,942	228.3	4,691.3	2,523
Stand-alone	0.085	8,604	194	5,838	2,285.3

Table 5.11: Comparison of costs for the different scenarios of Cluster I

Cluster II	COE (€/kWh)	NPC (€)	Operating Cost (€/yr)	Initial Capital (€)	Cap Short (kWh/yr)
Grid-connected	0.122	38,588	1,532	17,780	8,906.1
Random blackout	0.125	40,727	1,283.3	22,458.7	8,863
Stand-alone	0.126	41,327	1,260	23,395	8,585.5

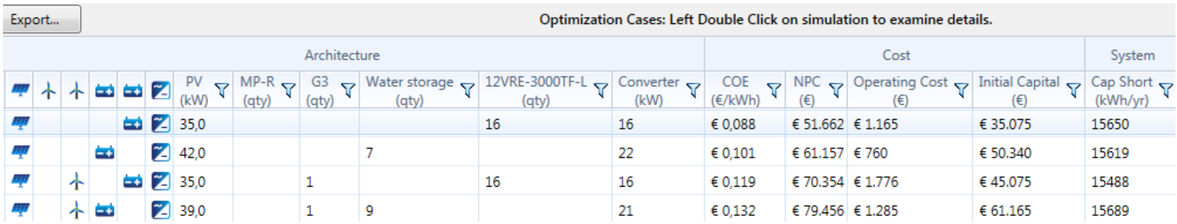
Table 5.12: Comparison of costs for the different scenarios of Cluster II

Cluster III	COE (€/kWh)	NPC (€)	Operating Cost (€/yr)	Initial Capital (€)	Cap Short (kWh/yr)
Grid-connected	0.078	44,923	1,524	23,225	15,643
Random blackout	0.081	47,116	1,347.3	27,941.7	15,629.3
Stand-alone	0.085	50,128	1,178	33,360	15,446

Table 5.13: Comparison of costs for the different scenarios of Cluster III

Scenarios Cluster CIII-5 with Water Storage

We present the results of the scenario of a stand-alone plant with a water storage system for Cluster III. Aboveground water tanks could be an interesting solution for the irrigation because they allow to store water when there is availability of electricity and to irrigate in every instant without the need of electricity. Moreover, they allow to remove or to decrease the number of batteries in the system, decreasing the O&M costs and the need to replace these components. To convert batteries into water tanks we use the methodology explained in paragraph 5.1.4. HOMER Energy does not allow to simulate a system with two kinds of batteries. For this reason the solutions are systems with the presence either of water tanks or batteries and not with both components. HOMER Energy gives as output four different systems which presents increasing NPC and COE. The best solution is the stand-alone plant of scenario CIII-1. The presence of water storage instead of the batteries is the solution with the second best NPC. Water storage is not a convenient solution if compared with a system with batteries. Even if O&M costs of water storage decrease, the solution is too expensive for the initial capital costs of the system.



Optimization Cases: Left Double Click on simulation to examine details.

Architecture						Cost					System
PV (kW)	MP-R (qty)	G3 (qty)	Water storage (qty)	12VRE-3000TF-L (qty)	Converter (kW)	COE (€/kWh)	NPC (€)	Operating Cost (€)	Initial Capital (€)		Cap Short (kWh/yr)
35,0				16	16	€ 0,088	€ 51.662	€ 1.165	€ 35.075		15650
42,0			7		22	€ 0,101	€ 61.157	€ 760	€ 50.340		15619
35,0		1		16	16	€ 0,119	€ 70.354	€ 1.776	€ 45.075		15488
39,0		1	9		21	€ 0,132	€ 79.456	€ 1.285	€ 61.165		15689

Fig. 5.35: Optimized solutions for scenario CIII.4

Configuration C: summary of results

In Table 5.14 we report the optimized solutions for the different scenarios of Configuration C for each cluster. We simulated five different scenarios for this configuration. The stand-alone scenario and the grid-connected scenario with electricity supply during the night present the same result and are reported on the same row.

The differences between an ideal situation with a reliable, even if limited, electricity supply and an unreliable electricity supply are highlighted by scenario 4, in which random blackouts are added. The unreliability brings to an increase in the PV installed with a consequent cost increase.

We report also the results of the solution with water storage. This solution presents an excessive initial investment cost, which is not balanced out by the low O&M costs.

CLUSTER I									
	PV	**Grid**	**Battery**	**Inverter**	**COE**	**NPC**	**O&M Cost**	**Initial Capital**	**Water tank**
Scenario	kW	kW	Qty	kW	€/kWh	€	€/yr	€	m^3
C1-C3	5.5	0	4	2.5	0.085	8,604	194	5,838	
C2	3	2.5	4	1.5	0.08	7,858	290	3,733	
C4	4	3	4	3	0.081	7,942	227	4,718	
C5	6	0	0	3	0.094	9,722	121	7,993	8.3

CLUSTER II									
	PV	**Grid**	**Battery**	**Inverter**	**COE**	**NPC**	**O&M Cost**	**Initial Capital**	**Water tank**
Scenario	kW	kW	qty	kW	€/kWh	€	€/yr	€	m^3
C1-C3	20	0	28	10	0.129	42,199	1,260	24,260	
C2	14	6.5	28	9	0.122	39,927	1,446	19,348	
C4	18	7	28	10	0.125	40,852	1,262	22,888	
C5	25	0	0	16	0.225	73,096	146	71,015	230
CLUSTER III									
	PV	**Grid**	**Battery**	**Inverter**	**COE**	**NPC**	**O&M Cost**	**Initial Capital**	**Water tank**
Scenario	kW	kW	Qty	kW	€/kWh	€	€/yr	€	m^3
C1-C3	33	0	20	16	0.086	51,026	1,180	34,225	
C2	17	15	20	12	0.078	44,935	1,689	20,890	
C4	26	12	20	16	0.081	47,120	1,285	28,830	
C5	42	0	0	22	0.101	61,157	760	50,340	61.6

Table 5.14: Configuration C: optimized solutions (size of components and costs)

5.3.4 Summary

To close this section we present a summary of the NPC and of the initial investment costs of the best solution for the different scenarios shown in Table 5.15.

We calculated the NPC per farmer and the initial investment per farmer of the scenario to evaluate the differences which the scenarios imply in farmer participation. For Configuration A this is not possible because we do not know the number of farmers in the area considered.

Configuration	Scenario	Total NPC	NPC per farmer	Total initial investment	Initial investment per farmer
A	Stand-alone	696,209		450,000	
	Grid	632,515		332,550	
B average	Stand-alone	10,054.8	10,054.8	5,682	5,682
	Grid	10,012	10,012	5,196	5,196
CI	Stand-alone	8,604	2,868	5,838	1,946
	Grid	7,858	2,619.3	3,733	1,244
CII	Stand-alone	42,199	8,439.8	24,260	4,852
	Grid	39,927	7,985.4	19,348	3,869.6
CIII	Stand-alone	51,026	12,756	34,225	8,556
	Grid	44,935	11,234	20,890	5,222.5

Table 5.15: Comparison of total NPC and total initial capital cost of the different scenarios and of the NPC and initial capital cost specific per farmer

As concerns the difference in the total NPC among the various configurations, Configuration A has the highest value while the lowest value is that of Cluster I. The grid-connected solution has always a lower NPC than the stand-alone plant. The total initial investment costs reflect the trend of the NPC: they are higher for the stand-alone solution because of the bigger size of solar PV power installed.

When we consider the NPC specific per farmer, the differences between stand-alone and grid-connected solutions become thinner. It is interesting to observe that the Cluster II and the Cluster III configurations have costs similar to Configuration B. In particular, Cluster II has a NPC per farmer lower than Configuration B even if the total NPC is more than four times the total NPC of Configuration B.

5.4 Beyond HOMER analysis

After the analysis of all the scenarios, we report some considerations, a SWOT analysis of the three configurations and a comparison of the different scenarios for each configuration.

5.4.1 Configuration A

	PV	Grid	Battery	Converter	COE	NPC	O&M Cost	Initial Capital	Capacity Shortage
	kW	kW	qty	kW	€/kWh	€	€/yr	€	kWh/yr
Stand alone	400	0	400	200	0.092	696,209	17,297	450,000	195,913
Grid	300	150	240	150	0.085	632,515	21,075	332,550	197,253

Table 5.16: Comparison of the scenarios of Configuration A

When we consider the electrification of the total area, we can choose between two different solutions. A stand-alone plant able to satisfy the need of each farmer or a grid-connected system which rely also on the national grid to satisfy all the electric load. Since we imposed the same capacity shortage for our simulations, the performance of these systems result to be similar. The differences are in the cost of the power plants.

The NPC of the stand-alone system exceeds the grid-connected NPC by about 60,000 €. Also the COE of the grid-connected system is lower than the COE of the stand-alone solution and this is a further advantage for farmers. The more significant difference between the solutions is the initial capital cost: the stand-alone solution requires an initial investment of 450,000 €, while the grid-connected solution of only 332,550 €. The main difference is how costs are allocated during the lifetime of project: the stand-alone solution implies an high investment cost and in the following years expenses are related to O&M costs. The grid-connected solution requires a smaller investment to start the project and farmers continue to pay the electric bill for the supply of electricity from the national grid.

The installed PV results to be 300 kW in one scenario and 400 kW in the other. We evaluate some criteria to choose the install location of the plant.

The best solution for installing the power plant is an uncultivated area or an area for grazing. This way, we do not take away productive resources to farmers. From our visit we know that the grazing and not cultivated area is far away from the project area and this solution is not feasible. According to HOMER Energy output and with data on solar PV system dimensions, the surface covered by the stand-alone plant is 5945 m^2 and the surface covered by the grid-connected plant is about 4,459 m^2 (Fig. 5.36). These areas correspond to the dimension of a small farm.

Fig. 5.36: Surface covered by the stand-alone system (on the left)
and by the grid-connected system (on the right)

Fig. 5.36 and the data reported show that it is necessary to buy land from one or more farmers. Once that the best location has been chosen, the willingness of farmers to sell the land should be verified and a fair economic return should be considered.

If possible, we evaluate the opportunity to install the power plant on the land of a Harnai member. Harnai members are directly involved in the project and should be more willing to accept the idea of selling their land. In the target group there are Farmer VII and XI who are members of Harnai. Moreover Farmer XI has a vast farm (compared with the average farm area) and we already installed the measurement kit in his farm.

Another aspect that should be considered is the accessibility of the location. The village is in a remote area, with roads in poor conditions. Roads which connect the main road to the land might hinder the transport of materials and system components and make the O&M operations more difficult.

To minimize distribution costs and electric losses (which on this small area are minimal) the power plant should be installed in a central position and the distribution grid should be radial.

As to system management we considered different alternatives. It should be considered if farmers have to pay for the electricity supplied by the power plant or if they have electricity for free. The first alternative is better because it allows to sustain the cost of O&M required by the plant and makes farmers more responsible. Considering the great number of farmers involved in this configuration, the system of collecting money should be organized in a proper way. For example a cooperative for the management of the plant could be set up with the task of collecting money, checking the proper operation of the plant and the conduct of farmers connected to the plant. For the safety of the plant, a keeper could be employed among unemployed people in the village.

Table 5.17, which presents the SWOT matrix for Configuration A, shows the positive and negative aspects of this configuration. In this matrix we represented the internal strengths and weaknesses of this configuration which our project should value or minimize and the external opportunities and threats to the success of the solution which the project should monitor.

	Positive	Negative
Internal	**Strengths**	**Weaknesses**
	Involvement of all the farmers present in the area Economies of scale (€/kW) Lower COE (€/kWh)	High investment cost (€) Vast area needed for the power plant Sizing of the power plant on the base of a hypothetical load profile A vast distribution grid is needed Need to implement the solution with a unique activity
External	**Opportunities**	**Threats**
	Great resonance of the project	Difficulty in cooperation among farmers Difficulties in the O&M by farmers due to the big size of the power plant

Table 5.17: SWOT matrix for Configuration A

5.4.2 Configuration B

Configuration B involves the design of a single power plant for each beneficiary of the project.

For most of the farmers the best scenario is the stand-alone plant. Only for two farmers the best solution is the grid-connected one. However, the difference in the NPC between the stand-alone and the grid-connected solutions is really thin. The main difference is due to the initial investment cost for the reasons explained in this Chapter.

For the farmers with the smaller power plant installed, this solution could be implemented through the installation of solar pumps. This solution could require the replacement of the pump with an increase in the initial investment cost. Currently there is a scheme of the

Ministry of New and Renewable Energy for the installation of solar PV water pumping systems for irrigation purpose, which give incentives for the purchase of these systems. This is an important advantage that should be considered for the selection of the solution.

For farmers with bigger power plants the solar pump solution is not feasible. They have to install a bigger PV plant, which is more complex and has higher costs. This could be balanced by the fact that these farmers have also a higher income.

The management of the power plants is committed to the single farmer. This solution is therefore simpler than the previous one under the management aspect. Farmers should not pay the electricity used (because it is directly produced by their own plant), but everyone should be able to sustain the O&M costs and to use the system in a correct way.

There is no need to find farmers willing to rent or sell part of their land. Every farmer has to use his own land decreasing the total area available for farming. The occupation of land varies with the size of the power plant and for the target group it amounts to a maximum value of 150 m^2.

Farmers could take part to the initial investment if they are interested and have financial means in order to be more responsible for the system. Therefore, our tasks are to design the project, but also to act as intermediaries between farmers and suppliers of the power systems.

An important advantage is that this solution could have a domino effect: farmers not involved in the pilot project could be attracted by this technology and if they have enough income they could install a solar PV system independently from our mediation.

	Positive	**Negative**
Internal	**Strengths**	**Weaknesses**
	Low investment cost (€) Investment cost proportional to farmer's economical availability Sizing of the power plant on the base of the real load profile No need of distribution grid Possibility to implement the solution one farmer at a time	High COE (€/kWh) Need of multiple systems which involve the careful evaluation of the load demand of each farmer (time and resource consuming)
External	**Opportunities**	**Threats**
	Incentives from government for solar pumps No need of collaboration between farmers Domino effect: other farmers install the same plant attracted by the project	Each farmer should manage his own plant

Table 5.18: SWOT matrix for Configuration B

5.4.3 Configuration C

In this configuration, the power plant is shared by a small number of farmers grouped into different clusters.

The plant costs for this configuration vary according to the sizes of the land of farmers who belong to the same cluster. This system is affordable for every farmer, that means rich and poor farmers have the same benefits investing in the system an amount of money proportional to their economic conditions.

Also in this configuration, the NPC is better for the grid-connected solution for the reasons explained in this Chapter. However, we analyzed in depth the influence of the grid reliability on the costs of the system (influence of random blackouts) and we figured out that considering the actual conditions of the grid, the difference between the NPC of the stand-alone and grid-connected solutions, with the same capacity shortage, becomes thin. This is due to the need of balancing out the unreliability of the grid increasing the PV size.

Therefore, if there are enough financial resources the best solution is a stand-alone power plant because it guarantees that all requirements are satisfied. The grid-connected solution could be a good solution only if the unreliability of the grid is carefully evaluated and if the power plant is carefully designed.

In this configuration, we considered the possibility to switch from batteries to water tanks. Analyzing this scenario we figured out that it is not advantageous due to the high cost of water tanks.

The area covered by the plant depends on the cluster’s size and in every case it could be installed on the land of a single farmer.

The system management would be committed to the farmer who is the owner of the land in which the plant is placed. This solution implies a participation to the O&M expenses by the other farmers in the cluster.

The participation of farmers to the initial investment should be evaluated according to their economic wealth.

This solution could create disagreement among farmers but, as explained in Chapter 2:, the members of the cluster belong often to the same family, so the problem could be reduced.

	Positive	Negative
Internal	**Strengths**	**Weaknesses**
	Investment cost proportional to farmer's economical availability Power plant near the land of cluster members Sizing of the power plant on the base of the real load profile Possibility to implement the solution for the clusters one by one	Need of a distribution grid Need to find a farmer available to give up part of his land for the power plant
External	**Opportunities**	**Threats**
	Cluster members belong to the same families Easier integration of the different systems in a future project which involves all the village area	Farmers not involved hinder the implementation of the project Illegal connection to the distribution grid

Table 5.19: SWOT matrix for Configuration C

5.4.4 Financial considerations

This analysis reveals that each configuration has both positive and negative aspects. The choice of the best solution to implement in the village depends on the type of funding system.

According to the amount and the type of budget obtainable, it could be appropriate to choose a solution rather than another, which implies or not the farmers' involvement into the power plant costs. A high budget, for example obtained from a call, could allow building the stand-alone plant of scenario A, which does not imply further costs for farmers. In case of a loan, on the contrary, for example obtained from an international fund, the scenario B or C could allow a more direct monitoring of the use of each power plant from the single farmer or cluster.

Therefore it is necessary to make a financial analysis and to evaluate the different funding options available in the context in which the project is implemented.

Conclusions

The goal of this thesis is the design of an energy system for the irrigation of the lands of Katgaon, a village located in State of Maharashtra in the South of India. This thesis is developed in the context of "Project Sanjeevani", in collaboration with Engineers Without Borders Milano (ISF-MI) and the UNESCO Chair in Energy for Sustainable Development.

To collect data and information necessary for the design of the appropriate energy system, we made a mission of two months in India to analyze the local context. We analyzed the general Indian context through the use of some indicators and, in particular, we analyzed the local energy, economic and social situation (Chapter 1).

For the analysis of the village of Katgaon, we submitted a questionnaire, developed for this purpose, to a target group of 15 farmers selected by our local partner Harnai. We collected information about the household characteristics, the characteristics of the land, the agricultural and livestock activities, the energy uses for irrigation, the energy uses for domestic purposes and the market of products. The analysis of these data is reported in Chapter 2.

For the management of the project we used the PCM methodology. In Chapter 3 we identified the stakeholders involved in our project, we studied the problems emerged by means of a "problem tree", according to a cause-effect relationship. Through the strategy analysis we identified the effective problem we wanted to address: farmers cannot irrigate the fields because of the lack of an adequate electricity supply and this situation has a negative impact on their revenues. Goal of the work is therefore the improvement of the economic conditions of farmers through the increase of profit from crops by means of a proper irrigation of the fields.

We evaluated the presence of energy sources at the village level with the help of online databases and data collected on site (Chapter 4), then we evaluated the local energy needs. We focused on the energy load for irrigation and we obtained the daily energy load profile for the target group of farmers.

We chose three different configurations for the design of the energy system (Chapter 5). The first one involves a large number of farmers with fields in the same area. The second one provides the supply of electricity to the 15 farmers individually. In the third one, the 15 farmers are grouped in three different clusters according to their position and, for each cluster, an energy system was designed.

For the design of the energy system we used HOMER Energy software. For all the configurations we considered three different scenarios: a stand-alone solution, a grid-connected solution with electricity supply during the day and a grid-connected solution with electricity supply during the night. For the configuration composed of clusters we analysed also the impact of the unreliability of the national grid simulating random blackouts and the feasibility of a system composed of an aboveground tank for the water storage.

The costs calculated for the three configurations are different. The configuration which involves a larger number of farmers is the most expensive. The other two configurations present variable costs according to the energy demand of single farmers. An important feature of the last two configurations is that the costs might be allocated over different years because the energy systems for each farmer can be installed in different periods.

The main difference between the grid-connected and the stand-alone scenarios is the distribution of costs among the stakeholders. The stand-alone solution implies higher initial investment costs which could be sustained by the donors, while the grid-connected solution implies higher costs for farmers, which have to pay the electric bill for the electricity supply.

The impact of the unreliability of the grid is relevant. The weakness of the national grid is balanced out by an increase in the size of the energy system, due to the share of energy load that has to be satisfied with alternative sources of energy. The gap between the initial investment cost of the stand-alone and the grid-connected solutions is reduced and the NPC of the two solutions is similar.

The installation of a water tank as replacement of the batteries emerges as unfeasible from an economic point of view: water tanks are too expensive to be competitive with batteries, despite of the high O&M and replacement costs of batteries.

In the end of this thesis, we tried to go beyond the techno-economic optimization to select the best solution, since the sustainability of the project is not related only to the economic aspect. We presented therefore some practical considerations for the installation and maintenance of the energy systems. We compared the three configurations with the help of a SWOT analysis to characterize their positive and negative aspects.

In conclusion, this thesis wants to be a helpful analysis for Engineers Without Borders and all the stakeholders involved in the project, to promote the access of energy in rural India and highlight the importance of energy as a fundamental link to water and food and as a basic means to improve the living conditions of local population.

Appendix A: The questionnaire

PROJECT “SANJEEVANI”

SURVEY ON WATER AND ENERGY NEEDS AND CONTEXT ANALYSIS

Personal data: Name___________ Surname____________ Place________________

This survey is developed by the association Engineering Without Borders. The purpose of the survey is to gain information of the current situation of farmers and build the basis for a project aiming at improving their conditions of life. It is divided in five parts: household characteristics, characteristics of the area, agricultural and livestock activities, energy uses and market assessment.

HOUSEHOLD CHARACTERISTICS

1. Position in the family?

☐ Head of the family ☐ Family member ☐ Other (specify) ________

2. Person responsible for household?

☐Me ☐Father ☐Mother ☐Husband ☐Wife ☐Son ☐Daughter ☐Brother ☐Relatives

3. Number and sex of occupant in the house?

Male _______ Female ________

4. How many people, who live in your house, have a job?

5. Monthly household income

Rs

CHARACTERISTICS OF THE AREA:

6. Which is the dimension of your cultivated land?

ha	or	acres	or	R

7. Do you have animals? (If yes fill the table)

☐ Yes ☐ No

	Buffalo	Bull	Cow	Chicken	Pet	Other_______________
Quantity						

8. Do you use dung to fertilize?

☐ Yes ☐ No

9. Do you have water resources near your land?

☐ Yes ☐ No

9.1. If yes specify

☐ Lake ☐ River ☐ Open well ☐ Closed well ☐ Other ________

9.2. Are you able to use it?

☐ Yes ☐ No

9.3. How far is it?

Meters	or Minutes

9.4. How deep is the well?

Feet

AGRICULTURAL ACTIVITIES:

10. Which are the main products you cultivate?

☐ Sugarcane ☐ Jowar ☐ Onion ☐ Soya ☐ Bajra ☐ Corn ☐ Cotton

☐ Wheat ☐ Mothbean ☐ Pigeon pea ☐ Banana ☐ Bitter ☐ Grapes ☐ Chana

☐ Black gram ☐ Green gram ☐ Horse gram ☐ Marigold ☐ Other ______(specify)

11. How many area do you use for each product? And in which season? Specify if the product is for selling or for self consumption

Product	Area	Season	Kind of soil	Productivity (ton/yr)	Selling/Self consumption

12. Do you use organic or high yields seeds?

☐ Organic ☐ High yields ☐ Both

13. How do you take the water?

☐ Solar pump ☐ Electric pump ☐ Diesel pump ☐ Manual pump ☐ Other ______

14. Which is the power of the pumps?

Pump	Power

15. In which season do you irrigate?

☐Kharif (Jun-Sept) ☐Rabi (Oct-Feb)

16. Do you have enough water? (for each season)

Kharif	☐ Yes	☐ No	**Rabi:**	☐ Yes	☐ No

16.1. If no, which is the problem?

☐ Scarcity	☐ No electricity	☐ Other ______________

17. How do you irrigate your land?

☐ Canals ☐ Pipe ☐ Drip irrigation ☐ Sprinkler ☐ No irrigation system ☐ Other ________

18. Do you have water storage systems? (if yes specify the capacity)

☐ Yes ________ litres ☐ No

19. Do you have difficulties in cultivating or irrigating your field? Which ones?

Kharif:

☐ High energy price for irrigation ☐ Blackout ☐ High rent prices for tractors

☐ High seeds price ☐ Shortage of water ☐ Low voltage

☐ Time slot of electricity supply different from the irrigation time ☐ Other ____________

Rabi:

☐ High energy price for irrigation ☐ Blackout ☐ High rent prices for tractors

☐ High seeds price ☐ Shortage of water ☐ Low voltage

☐ Time slot of electricity supply different from the irrigation time ☐ Other ____________

20. Do you use tractor to plough your land?

☐ Yes ☐ No

20.1. If yes, do you rent or own the tractor? Specify the price

☐ Rent __________Rs/acre ☐ Own _________Rs

20.2. If no, specify the method used

☐ Animal-drawn plough ☐ Manual-drawn plough ☐ Other _______________

21. Do you conserve you products after the harvesting?

☐ Yes ☐ No

21.1. If yes, how do you conserve your products after the harvesting?

☐ refrigerator ☐ salt ☐ warehouse ☐ other_____________________

21.2. If yes, how much do you spend for conserving your products?

Rs

21.3. If no, why?

☐ no refrigerator ☐ not useful ☐ too expensive ☐ other______________________

____

____

____

22. How long do your products last before rotting?

Product	Days

ENERGY USES

Irrigation

23. Do you have the connection to the national electric grid in your land?

☐ Yes ☐ No

24. (if yes go to 24.1; if no go to 24.5)

IF YES:

24.1. How many times the time slot of electricity supply is different from the irrigation time?

Weekly ___________ Or Monthly _______________

24.2. How much do you pay monthly for electricity? (in Rupees)

Rs

24.3. Is electricity from national grid enough for irrigation?

Kharif: ☐ Yes ☐ No	**Rabi:** ☐ Yes ☐ No

IF NO:

24.4. Which fuel do you use for your irrigation system?(per season)

☐ Diesel:_______ litres ☐ Manual ☐ Solar ☐ Other, specify the quantity ________ litres

24.5. Reason for use this fuel?

☐ Cheap ☐ Easily available ☐ Easy to use ☐ Only available fuel ☐ Other ______

25. If electricity was available all the day, when would you irrigate the fields?

RABI																	
Products	Hours																
	5 6	6 7	7 8	8 9	9 10	10 11	11 12	12 13	13 14	14 15	15 16	16 17	17 18	18 19	19 20	21 22	22 23

KHARIF																	
Products	Hours																
	5 6	6 7	7 8	8 9	9 10	10 11	11 12	12 13	13 14	14 15	15 16	16 17	17 18	18 19	19 20	21 22	22 23

Domestic use

26. Do you have the connection to the national electric grid in your house?

☐ Yes ☐ No

26.1. How much do you pay monthly for electricity? (in Rupees)

Rs

27. How many hours do you have electricity daily?

Hrs

28. Do you have systems to storage the electricity?

☐ Yes ☐ No

29. How do you compensate the lack of electricity?

30. Which are the devices using electricity in the house?

ITEM	N°	AVERAGE DAILY USE
Radio		
TV		
Charging Phone		
Computer		
Refrigerator		

ITEM	N°	AVERAGE DAILY USE
Oven		
Freezer		
Electric iron		
Fan		
Other		

Cooking

31. Main fuel for cooking:

☐ LPG (liquid petroleum gas) ☐ Electricity ☐ Wood ☐ Charcoal ☐ Gas (Methane)

☐ Dung ☐ Paraffin ☐ Kerosene ☐ Other ___________________

31.1. Could you state/estimate how much fuel do you consume monthly? (specify unit of measure)

31.2. How much dry wood do you buy yearly? (specify unit of measure)

31.3. How much do you pay for dry wood? (specify unit of measure)

32. Reason for use? (you can cross more than one answer)

☐ Cheapest ☐ Easily available ☐ Easy to use ☐ Only available fuel ☐ Other ______

33. Which appliance do you use to cook?

☐ Three stone fire ☐ Saw dust stove ☐ Improved stove ☐ Other ______________________

Water heating

34. Main fuel for water heating:

☐ LPG (liquid petroleum gas) ☐ Electricity ☐ Wood ☐ Paraffin ☐ Charcoal

☐ Gas (Methane) ☐ Other _________

34.1. How many people use hot water in the house?

34.2. Could you state/estimate how much fuel do you consume monthly? (specify unit of measure)

35. Reason for use it? (you can cross more than one answer)

☐ Cheapest ☐ Easily available ☐ Easy to use ☐ Only available fuel ☐ Other ______

Lighting

36. Main fuel for lighting:

☐ LPG (liquid petroleum gas) ☐ Electricity ☐ Wood ☐ Paraffin ☐ Kerosene
☐ Candles ☐ Other _________

36.1. Could you state/estimate how much fuel do you consume monthly? (specify unit of measure)

37. Reason for use? (you can cross more than one answer)

☐ Cheapest ☐ Easily available ☐ Easy to use ☐ Only available fuel ☐ Other ______

38. How many light bulbs do you have in your house?

MARKET ASSESSMENT

39. What is your profit from selling your products (yearly)?

Rs

40. To whom do you sell your products mainly?

☐ Local market ☐ Other farmers ☐ Sugar factory ☐ Companies ☐ Other___________

41. How do you sustain when you cannot produce and/or sell?

☐ Bank loan ☐ Loan from relatives ☐ Borrow from friends ☐ Mortgaging land
☐ I don't have a period without producing ☐ Moneylender ☐ Other___________

PROJECT EXPECTED RESULTS

42. What do you expect from such a project?

____

____

43. What situation do you wish for your future?

____

____

____

" संजीवनी प्रकल्प - काटगाव "

पाणी आणि उर्जा - वापर व गरजेचे सर्वेक्षण

वैयक्तिक माहिती : **नाव** ___________ **वडील/पालक**______________ **आडनाव** _____________

हे सर्वेक्षण Engineering Without Borders या संस्थेमार्फत तयार करण्यात आले आहे. या सर्वेक्षणाचा मुख्य उद्देश हा शेतकऱ्यांच्या सद्य परिस्थितीचा आढावा घेणे आणि संजीवनी प्रकल्पाद्वारे त्यांच्या जीवनमानात सुधारणा करणे हा आहे. या प्रश्नावलीचे पाच प्रकारे विभाजन केले आहे: कौटुंबिक माहिती, क्षेत्राविषयी माहिती, शेतीविषयक माहिती, उर्जेचा वापर आणि बाजाराचे मुल्यांकन.

कौटुंबिक माहिती

१. घरातील स्थान?

☐ कुटुंब प्रमुख ☐ कुटुंब सदस्य ☐इतर __________

२. घरातील जबाबदार व्यक्ती ?

☐स्वतः ☐वडील ☐आई ☐पती ☐बायको ☐मुलगा ☐मुलगी ☐भाऊ ☐ नातेवाईक

३. घरातील स्त्री आणि पुरुष (लहान मुलांसह) यांची संख्या ?

पुरुष _________ महिला _______

४. घरात राहणाऱ्या किती व्यक्ती नोकरदार आहेत?

५. घराचे एकूण मासिक उत्पन्न ?

क्षेत्राविषयी माहिती :

६. शेतीयोग्य क्षेत्रफळ किती आहे ?

हेक्टर or एकर or गुंठे

७. तुमच्याकडे जनावरे आहेत का?(असल्यास खालील तक्त्यात तपशीलवार माहिती भरा)

☐ होय ☐ नाही

प्रकार	म्हैस	बैल	गाय	कोंबडी	पाळीव प्राणी (मांजर ई.	इतर________
संख्या						

८. शेणाचा वापर तुम्ही खत म्हणून करता काय?

☐ होय ☐ नाही

९. तुमच्या शेता शेजारी पाण्याची सोय आहे का?

☐ होय ☐ नाही

९.१ असेल तर कशा प्रकारची आहे ते नमूद करा.

☐ तळे ☐ नदी ☐ विहीर ☐ बोअर ☐ इतर ________

९.२ तुम्ही त्याचा वापर करून घेऊ शकता का ?

☐ होय ☐ नाही

९.३ ते किती अंतरावर आहे?

मीटर किंवा वेळ

९.४ विहिरीची खोली किती आहे ?

शेतीविषयक माहिती :

१०. तुम्ही कुठली मुख्य पिकं घेतात?

☐ ऊस ☐ ज्वारी ☐ कांदे ☐ सोयाबीन ☐ बाजरी ☐ मका ☐ कापूस
☐ गहू ☐ मटकी ☐ तूर ☐ केळी ☐ कारले ☐ द्राक्ष ☐ हरबरे
☐ उडीद ☐ मुग ☐ कुळीद ☐ झेंडू ☐ इतर

११. प्रत्येक पिकासाठी तुम्ही किती क्षेत्र वापरतात ? कुठल्या हंगामात ? ती पिकं तुम्ही विकतात कि स्वतः घरी वापरतात? (तक्त्यामध्ये तपशील भरा)

पिक	क्षेत्र	हंगाम	मातीचा प्रकार	उत्पादन क्षमता (टन/ हंगाम)	विकतात/घरात वापरतात

१२. तुम्ही पारंपारिक बीयाण वापरतात कि सुधारित?

☐ पारंपारिक ☐ सुधारित ☐ दोन्ही

१३. तुम्ही पाण्याचा उपसा कशाद्वारे करता?

☐ सोलर मोटार ☐ इलेक्ट्रिक मोटार ☐ डीझेल मोटार ☐ मोट ☐ इतर _______

१४. मोटार किती अश्व शक्तीची (पावर ची) आहे ?

मोटार	पावर

१५. तुम्ही कुठल्या हंगामात पिकला पाणी देतात?

☐ खरीप (जून - सप्टेंबर) ☐ रब्बी (ऑक्टोबर -फेब्रुवारी)

१६. प्रत्येक हंगामात तुमच्याकडे शेतीला पुरेसे पाणी असते का?

खरीप ☐ होय ☐ नाही	रब्बी ☐ होय ☐ नाही

१६.१ नसेल तर काय अडचण आहे?

☐ पाण्याची कमतरता	☐ उर्जेचा अभाव	☐ इतर _____________

१७. तुम्ही पिकाला पाणी कोणत्या पद्धतीने देता?

☐ पाटाचेपाणी
☐ तुषार सिंचन
☐ पाईप लाइन
☐ पाणी द्यायला सोय नाही
☐ ठिबक सिंचन
☐ इतर

१८. तुमच्याकडे पाणी साठविण्याची सुविधा आहे का? (असेल तर क्षमता नमूद करा)

☐ होय _________ लिटर ☐ नाही

१९. तुम्हाला पिकाला पाणी देण्यासाठी अडचणी आहेत का? असतील तर नेमक्या कुठल्या?

खरीप :

☐ महाग इलेक्ट्रिसिटी
☐ महाग बियाणे
☐ भार नियमना ची वेळ हि नेमकी पिकाला पाणी देण्याच्या वेळेतच असते
☐ भार नियमन
☐ कमी voltage चा विद्युतप्रवाह
☐ ट्रक्टरचे महाग भाडे
☐ पाण्याची कमतरता
☐ इतर _________

रब्बी :

☐ महाग इलेक्ट्रिसिटी
☐ महाग बियाणे
☐ भार नियमना ची वेळ हि नेमकी पिकाला पाणी देण्याच्या वेळेतच असते
☐ भार नियमन
☐ कमी voltage चा विद्युतप्रवाह
☐ ट्रक्टरचे महाग भाडे
☐ पाण्याची कमतरता
☐ इतर _________

२०. तुम्ही नांगरणीसाठी ट्रक्टरचा वापर करतात का?

☐ होय ☐ नाही

२०.१ असेल तर ते भाड्याने कि स्वतःचे ? खर्च किती होतो?

☐ भाडे रु./एकर ☐ स्वतःचे रु.

२०.२ नसेल तर नांगरणी कशी करतात?

☐ बैल-जोडीने ☐ स्वतः ☐ इतर ________________

२१. तुम्ही उत्पादित केलेले पिक साठवतात का?

☐ होय ☐ नाही

२१.१ असेल तर पिक काढणी नंतर ते कोणत्या पद्धतीने साठवतात?

☐ शीतपेटी ☐ खारवने ☐ शीतगृह ☐ इतर ________________________

२१.२ असेल तर त्यासाठी किती खर्च येतो?

रु.

२१.३ नसेल तर साठवणूक का करत नाही?

☐शीतपेटी उपलब्ध नाही ☐ निरुपयोगी ☐ न परवडणारे ☐ इतर

____

____

____

२२. तुम्ही उत्पादित केलेला शेतीमाल किती काळ टिकू शकतो?

शेतीमाल	दिवस

शेतीमाल	दिवस

उर्जेचा वापर

सिंचन

२३. तुमच्या शेतापर्यंत शासन पुरवत असलेली वीज (MSEB) उपलब्ध होते का?

☐ होय ☐ नाही

(तर प्रश्न २४.१ वर जा; नाही तर २४.५ वर जा)

असेल तर:

२३.१ विज पुरवठ्याच्या वेळेत आणि सिंचनाच्या वेळेत किती वेळा तफावत असते?

आठवड्यात किती वेळा---------- Or महिन्यात किती वेळा --------------

२३.२ महिन्याला तुम्ही किती वीजबिल भरतात ?

रु.

२३.३ शासनाने पुरवलेली वीज ही सिंचनासाठी पुरेसी आहे का?

खरीप : ☐ होय ☐ नाही	रब्बी : ☐ होय ☐ नाही

जर नाही तर:

२३.५ पाणी उपसा करण्यासाठी तुम्ही कुठले इंधन वापरतात?

☐ डीझेल:________लिटर ☐ स्वतः ☐ सोलर ☐ इतर,_________किती लिटर

२३.६ वरील इंधन वापरण्याचे कारण?

☐ स्वस्त ☐ सहज उपलब्ध होते ☐ वापरायला सोपे ☐ याशिवाय पर्याय नाही ☐ इतर __

२४. जर वीज उपलब्ध असती तर पिकाला पाणी केव्हा दिले असते?

रब्बी																				
पीक	5 6	6 7	7 8	8 9	9 10	10 11	11 12	12 13	12 13	13 14	14 15	15 16	16 17	17 18	18 19	19 20	20 21	21 22	दिवस/ महिना	सिंचनासाठी पंपाची अश्व शक्ति

२५. रब्बीमधे तुम्ही पिकांना सहसा कोणत्या दिवसात पाणी देता (त्या दिवसावर खुणा करा)?

पीक							
	1st सोमवार ☐	1st मंगळवार ☐	1st बुधवार ☐	1st गुरुवार ☐	1st शुक्रवार ☐	1st शनिवार ☐	1st रविवार ☐
	2nd सोमवार ☐	2nd मंगळवार ☐	2nd बुधवार ☐	2ndगुरुवार ☐	2nd शुक्रवार ☐	2nd शनिवार ☐	2ndरविवार ☐
	3rd सोमवार ☐	3rd मंगळवार ☐	3rd बुधवार ☐	3rd गुरुवार ☐	3rd शुक्रवार ☐	3rd शनिवार ☐	3rd रविवार ☐
	4th सोमवार ☐	4th मंगळवार ☐	4th बुधवार ☐	4th गुरुवार ☐	4th शुक्रवार ☐	4th शनिवार ☐	4th रविवार ☐

घरगुती वापर

२६. शासन पुरवत असलेली वीज तुमच्या घराला जोडली आहे का?

☐ होय ☐ नाही

२६.१ तुम्ही महिन्याला किती वीजबील भरतात? (रु.)

रु

२७. दिवसभर किती तास वीज असते?

रु

२८. तुमच्याकडे वीज साठऊन सुविधा आहे का ?

☐ होय ☐ नाही

२९. विदुयत पुरवठा अपुरा असल्यास तुम्ही कुठल्या पर्यायी व्यवस्था वापरता ?

३०. खालील पैकी कुठली उपकरणे वापरण्यासाठी तुम्ही विजेचा उपयोग करता ?

उपकरण	संख्या	सरासरी दैनंदिन वापर
रेडीओ		
टीवी		
मोबाईल		
संगणक		
शीतपेटी (फ्रीज)		
भट्टी		
शितग्रह (फ्रीजर)		
इस्त्री		
पंखा		

स्वयंपाक

३१. स्वयंपाकासाठी लागणारे प्रमुख इंधन :

☐ ग्यास (एल पी जी) ☐ वीज ☐ लाकूड ☐ प्याराफिन ☐ चारकोल ☐ बायोग्यास (मिथेन)
☐ शेण ☐ रॉकेल ☐ इतर ____________________________

३१.१ महिन्याला किती (लिटर /किलो)इंधनाची खपत होते ?

३१.२ वर्षाला इंधन म्हणून किती किलो लाकूड लागते?

३१.३ इंधन म्हणून वापरलेल्या लाकडासाठी वार्षिक किती खर्च येतो?

३२. इंधन वापरासाठीचे कारण? (एकापेक्षा जास्त उत्तरे असल्यास, त्या सर्व ठिकाणी खूण करा)

☐ स्वस्त ☐ उपलब्धता ☐ वापरासाठीसुलभ ☐ फक्त हाच पर्याय आहे ☐ इतर _______

३३. स्वयंपाकासाठी कोणती उपकरणे वापरता?

☐ चूल ☐ शेगडी (लाकडी भुस्सा) ☐ सुधारित चूल ☐ इतर ________________________

पाणी तापवणे

३४. पाणी तापवण्यासाठी मुख्य इंधन :

☐ ग्यास (एल पी जी) ☐ वीज ☐ लाकूड ☐ प्याराफिन ☐ चारकोल ☐ बायोग्यास (मिथेन)
☐ इतर __________

३४.१ घरातील किती माणसे गरम पाणी वापरतात?

३४.२ पाणी तापविण्यासाठी किती (लिटर /किलो)इंधन लागते ?

३५. वापरासाठीचे कारण? (एकापेक्षा जास्त उत्तरे असल्यास, त्या सर्व ठिकाणी खूण करा)

☐ स्वस्त ☐ उपलब्धता ☐ वापरासाठीसुलभ ☐ फक्त हाच पर्याय आहे ☐ इतर _______

प्रकाश

३६. प्रकाशासाठी वापरत येणारे प्रमुख इंधन :

☐ ग्यास (एल पी जी) ☐ वीज ☐ लाकूड ☐ प्याराफिन ☐ रॉकेल ☐ मेणबत्ती
☐ इतर ______________

३६.१ महिन्याला किती (लिटर /किलो)इंधनाची खपत होते?

३७. वापरासाठीचे कारण? (एकापेक्षा जास्त उत्तरे असल्यास, त्या सर्व ठिकाणी खूण करा)

☐ स्वस्त ☐ उपलब्धता ☐ वापरासाठीसुलभ ☐ फक्त हाच पर्याय आहे ☐ इतर _______

३८. तुमच्या घरात किती विजेचे दिवे आहेत?

बाजार मुल्यांकन

३९. तुमची उत्पादने विकून तुम्हाला वार्षिक किती उत्पन्न मिळते?

रु

४०. तुम्ही तुमची उत्पादने प्रामुख्याने कोणाला विकता?

☐ जवळचा बाजार ☐ इतर शेतकरी ☐ कारखाने ☐ व्यापारी ☐ इतर____________

४१. तुम्ही ज्यावेळी काही उत्पन्न काढू शकत नाही किंवा विकू शकत नाही, तेंव्हा तुमच्या गरज कशा भागवता?

☐ बँक कर्ज ☐ नातेवाईकाकडून उधार ☐ मित्रांकडून हात-उसने ☐ सावकार ☐ जमीन गहान ठेवणे
☐ उत्पन्न होत नाही असे होतच नाही ☐ इतर ____________

या प्रकल्पाकडून असणाऱ्या अपेक्षा

४२. अशा प्रकारच्या प्रकल्पाकडून तुम्ही काय अपेक्षा ठेवता?

____

____

____

४३. तुम्हाला परिस्थितीमध्ये कशा प्रकारचा बदल पाहायला आवडेल?

____

____

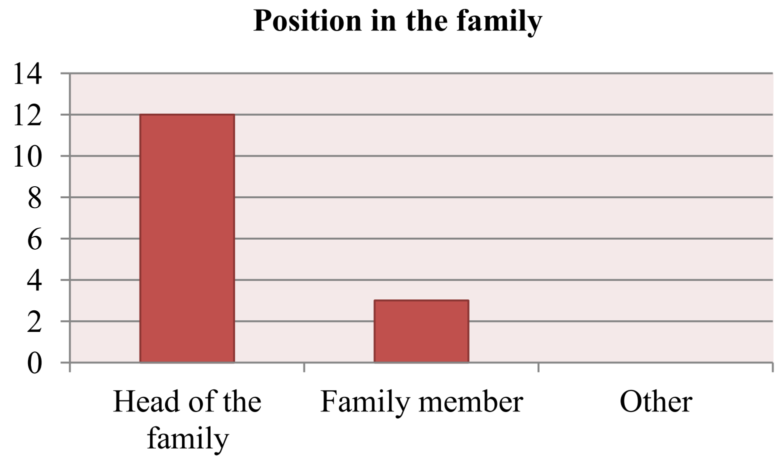
____

____

Appendix B: Analysis of questionnaires

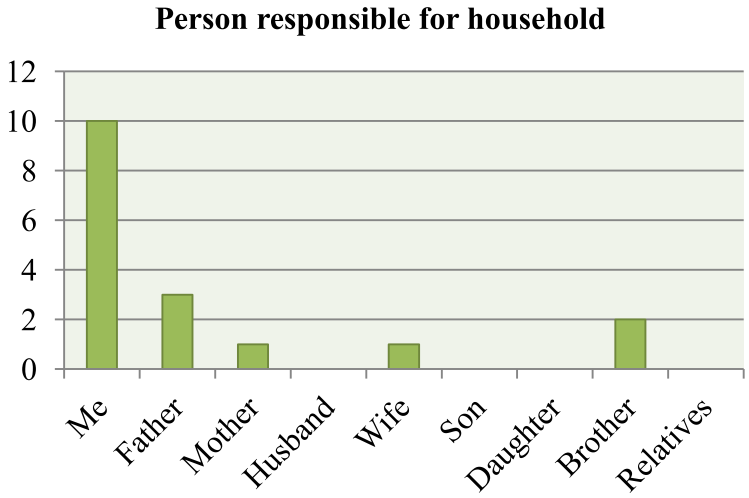
Q1. Position in the family?

Head of the family	**12**
Family member	**3**
Other	**0**



Q2. Person responsible for household?

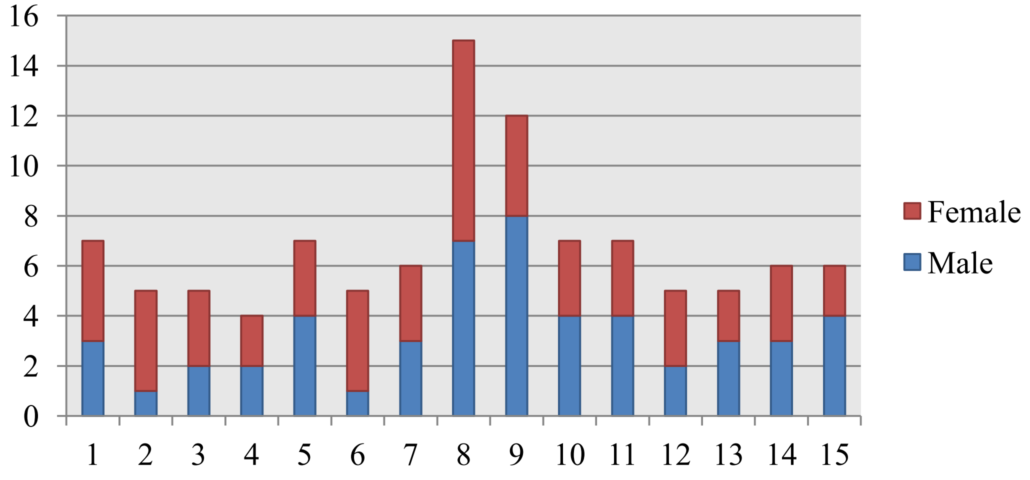
Me	**10**
Father	**3**
Mother	**1**
Husband	**0**
Wife	**1**
Son	**0**
Daughter	**0**
Brother	**2**
Relatives	**0**



Q3. Number and sex of occupant in the house

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Male	**3**	**1**	**2**	**2**	**4**	**1**	**3**	**7**	**8**	**4**	**4**	**2**	**3**	**3**	**4**
Female	**4**	**4**	**3**	**2**	**3**	**4**	**3**	**8**	**4**	**3**	**3**	**3**	**2**	**3**	**2**
Total	**7**	**5**	**5**	**4**	**7**	**5**	**6**	**15**	**12**	**7**	**7**	**5**	**5**	**6**	**6**

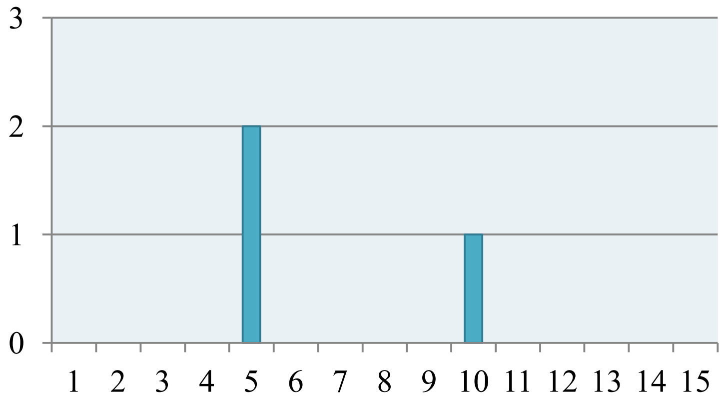
Composition of the family



Q4. How many people, who lives in yours house, have a job?

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
People with a job	**0**	**0**	**0**	**0**	**2**	**0**	**0**	**0**	**0**	**1**	**0**	**0**	**0**	**0**	**0**

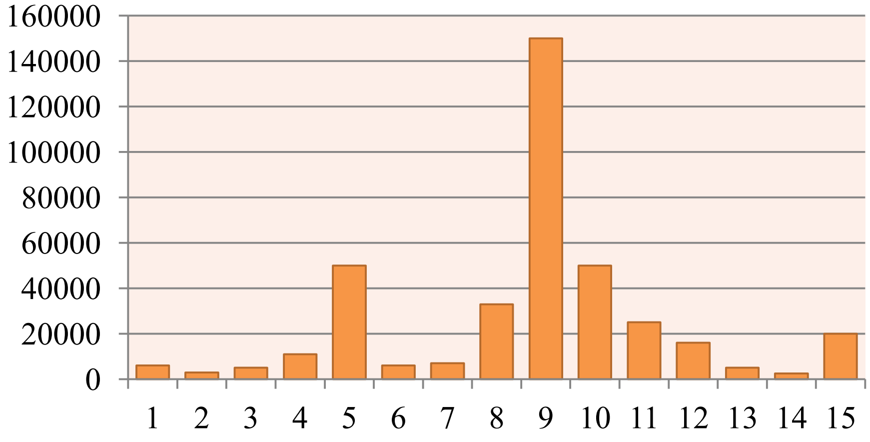
People with a job



Q5. Monthly household income

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Monthly income household (thousand of Rs)	**6**	**3**	**5**	**11**	**50**	**6**	**7**	**33**	**150**	**50**	**25**	**16**	**5**	**2.5**	**20**

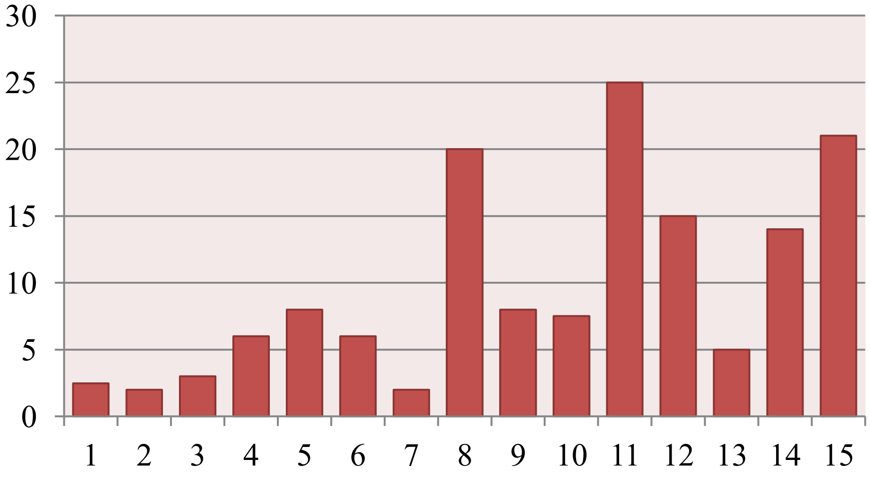
Monthly household income (Rs)



Q6. Which is the dimension of your cultivated land?

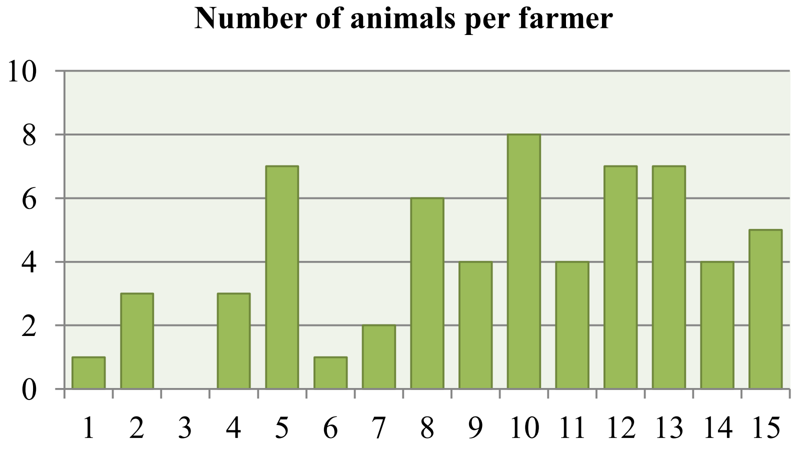
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Cultivated land (acres)	**2.47**	**2**	**3**	**6**	**8**	**6**	**2**	**20**	**8**	**7.5**	**25**	**15**	**5**	**14**	**21**

Cultivated land (acres)

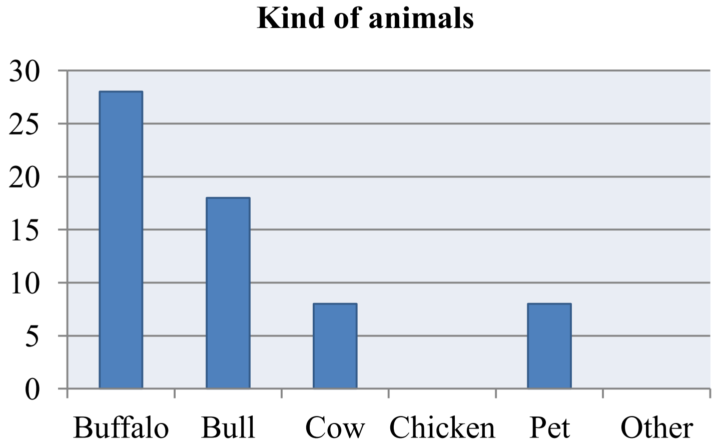


Q7. Do you have animals?

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Number of animals	**1**	**3**	**0**	**3**	**7**	**1**	**2**	**6**	**4**	**8**	**4**	**7**	**7**	**4**	**5**

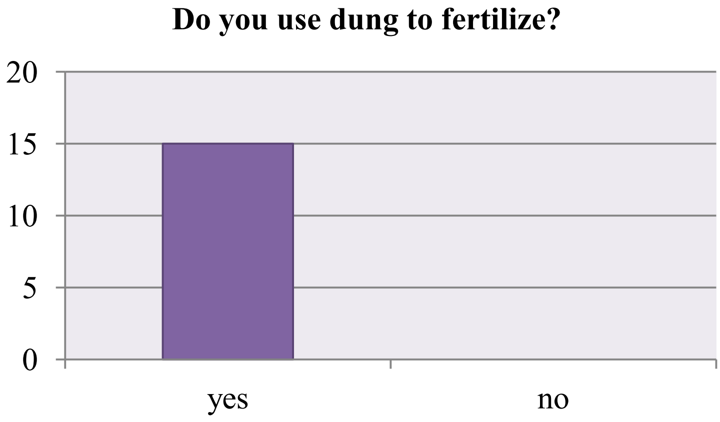


Kind of animals	
Buffalo	**28**
Bull	**18**
Cow	**8**
Chicken	**0**
Pet	**8**
Other	**0**



Q8. Do you use dung to fertilize?

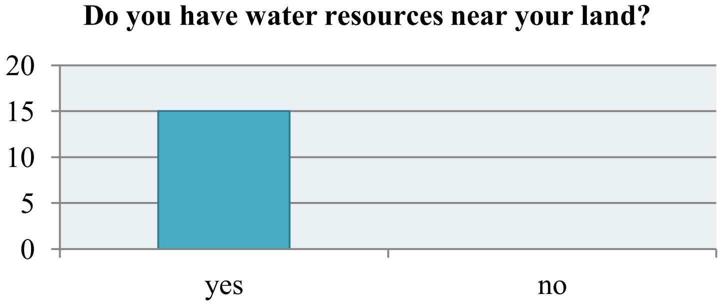
yes	**15**
no	**0**



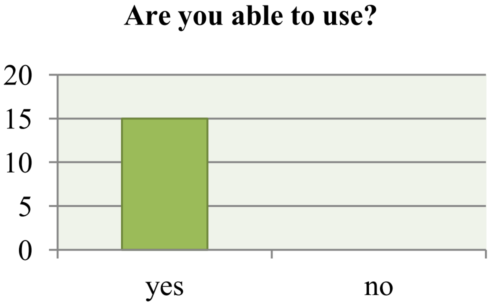
Q9. Do you have water resources near your land?

Q9.2. Are you able to use?

Do you have water resources near your land?	
Yes	**15**
No	**0**

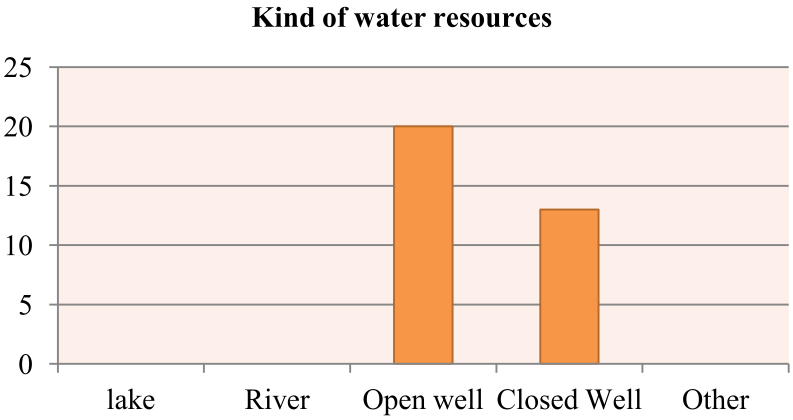


Are you able to use?	
Yes	**15**
No	**0**



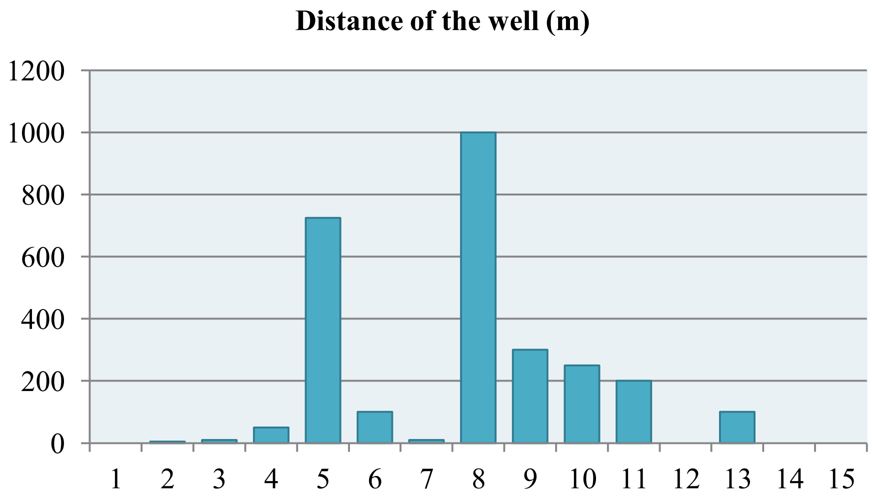
Q9.1. If yes specify

Lake	**0**
River	**0**
Open well	**20**
Closed Well	**13**
Other	**0**



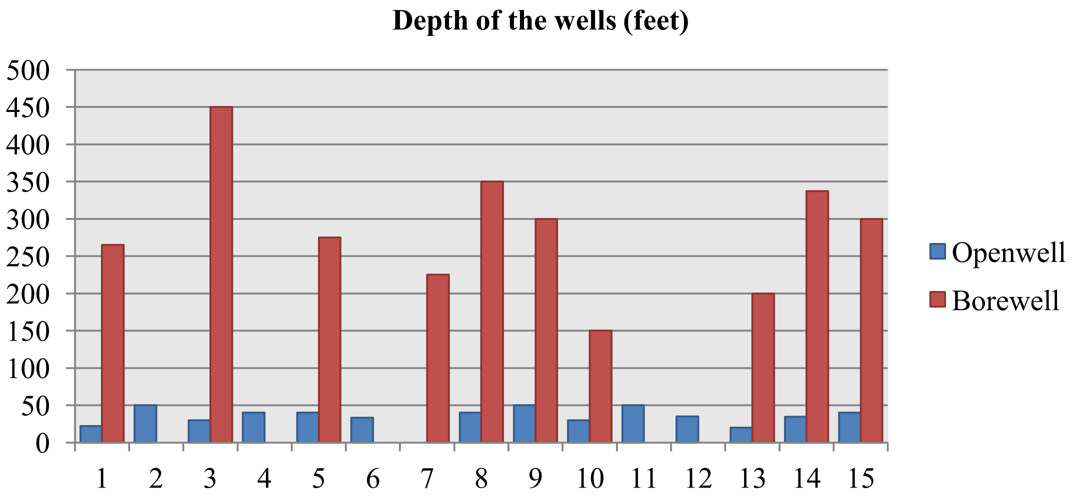
Q9.3. How far is it?

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
How far is it? (m)	**0**	**5**	**10**	**50**	**725**	**100**	**10**	**1000**	**300**	**250**	**200**	**0**	**100**	**0**	**0**



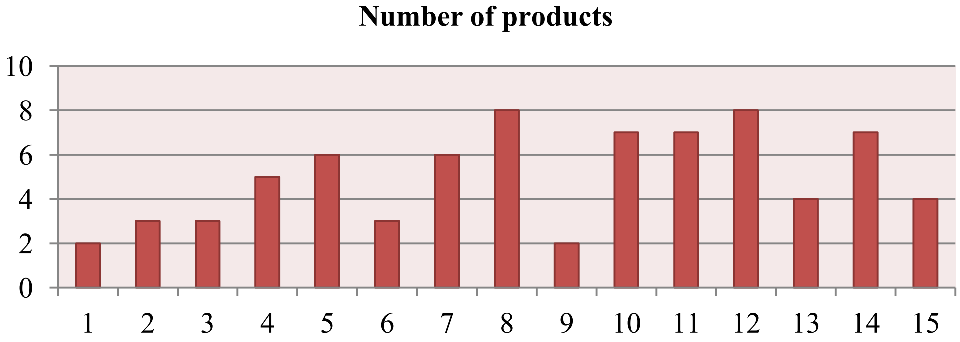
Q9.4. How deep is the well?

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Open well (feet)	**22**	**50**	**30**	**40**	**40**	**33**	**0**	**40**	**50**	**30**	**50**	**35**	**20**	**35**	**40**
Bore well (feet)	**265**	**0**	**450**	**0**	**275**	**0**	**225**	**350**	**300**	**150**	**0**	**0**	**200**	**337**	**300**

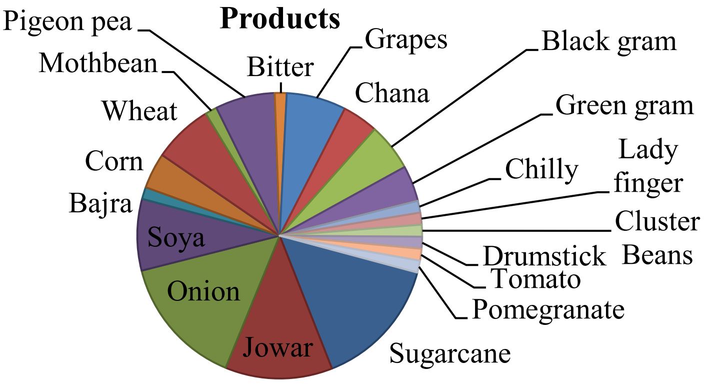


Q10. Which are the main products you cultivate?

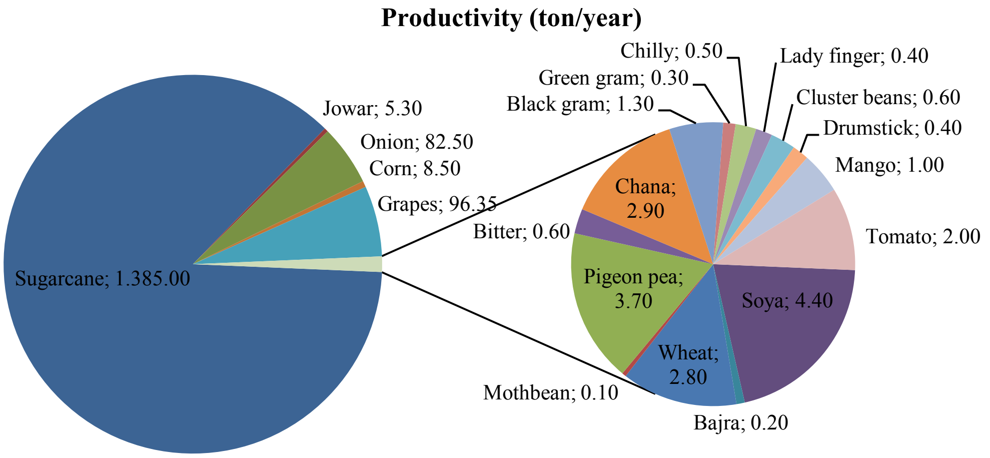
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Number of products	**2**	**3**	**3**	**5**	**6**	**3**	**6**	**8**	**2**	**7**	**7**	**8**	**4**	**7**	**4**



Which are the main products you cultivate?					
Sugarcane	**11**	Pigeon pea	**5**	Chilly	**1**
Jowar	**9**	Banana	**0**	Lady finger	**1**
Onion	**11**	Bitter	**1**	Cluster Beans	**1**
Soya	**6**	Grapes	**5**	Drumstick	**1**
Bajra	**1**	Chana	**3**	Mango	**0**
Corn	**3**	Black gram	**4**	Tomato	**1**
Cotton	**0**	Green gram	**3**	Pomegranate	**1**
Wheat	**5**	Horse gram	**0**		
Mothbean	**1**	Marigold	**0**		

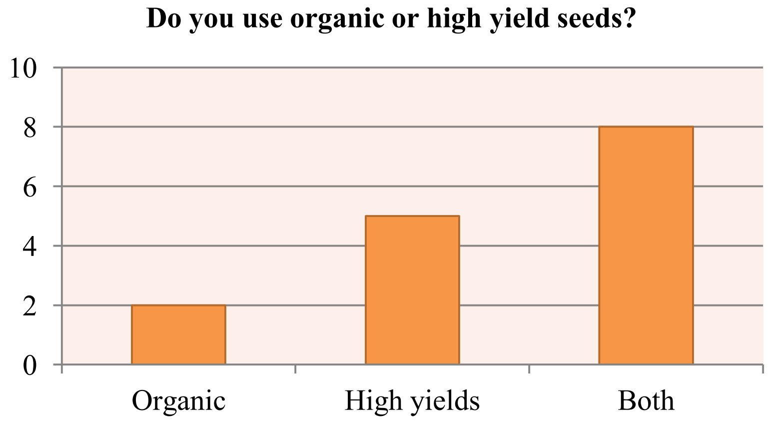


Q11. Productivity (ton/yr)



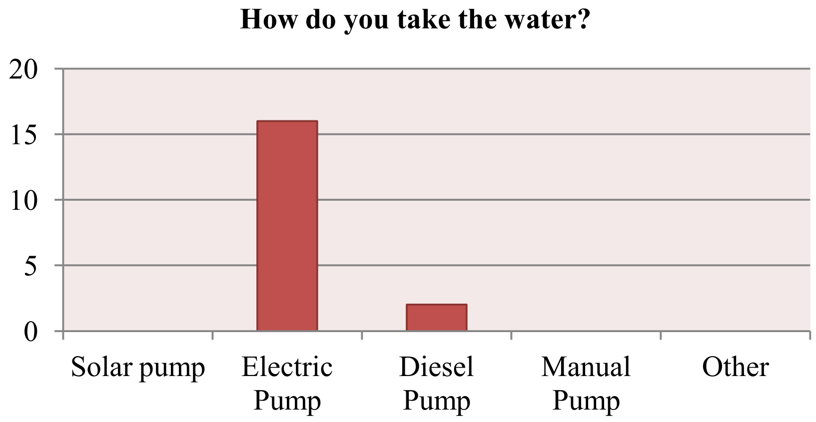
Q12. Do you use organic or high yields seeds?

Organic	**2**
High yields	**5**
Both	**8**



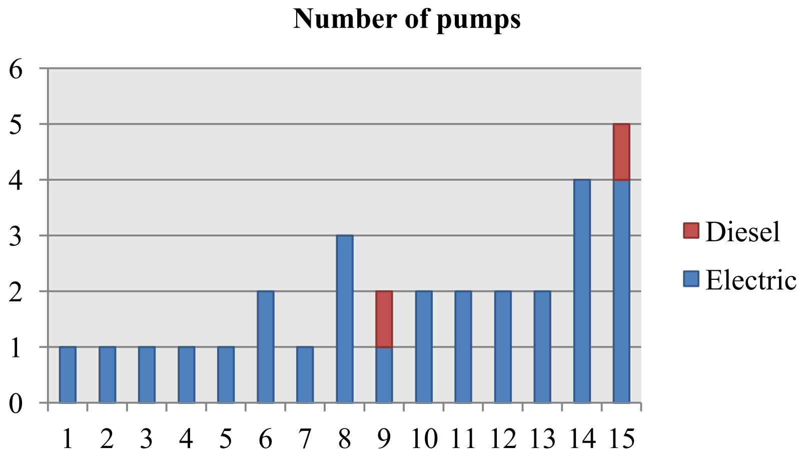
Q13. How do you take the water?

Solar pump	**0**
Electric Pump	**16**
Diesel Pump	**2**
Manual Pump	**0**
Other	**0**

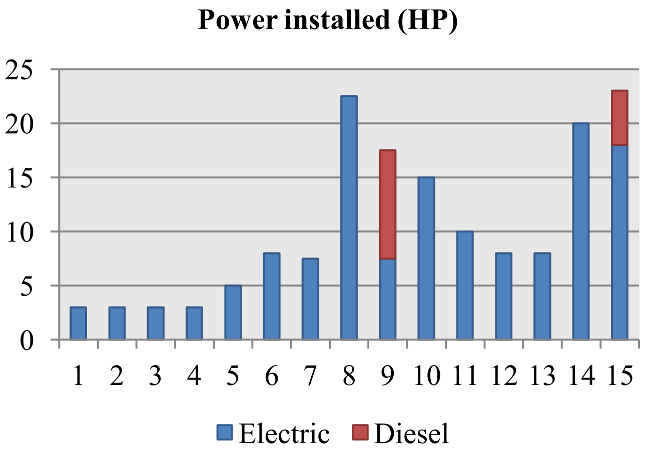


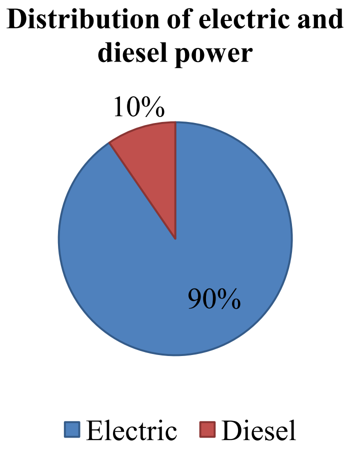
Q14. Pumps

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Number of electric pumps	**1**	**1**	**1**	**1**	**1**	**2**	**1**	**3**	**1**	**2**	**2**	**2**	**2**	**4**	**4**
Number of diesel pumps	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**1**	**0**	**0**	**0**	**0**	**0**	**1**



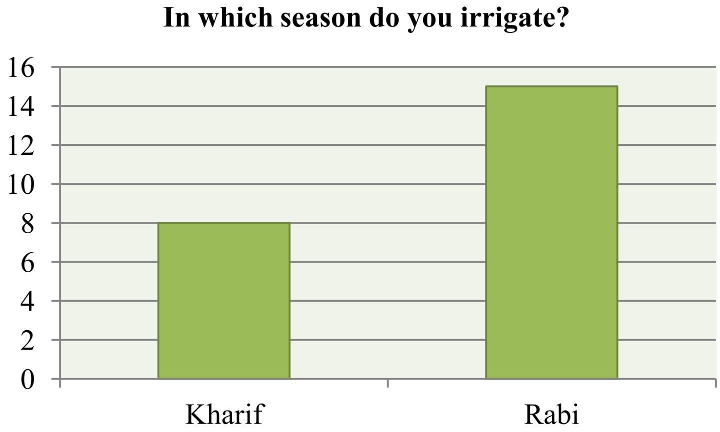
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Electric power (HP)	**3**	**3**	**3**	**3**	**5**	**8**	**7.5**	**22.5**	**7.5**	**15**	**10**	**8**	**8**	**20**	**18**
Diesel power (HP)	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**10**	**0**	**0**	**0**	**0**	**0**	**5**
Total power (HP)	**3**	**3**	**3**	**3**	**5**	**8**	**7.5**	**22.5**	**17.5**	**15**	**10**	**8**	**8**	**20**	**23**





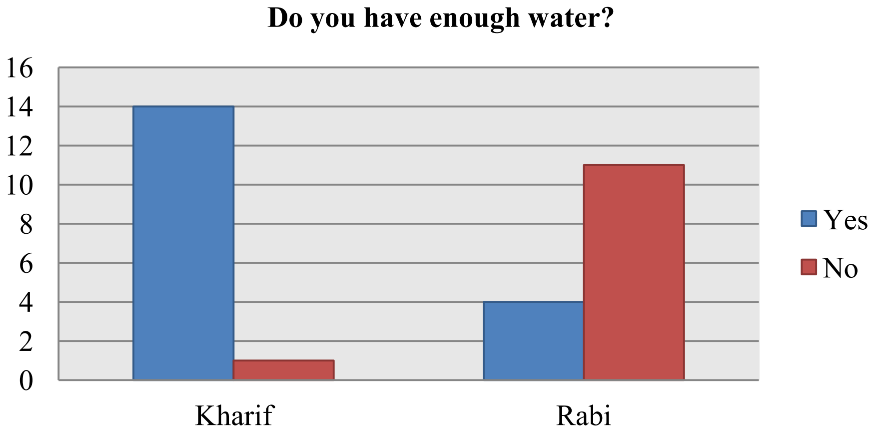
Q15 In which season do you irrigate?

Kharif	**8**
Rabi	**15**



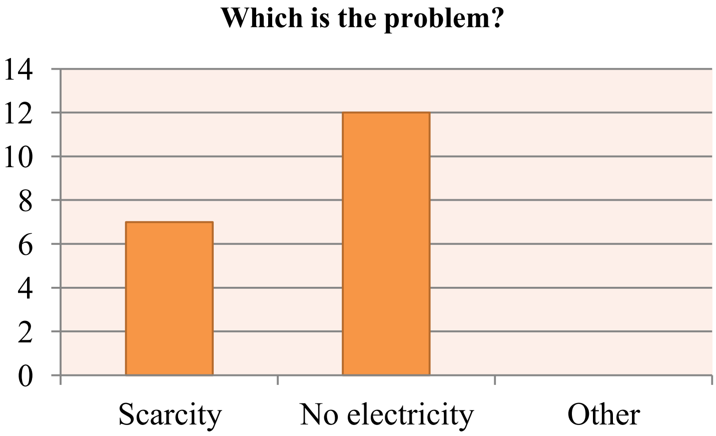
Q16 Do you have enough water ?

Kharif	
Yes	**14**
No	**1**
Rabi	
Yes	**4**
No	**11**



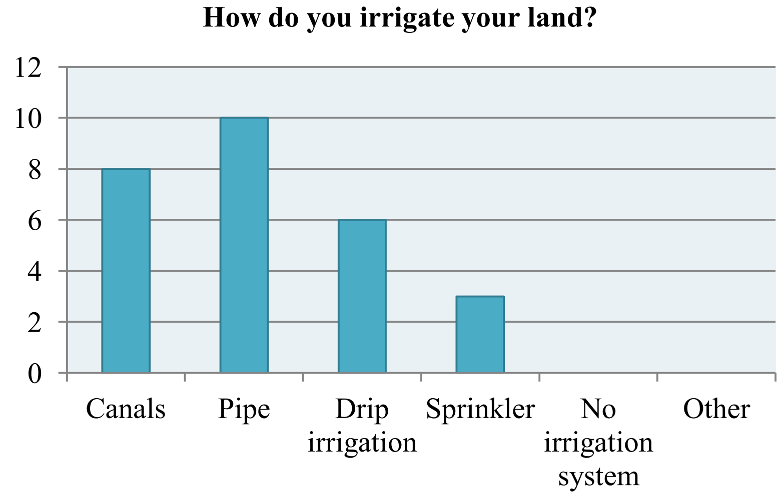
Q16.1 If no, which is the problem?

Scarcity	**7**
No electricity	**12**
Other	**0**



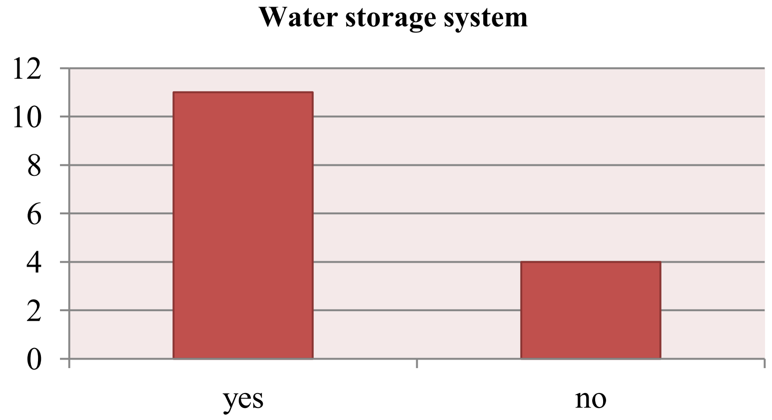
Q 17 How do you irrigate your land?

Canals	**8**
Pipe	**10**
Drip irrigation	**6**
Sprinkler	**3**
No irrigation system	**0**
Other	**0**



Q18 Do you have water storage systems?

yes	**11**
no	**4**

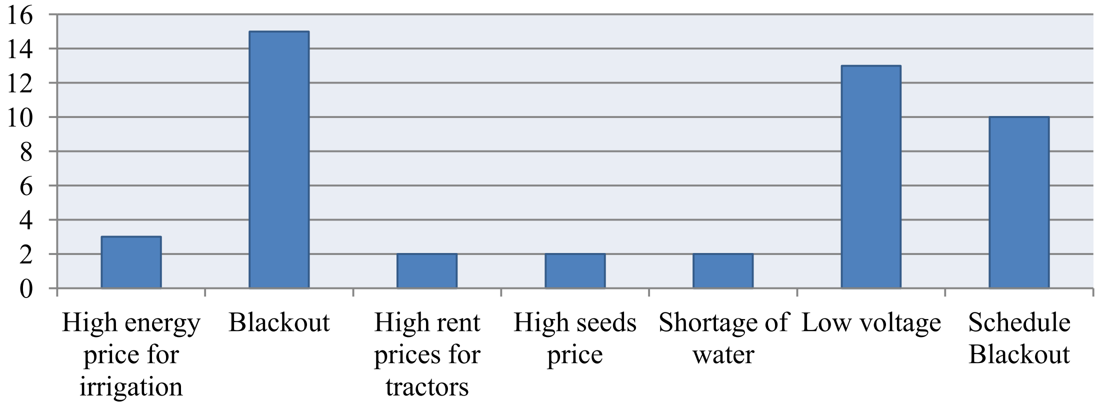


Q19 Do you have difficulties in cultivating or irrigating your field? Which ones?

High energy price for irrigation	**3**
Blackout	**15**
High rent prices for tractors	**2**
High seeds price	**2**

Shortage of water	**2**
Low voltage	**13**
Schedule Blackout	**10**

Difficulties in cultivating or irrigating (KHARIF)

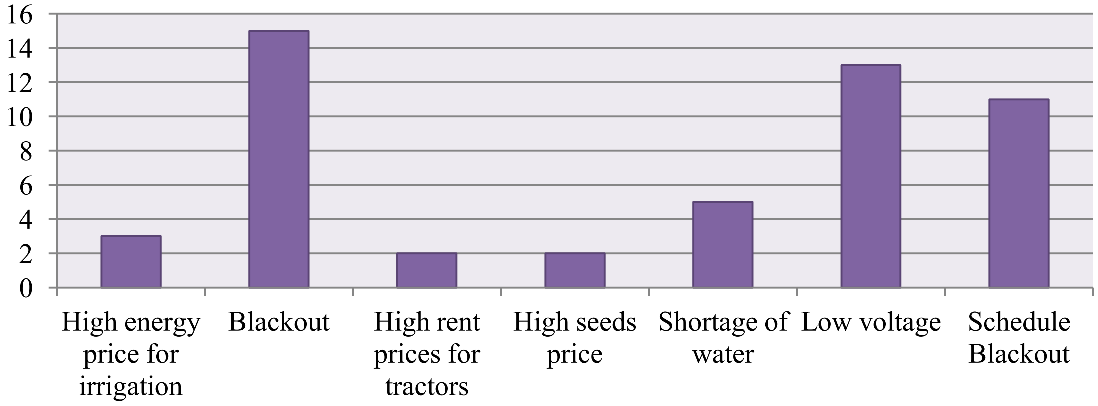


Q19 Do you have difficulties in cultivating or irrigating your field? Which ones?

High energy price for irrigation	**3**
Blackout	**15**
High rent prices for tractors	**2**
High seeds price	**2**

Shortage of water	**5**
Low voltage	**13**
Schedule Blackout	**11**

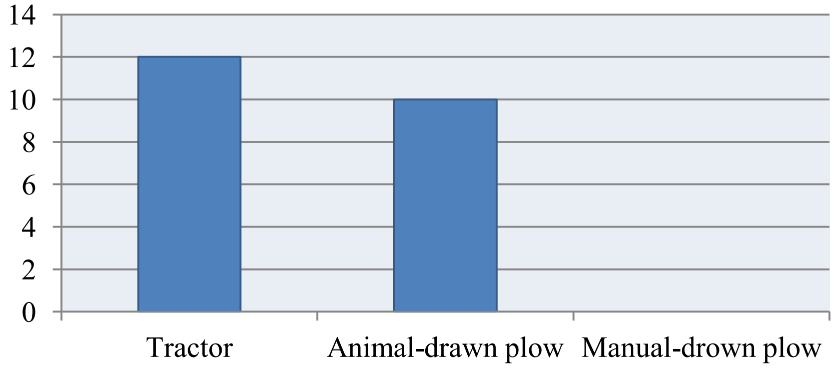
Difficulties in cultivating or irrigating (RABI)



Q20 Do you use tractor to plough your land?

yes	**12**
no	**3**

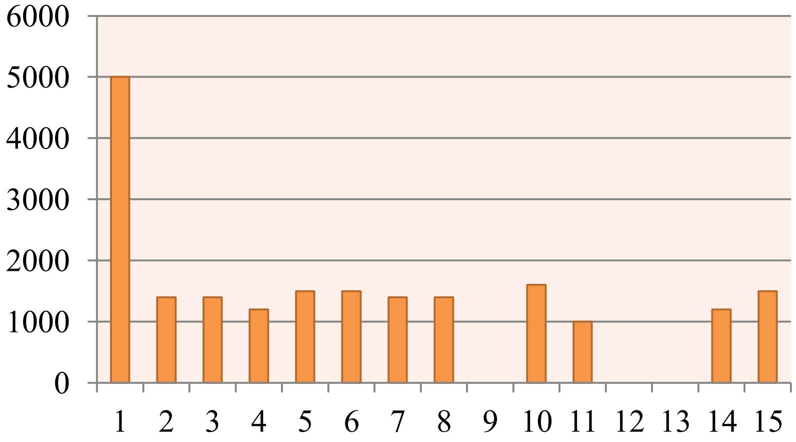
Method used to plough the land



Q20.1 If yes, do you rent or own the tractor? Specify the price

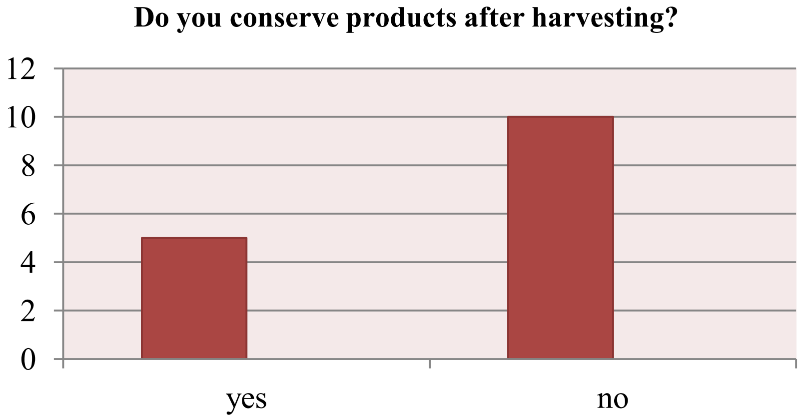
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Price (thousand of Rs/acre)	**5**	**1.4**	**1.4**	**1.2**	**1.5**	**1.5**	**1.4**	**1.4**	**-**	**1.6**	**1**	**-**	**-**	**1.2**	**1.5**

Price of tractor (Rs/acre)



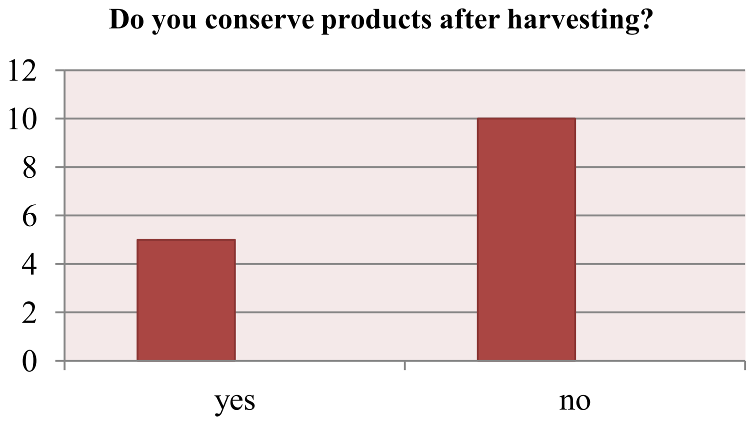
Q21 Do you conserve your products after the harvesting?

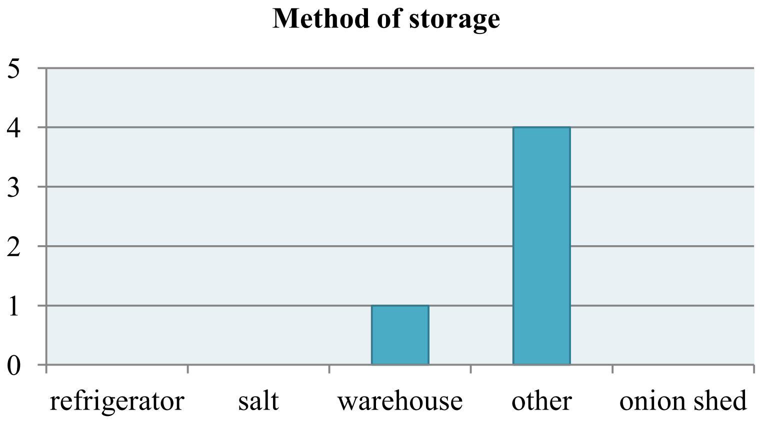
yes	**5**
no	**10**



Q21.1 If yes, how do you conserve your products after the harvesting?

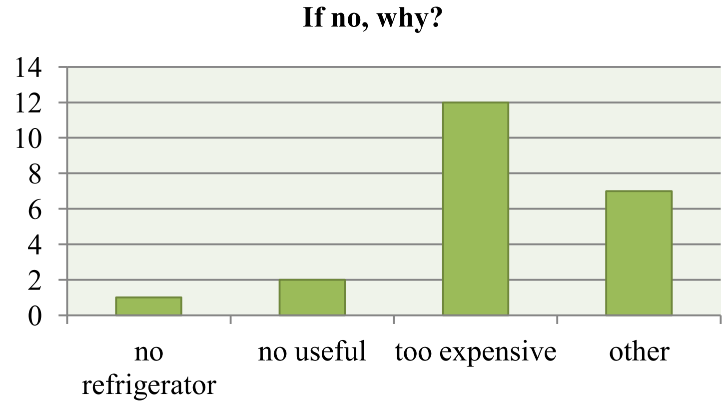
refrigerator	**0**
salt	**0**
warehouse	**1**
other	**4**
onion shed	**0**





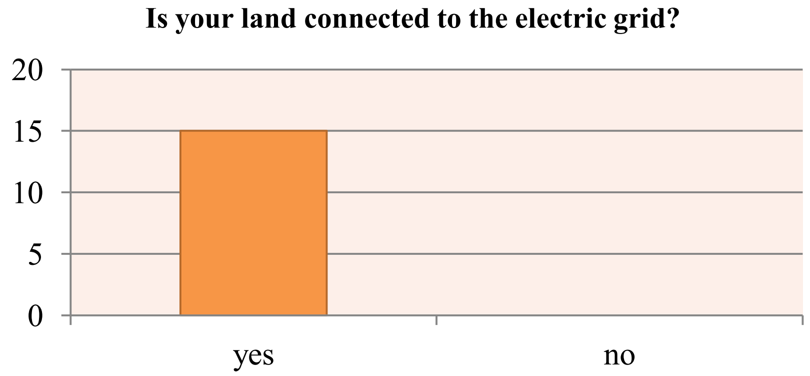
Q21.3 If no, why?

no refrigerator	**1**
no useful	**2**
too expensive	**12**
other	**7**



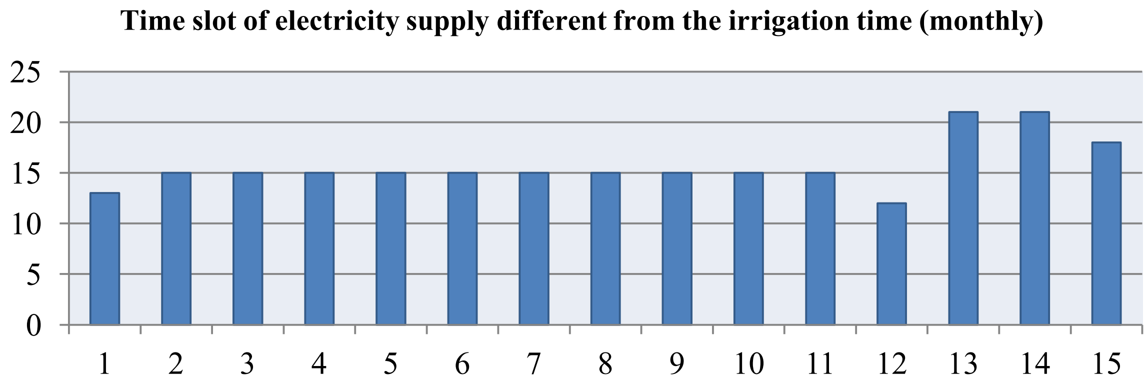
Q23 Have you the connection to the national electric grid for your land?

yes	**15**
no	**0**



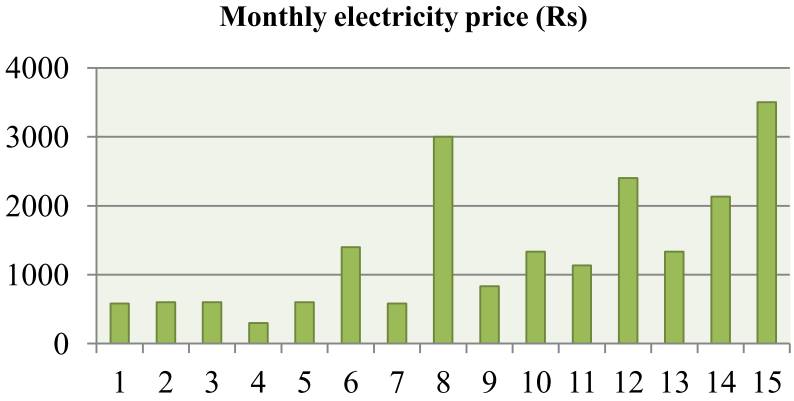
Q23.1 If yes, how many time slot of electricity supply is different from the irrigation time?

1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**
13	15	15	15	15	15	15	15	15	15	15	12	21	21	18



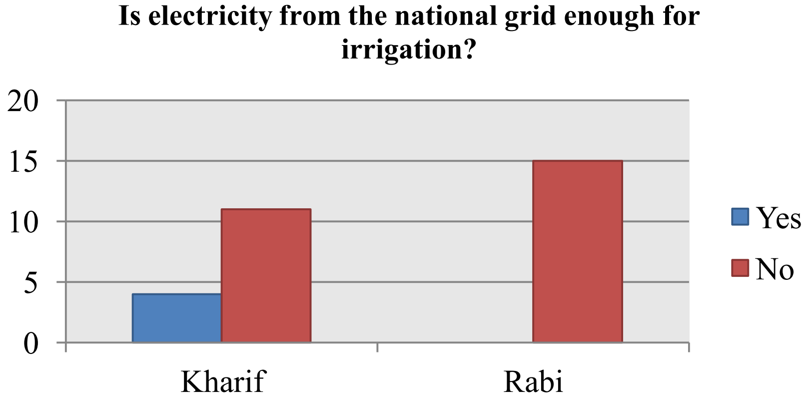
Q23.2 How much do you pay monthly for electricity?

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Rs	**583**	**600**	**600**	**300**	**600**	**1400**	**583**	**3000**	**833**	**1333**	**1133**	**2400**	**1333**	**2133**	**3500**



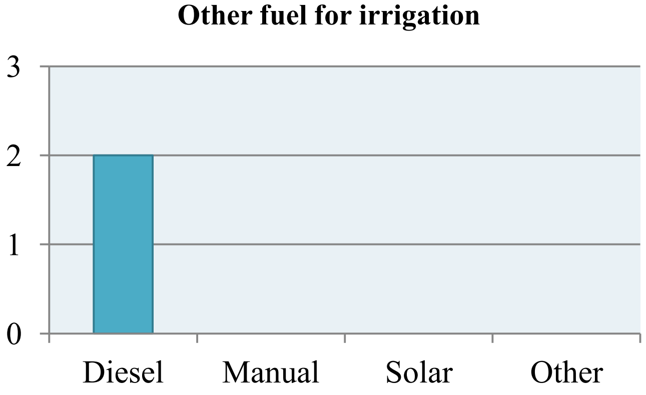
Q23.3 Is electricity from national grid enough for irrigation?

Kharif	
Yes	**4**
No	**11**
Rabi	
Yes	**0**
No	**15**



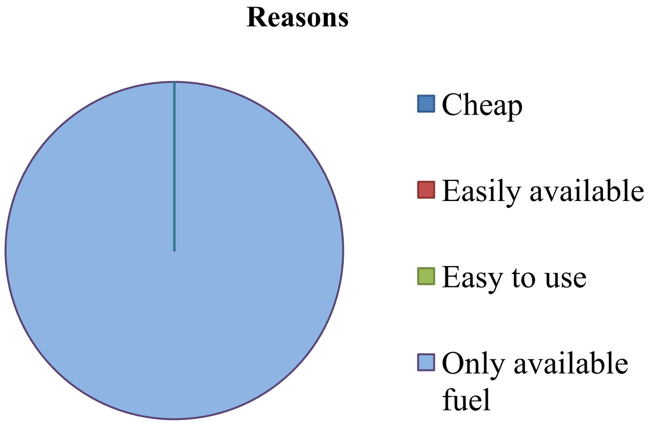
Q23.5 If no, which fuel do you use for your irrigation system?

Diesel	**2**
Manual	**0**
Solar	**0**
Other	**0**



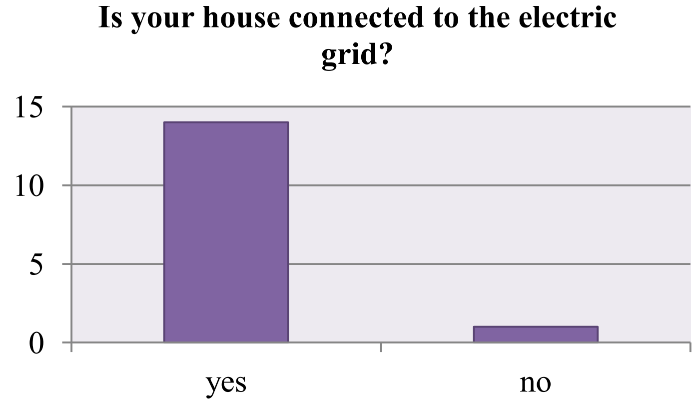
Q23.6 Reason for use this fuel?

Cheap	**0**
Easily available	**0**
Easy to use	**0**
Only available fuel	**2**
Other	**0**



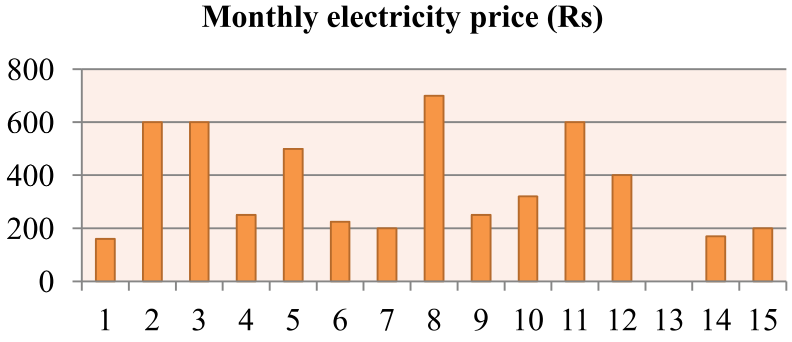
Q25 Do you have the connection to the national electric grid for your house?

yes	**14**
no	**1**



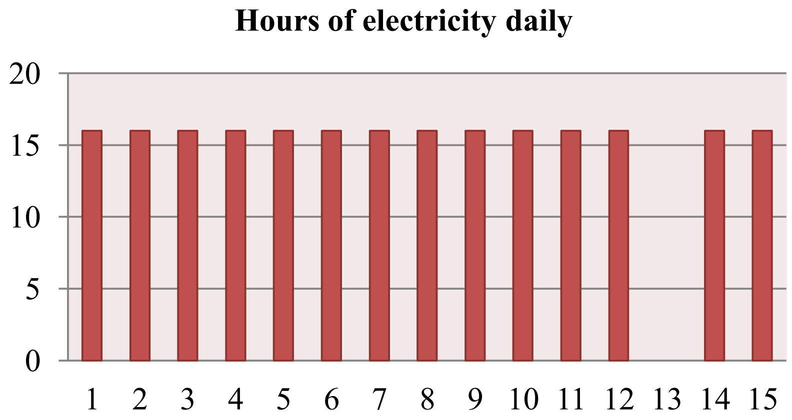
Q25.1 How much do you pay monthly for electricity?

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Rs	**160**	**600**	**600**	**250**	**500**	**225**	**200**	**700**	**250**	**320**	**600**	**400**	**0**	**170**	**200**



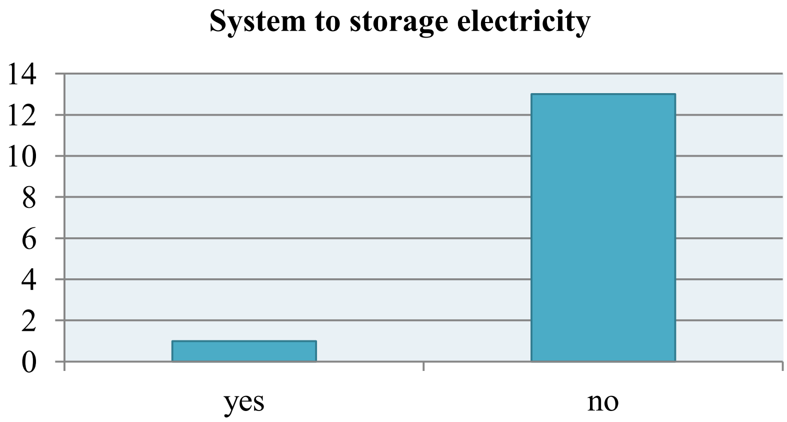
Q26 How many hours do you have electricity daily?

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
hours of electricity	**16**	**16**	**16**	**16**	**16**	**16**	**16**	**16**	**16**	**16**	**16**	**16**	**0**	**16**	**16**

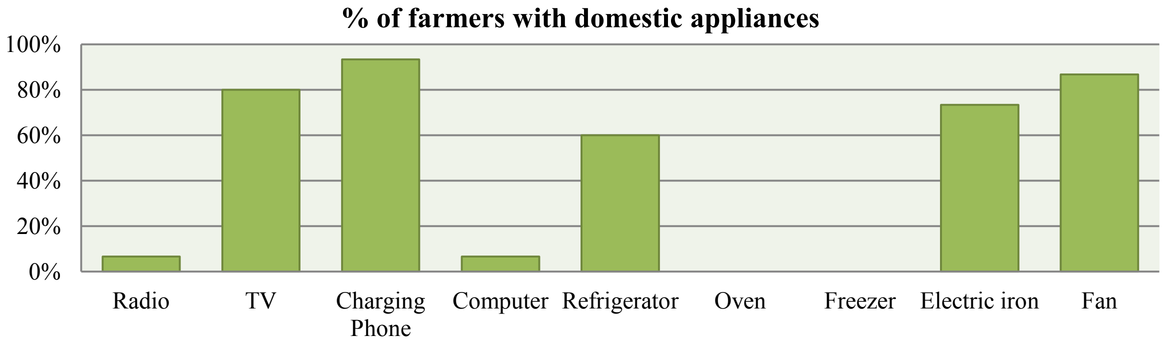


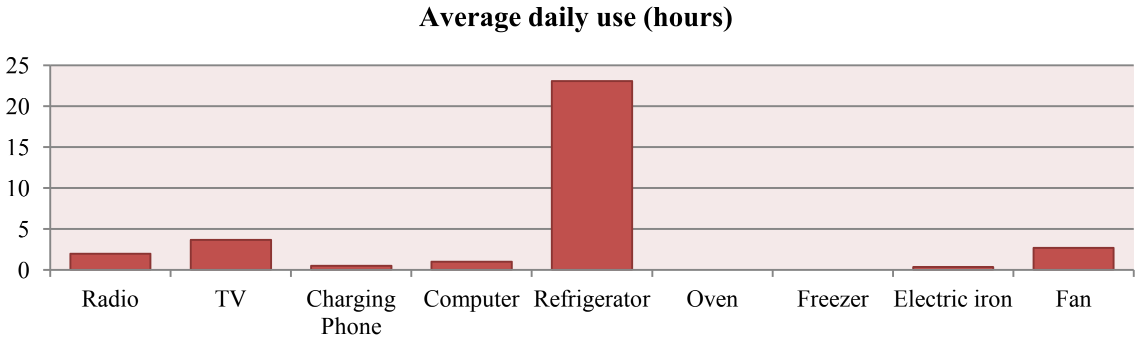
Q27 Do you have system to storage the electricity?

yes	**1**
no	**13**



Q29 Table

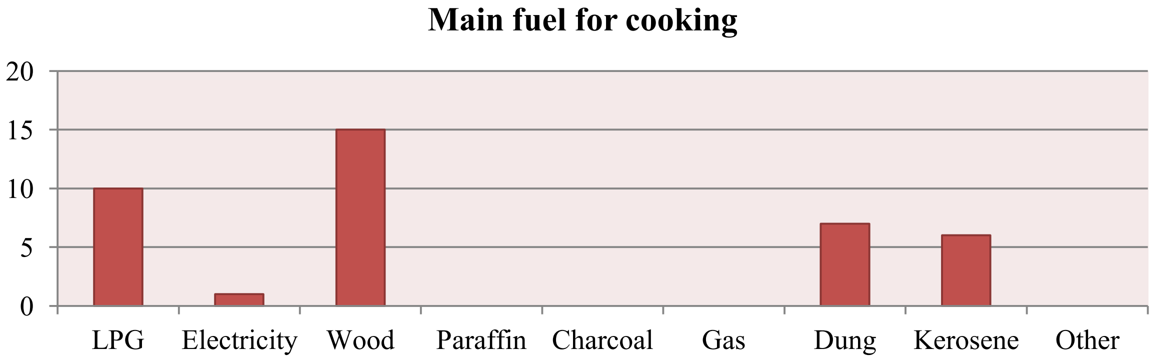




Q30. Main fuel for cooking

LPG	**10**
Electricity	**1**
Wood	**15**
Paraffin	**0**
Charcoal	**0**

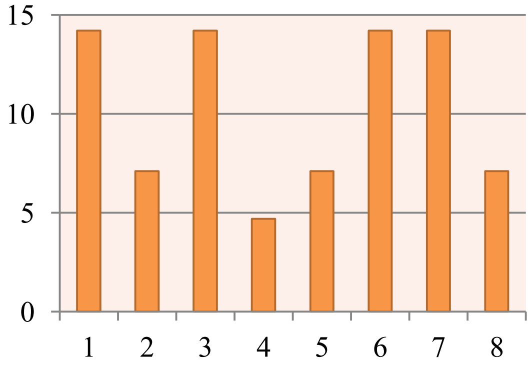
Gas	**0**
Dung	**7**
Kerosene	**6**
Other	**0**



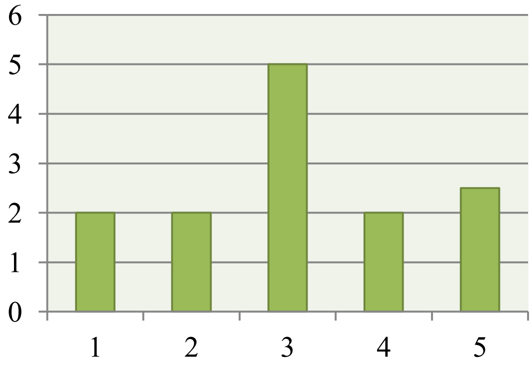
Q30.1. Could you estimate how much fuel do you consume monthly?

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
LPG (kg)				**14.2**	**7.1**	**14.2**			**4.7**	**7.1**	**14.2**			**14.2**	**7.1**
Wood (kg)	**200**	**80**	**80**	**80**	**80**	**60**	**80**	**50**	**300**	**60**	**100**	**20**	**200**	**30**	**200**
Kerosene (lt)				**2**		**2**					**5**	**2**			**2,5**

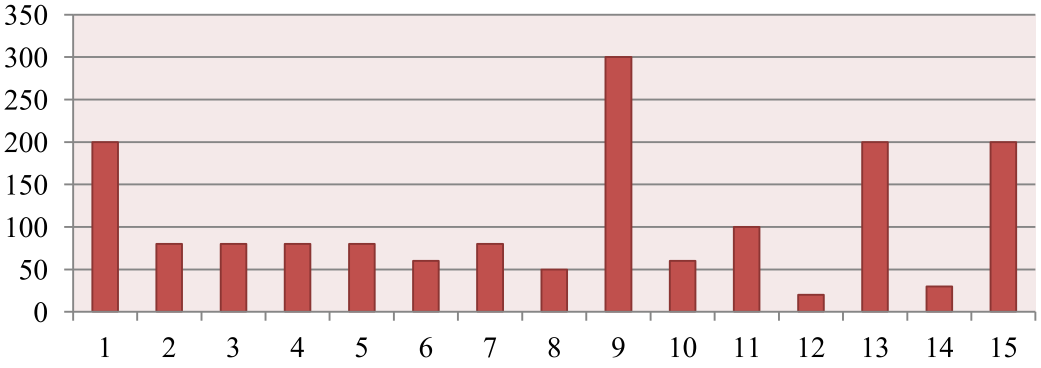
LPG (kg/month)



Kerosene (lt/month)

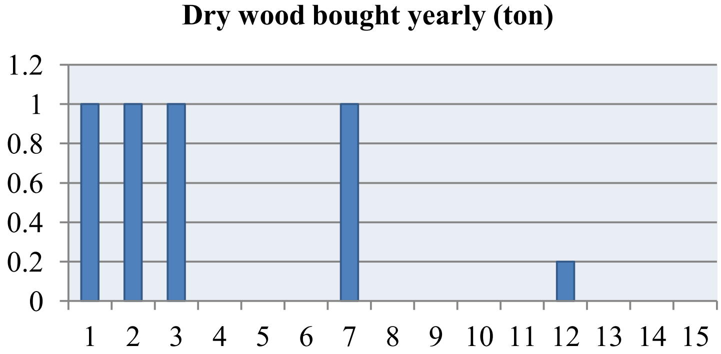


Wood (kg/month)



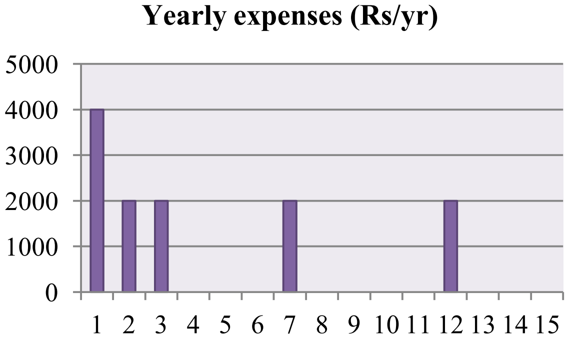
Q30.2. How much dry wood do you buy yearly?

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
dry wood (ton)	**1**	**1**	**1**	**0**	**0**	**0**	**1**	**0**	**0**	**0**	**0**	**0,2**	**0**	**0**	**0**



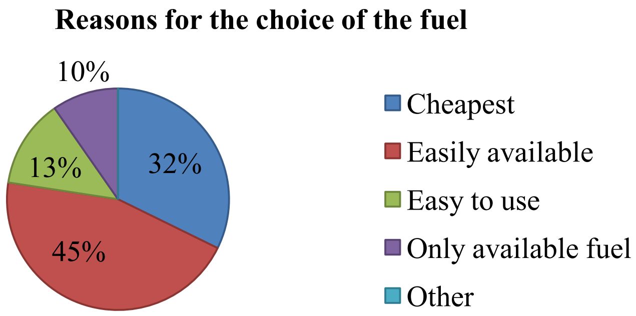
Q30.3. How much do you pay for dry wood?

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
yearly price (Rs)	**4000**	**2000**	**2000**	**-**	**-**	**-**	**2000**	**-**	**-**	**-**	**-**	**2000**	**-**	**-**	**-**



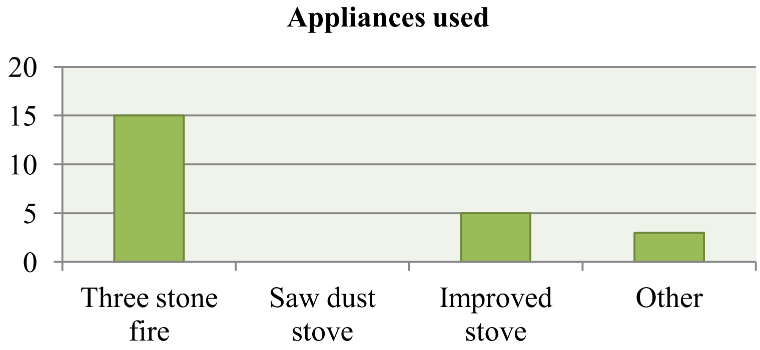
Q31. Reason for the choice of fuel

Cheapest	**10**
Easily available	**14**
Easy to use	**4**
Only available fuel	**3**
Other	**0**



Q32. Which appliance do you use to cook?

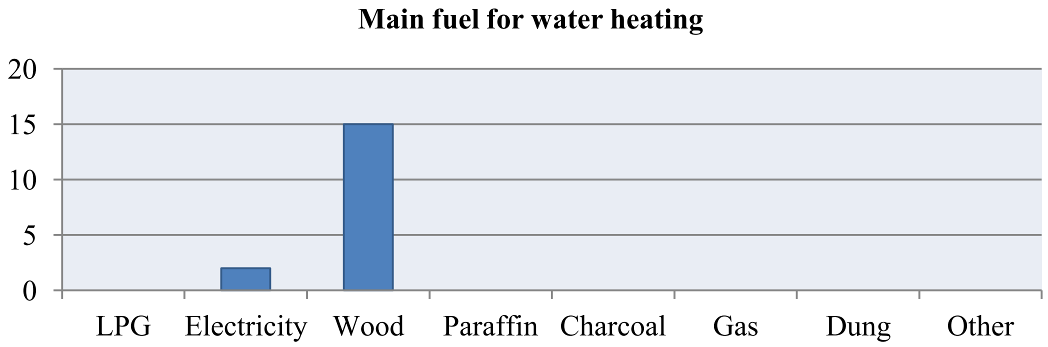
Three stone fire	**15**
Saw dust stove	**0**
Improved stove	**5**
Other	**3**



Q33. Main fuel for water heating

LPG	**0**
Electricity	**2**
Wood	**15**
Paraffin	**0**

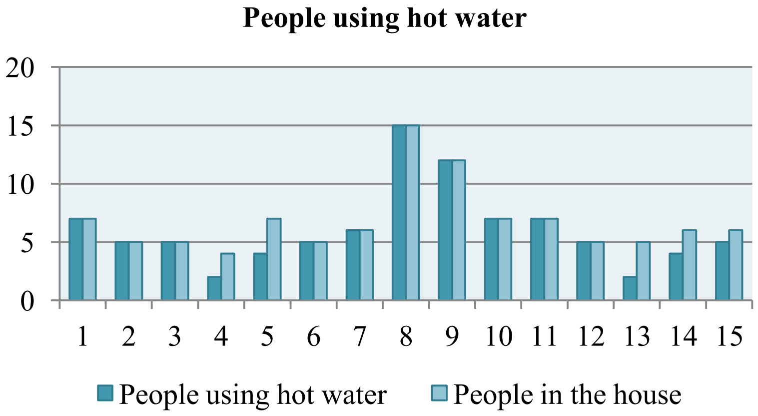
Charcoal	**0**
Gas	**0**
Dung	**0**
Other	**0**



Q33.1 How many people use hot water in the house?

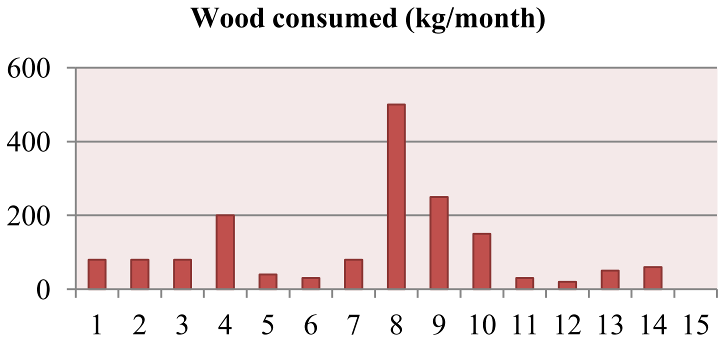
1	**7**
2	**5**
3	**5**
4	**2**
5	**4**
6	**5**
7	**6**
8	**15**

9	**12**
10	**7**
11	**7**
12	**5**
13	**2**
14	**4**
15	**5**



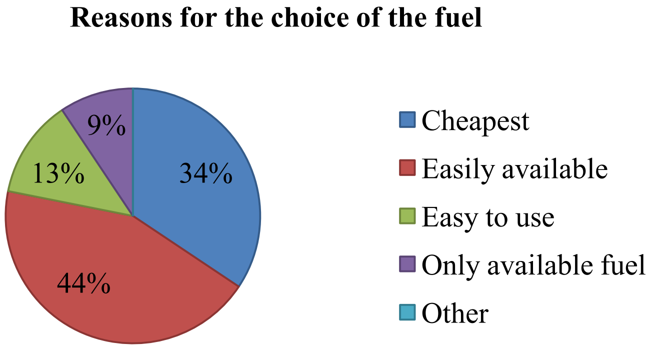
Q33.2 Could you estimate how much fuel do you consume monthly?

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Wood (kg/month)	**80**	**80**	**80**	**200**	**40**	**30**	**80**	**500**	**250**	**150**	**30**	**20**	**50**	**60**	**-**



Q34. Reason for the choice of fuel

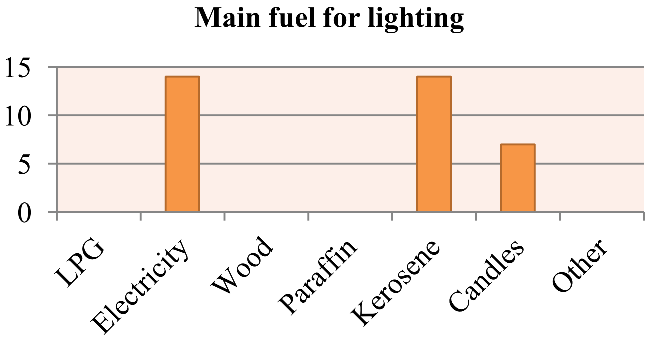
Cheapest	**11**
Easily available	**14**
Easy to use	**4**
Only available fuel	**3**
Other	**0**



Q35. Main fuel for lighting

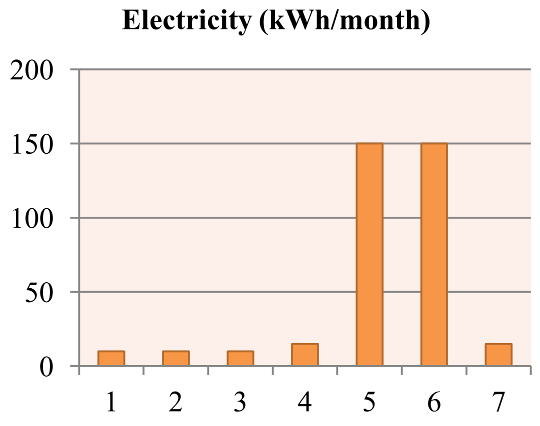
LPG	**0**
Electricity	**14**
Wood	**0**
Paraffin	**0**

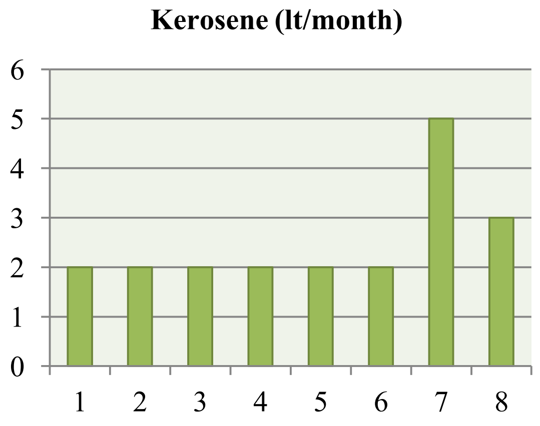
Kerosene	**14**
Candles	**7**
Other	**0**



Q35.1. Could you estimate how much fuel do you consume monthly?

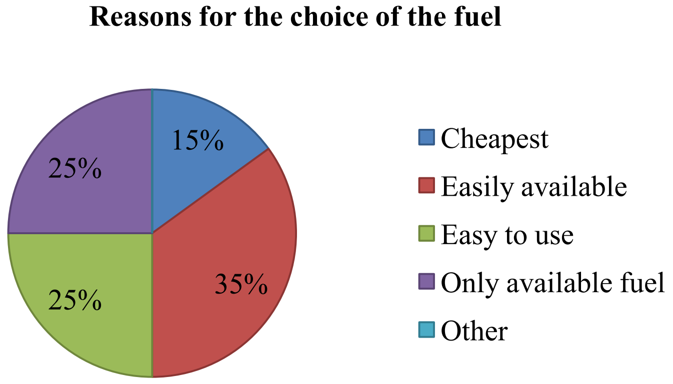
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Electricity (kWh/month)	**10**	**10**	**10**	**-**	**-**	**-**	**15**	**150**	**150**	**15**	**45**	**-**	**-**	**-**	**-**
Kerosene (lt/month)	**-**	**-**	**-**	**-**	**2**	**2**	**-**	**2**	**2**	**2**	**2**	**2**	**5**	**3**	**-**


Electricity (kWh/month)


Kerosene (lt/month)

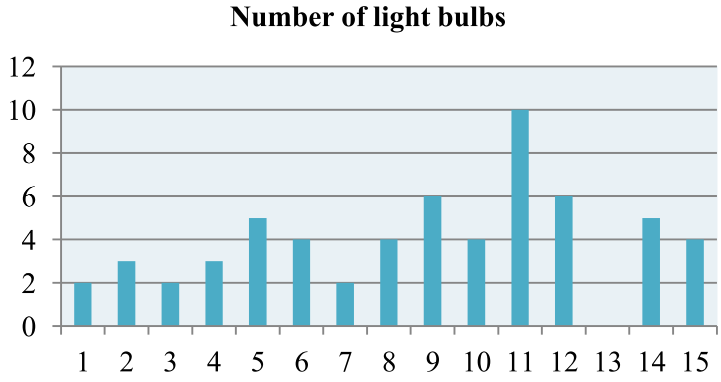
Q36. Reason for the choice of fuel

Cheapest	**3**
Easily available	**7**
Easy to use	**5**
Only available fuel	**5**
Other	**0**


Reasons for the choice of the fuel

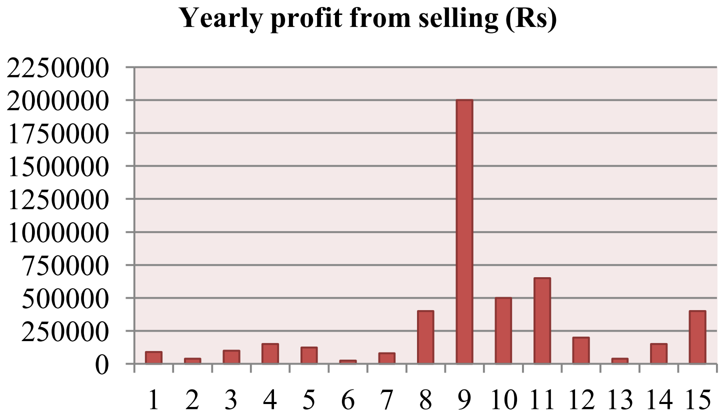
Q37. How many light bulbs do you have in your house?

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Number of light bulbs	**2**	**3**	**2**	**3**	**5**	**4**	**2**	**4**	**6**	**4**	**10**	**6**	**0**	**5**	**4**



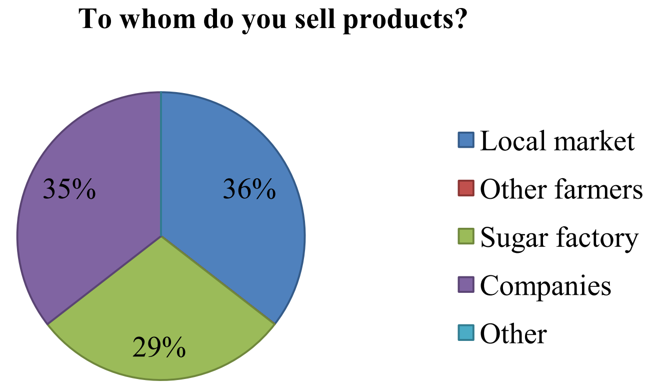
Q38. What is your profit from selling your products yearly?

	1	2	3	4	5	6	7	8
Yearly profit (Rs)	**90000**	**40000**	**100000**	**150000**	**125000**	**25000**	**80000**	**40000**
	9	10	11	12	13	14	15	
Yearly profit (Rs)	**2000000**	**500000**	**650000**	**200000**	**40000**	**150000**	**400000**	



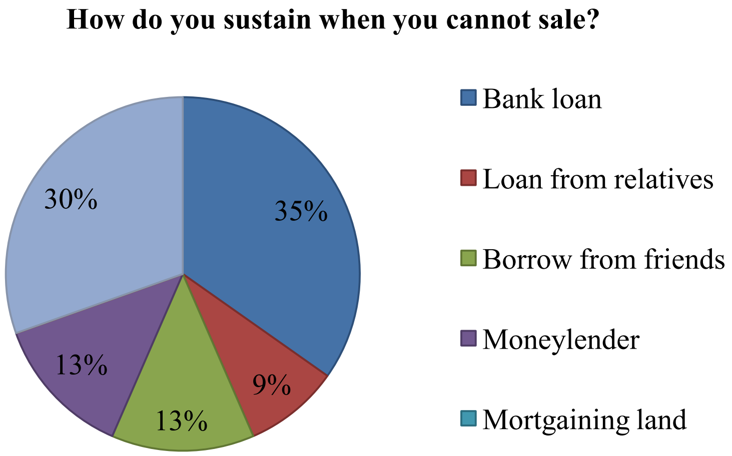
Q39. To whom do you sell your products mainly?

Local market	**11**
Other farmers	**0**
Sugar factory	**9**
Companies	**11**
Other	**0**



Q40. How do you sustain when you cannot produce and/or sale?

Bank loan	**8**
Loan from relatives	**2**
Borrow from friends	**3**
Moneylender	**3**
Mortgaging land	**0**
I don't have period without producing	**0**
Other	**7**

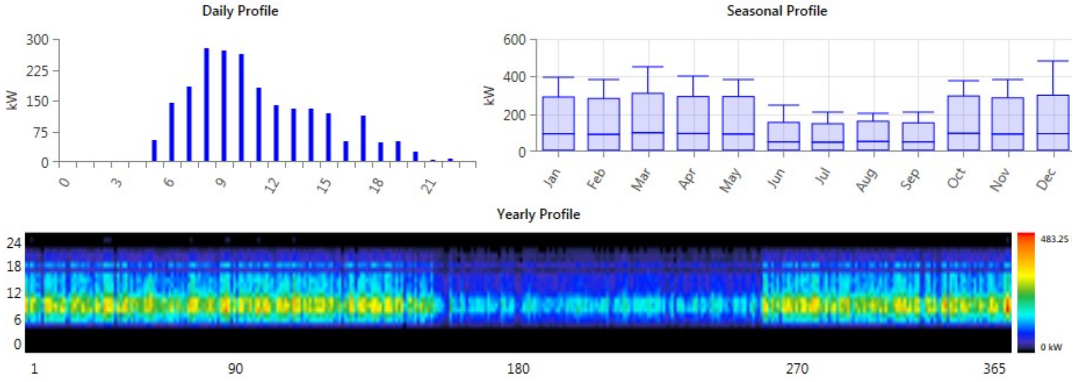


Appendix C: Simulation results

ENERGY LOAD PROFILES

Configuration A

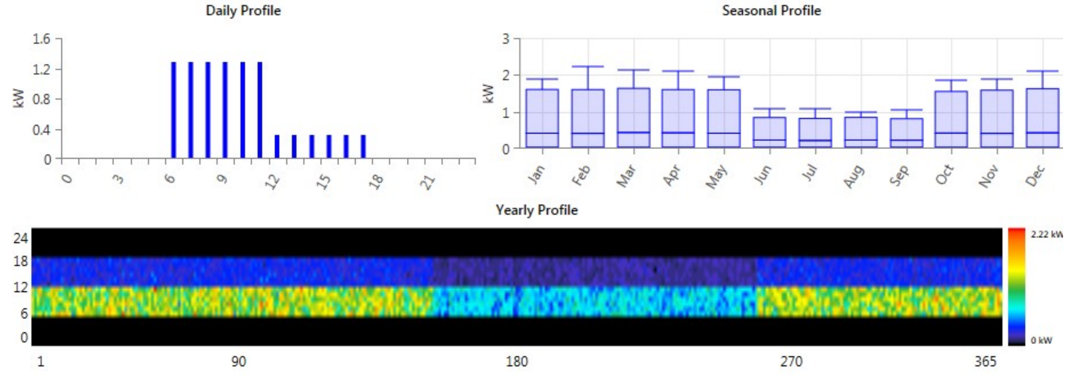
Hour	0	1	2	3	4	5	6	7	8	9	10	11
Load (kW)	0,00	0,00	0,00	0,00	0,00	0,00	145.5	182.9	276.0	272.9	263.2	182.2
Hour	12	13	14	15	16	17	18	19	20	21	22	23
Load (kW)	139.2	129.5	131.0	118.0	50.9	112.1	48.8	51.9	25.5	6.1	9.2	0,00



Configuration B

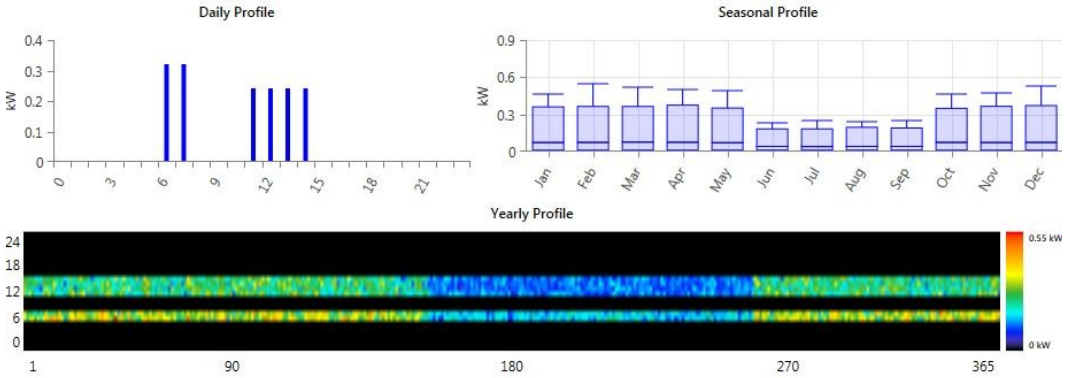
Farmer 1

Hour	0	1	2	3	4	5	6	7	8	9	10	11
Load (kW)	0.00	0.00	0.00	0.00	0.00	0.00	1.28	1.28	1.28	1.28	1.28	1.28
Hour	12	13	14	15	16	17	18	19	20	21	22	23
Load (kW)	0.32	0.32	0.32	0.32	0.32	0.32	0.00	0.00	0.00	0.00	0.00	0.00



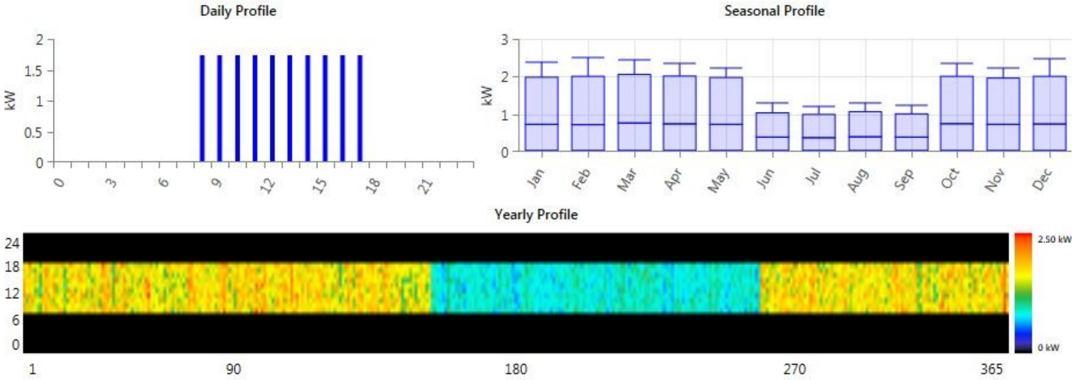
Farmer 2

Hour	0	1	2	3	4	5	6	7	8	9	10	11
Load (kW)	0.00	0.00	0.00	0.00	0.00	0.00	0.32	0.32	0.00	0.00	0.00	0.24
Hour	12	13	14	15	16	17	18	19	20	21	22	23
Load (kW)	0.24	0.24	0.24	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00



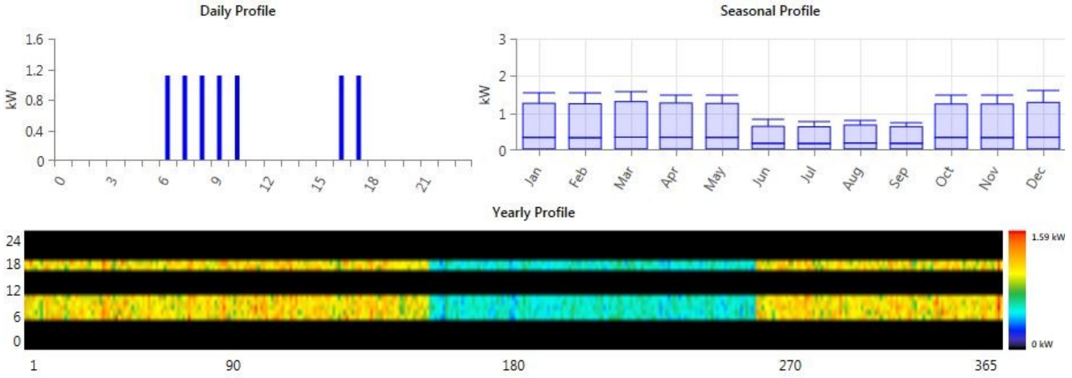
Farmer 3

Hour	0	1	2	3	4	5	6	7	8	9	10	11
Load (kW)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.73	1.73	1.73	1.73
Hour	12	13	14	15	16	17	18	19	20	21	22	23
Load (kW)	1.73	1.73	1.73	1.73	1.73	1.73	0.00	0.00	0.00	0.00	0.00	0.00



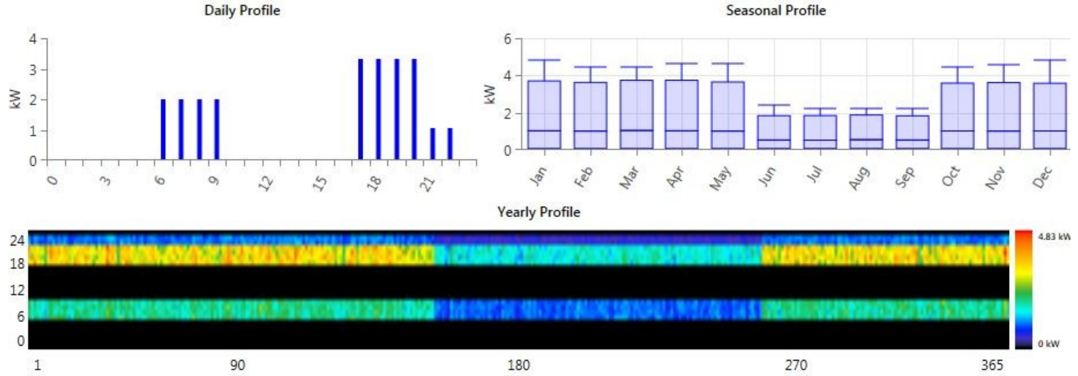
Farmer 4

Hour	0	1	2	3	4	5	6	7	8	9	10	11
Load (kW)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.73	1.73	1.73	1.73
Hour	12	13	14	15	16	17	18	19	20	21	22	23
Load (kW)	1.73	1.73	1.73	1.73	1.73	1.73	0.00	0.00	0.00	0.00	0.00	0.00



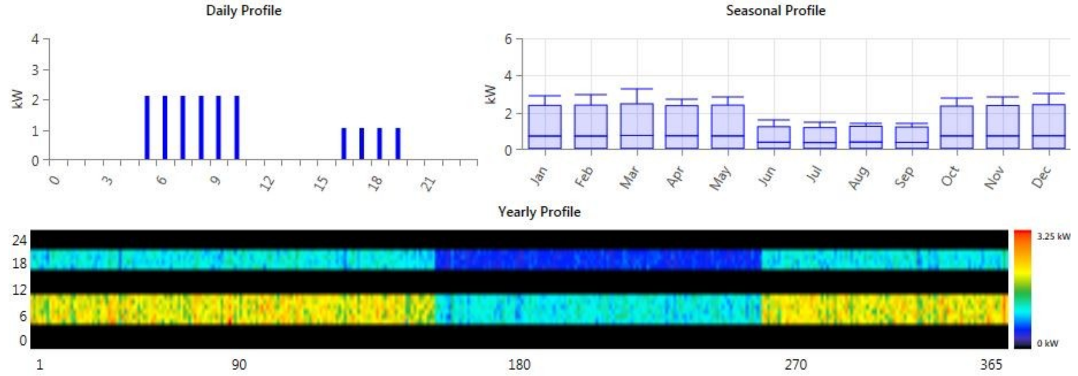
Farmer 5

Hour	0	1	2	3	4	5	6	7	8	9	10	11
Load (kW)	0.00	0.00	0.00	0.00	0.00	0.00	2.00	2.00	2.00	2.00	0.00	0.00
Hour	12	13	14	15	16	17	18	19	20	21	22	23
Load (kW)	0.00	0.00	0.00	0.00	0.00	3.33	3.33	3.33	3.33	1.07	1.07	0.00



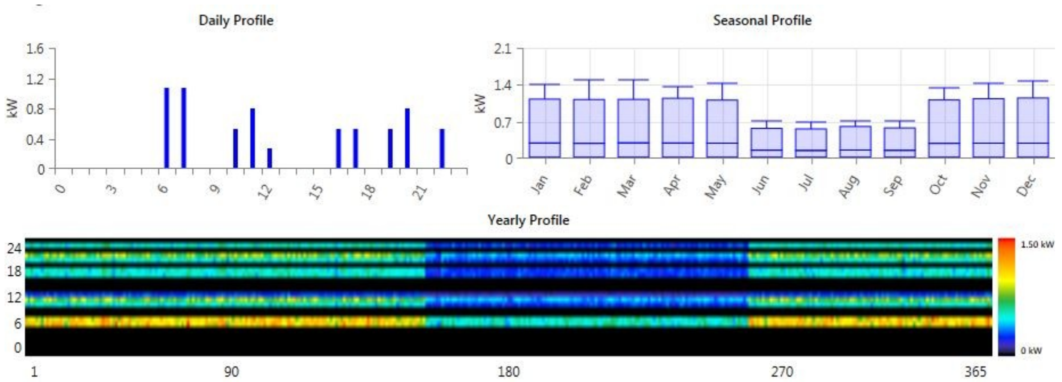
Farmer 6

Hour	0	1	2	3	4	5	6	7	8	9	10	11
Load (kW)	0.00	0.00	0.00	0.00	0.00	2.13	2.13	2.13	2.13	2.13	2.13	0.00
Hour	12	13	14	15	16	17	18	19	20	21	22	23
Load (kW)	0.00	0.00	0.00	0.00	1.07	1.07	1.07	1.07	0.00	0.00	0.00	0.00



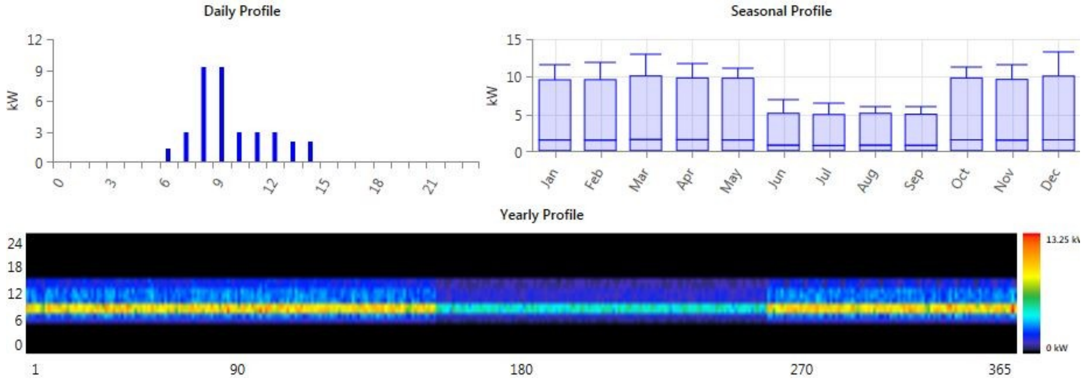
Farmer 7

Hour	0	1	2	3	4	5	6	7	8	9	10	11
Load (kW)	0.00	0.00	0.00	0.00	0.00	0.00	1.07	1.07	0.00	0.00	0.53	0.80
Hour	12	13	14	15	16	17	18	19	20	21	22	23
Load (kW)	0.27	0.00	0.00	0.00	0.53	0.53	0.00	0.53	0.80	0.00	0.53	0.00



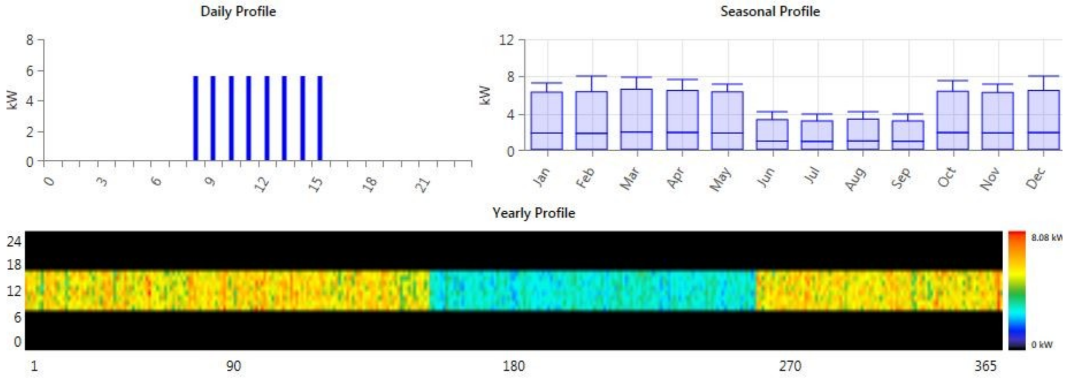
Farmer 8

Hour	0	1	2	3	4	5	6	7	8	9	10	11
Load (kW)	0.00	0.00	0.00	0.00	0.00	0.00	1.33	3.00	9.32	9.32	3.00	3.00
Hour	12	13	14	15	16	17	18	19	20	21	22	23
Load (kW)	3.00	2.00	2.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00



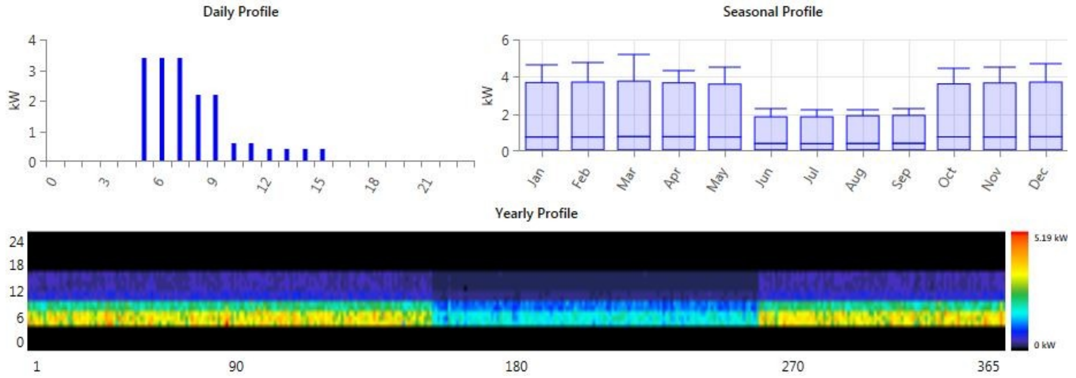
Farmer 9

Hour	0	1	2	3	4	5	6	7	8	9	10	11
Load (kW)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	5.59	5.59	5.59	5.59
Hour	12	13	14	15	16	17	18	19	20	21	22	23
Load (kW)	5.59	5.59	5.59	5.59	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00



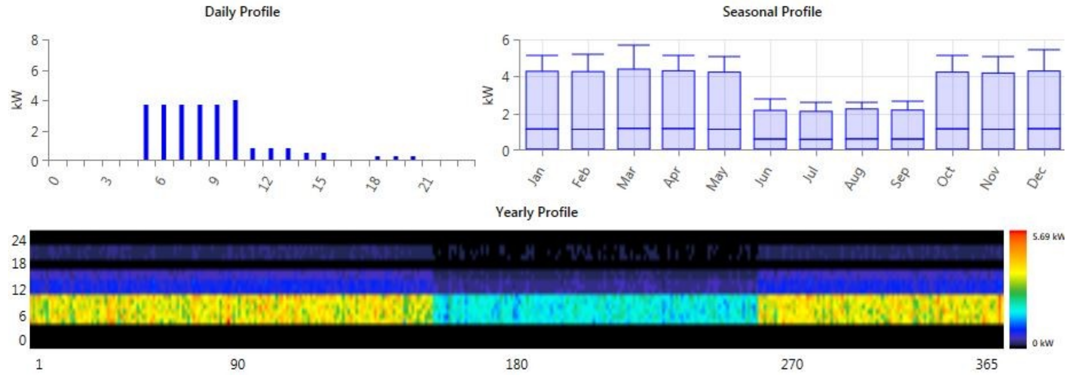
Farmer 10

Hour	0	1	2	3	4	5	6	7	8	9	10	11
Load (kW)	0.00	0.00	0.00	0.00	0.00	3.40	3.40	3.40	2.20	2.20	0.60	0.60
Hour	12	13	14	15	16	17	18	19	20	21	22	23
Load (kW)	0.40	0.40	0.40	0.40	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00



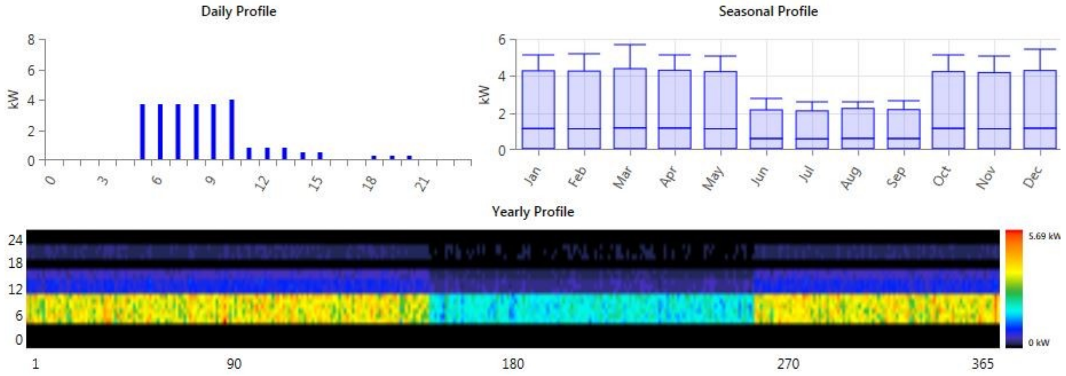
Farmer 11

Hour	0	1	2	3	4	5	6	7	8	9	10	11
Load (kW)	0.00	0.00	0.00	0.00	0.00	0.00	7.46	7.46	0.53	0.00	7.46	0.00
Hour	12	13	14	15	16	17	18	19	20	21	22	23
Load (kW)	0.27	0.27	0.27	0.27	0.27	7.46	0.00	0.00	0.00	0.00	0.00	0.00



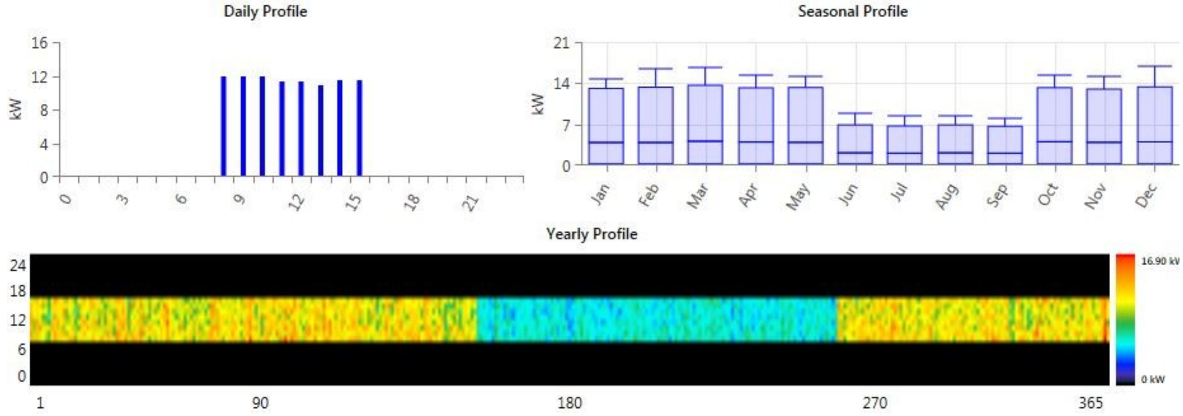
Farmer 12

Hour	0	1	2	3	4	5	6	7	8	9	10	11
Load (kW)	0.00	0.00	0.00	0.00	0.00	3.73	3.73	3.73	3.73	3.73	3.99	0.80
Hour	12	13	14	15	16	17	18	19	20	21	22	23
Load (kW)	0.80	0.80	0.53	0.53	0.00	0.00	0.27	0.27	0.27	0.00	0.00	0.00



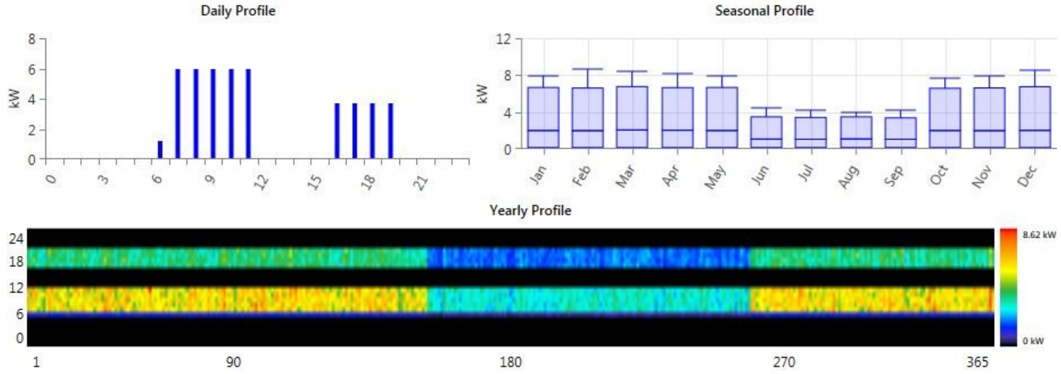
Farmer 14

Hour	0	1	2	3	4	5	6	7	8	9	10	11
Load (kW)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	11.85	11.85	11.85	11.32
Hour	12	13	14	15	16	17	18	19	20	21	22	23
Load (kW)	11.32	10.92	11.45	11.45	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00



Farmer 15

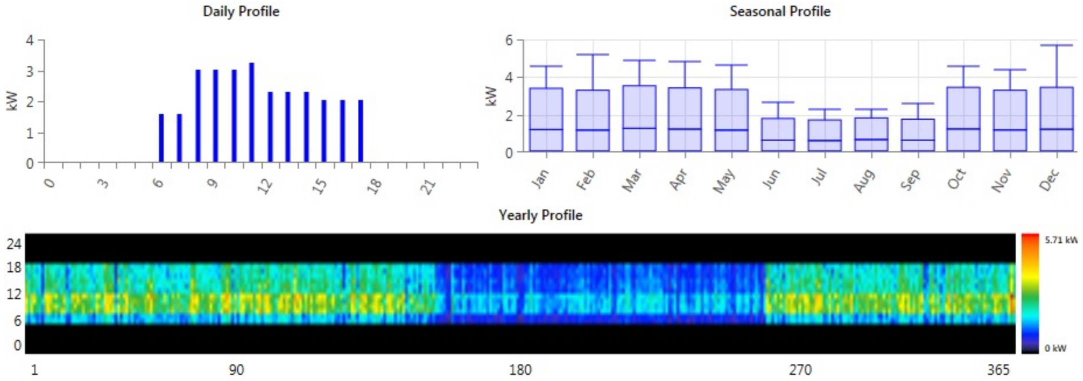
Hour	0	1	2	3	4	5	6	7	8	9	10	11
Load (kW)	0.00	0.00	0.00	0.00	0.00	0.00	1.20	5.97	5.97	5.97	5.97	5.97
Hour	12	13	14	15	16	17	18	19	20	21	22	23
Load (kW)	0.00	0.00	0.00	0.00	3.73	3.73	3.73	3.73	0.00	0.00	0.00	0.00



Configuration C

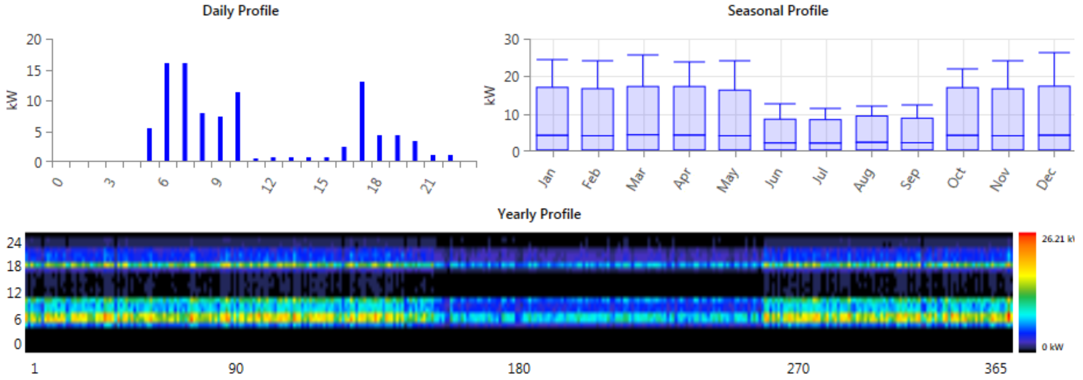
Cluster I

Hour	0	1	2	3	4	5	6	7	8	9	10	11
Load (kW)	0.00	0.00	0.00	0.00	0.00	0.00	1.60	1.60	3.01	3.01	3.01	3.25
Hour	12	13	14	15	16	17	18	19	20	21	22	23
Load (kW)	2.29	2.29	2.29	2.05	2.05	2.05	0.00	0.00	0.00	0.00	0.00	0.00



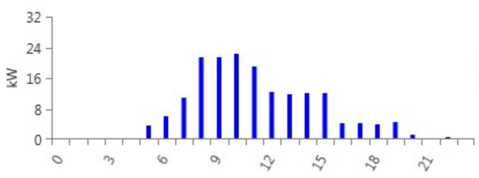
Cluster II

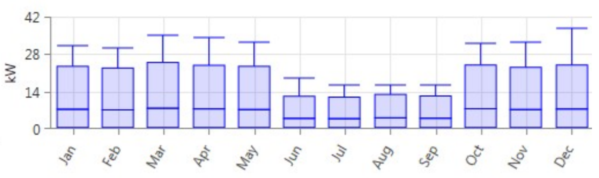
Hour	0	1	2	3	4	5	6	7	8	9	10	11
Load (kW)	0.00	0.00	0.00	0.00	0.00	5.53	16.10	16.10	7.98	7.44	11.31	0.60
Hour	12	13	14	15	16	17	18	19	20	21	22	23
Load (kW)	0.67	0.67	0.67	0.67	2.45	12.97	4.39	4.39	3.33	1.07	1.07	0.00

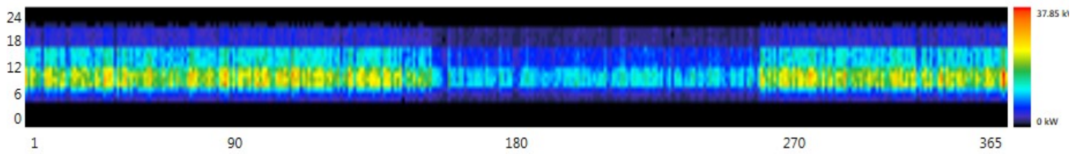


Cluster III

Hour	0	1	2	3	4	5	6	7	8	9	10	11
Load (kW)	0.00	0.00	0.00	0.00	0.00	3.73	5.99	10.76	21.55	21.55	22.34	18.88
Hour	12	13	14	15	16	17	18	19	20	21	22	23
Load (kW)	12.38	11.72	11.98	11.98	4.26	4.26	3.99	4.53	1.07	0.00	0.53	0.00


Daily Profile


Seasonal Profile


Yearly Profile

SIMULATION RESULTS

Stand-alone scenarios

CONFIGURATION A										
	Capacity shortage	*PV*	*MP-R*	*Battery*	*Converter*	*COE*	*NPC*	*O&M Cost*	*Initial Capital*	*Capacity shortage*
	%	*kW*	*qty*	*qty*	*kW*	*€/kWh*	*€*	*€/yr*	*€*	*kWh/yr*
	30%	400	0	400	200	0.092	696209	17297	450000	195913
	20%	450	0	520	250	0.098	811739	20240	523650	133305
	10%	550	0	520	350	0.106	948731	23226	618150	67371

CONFIGURATION B										
	Capacity shortage	*PV*	*MP-R*	*Battery*	*Converter*	*COE*	*NPC*	*O&M Cost*	*Initial Capital*	*Capacity shortage*
	%	*kW*	*qty*	*qty*	*kW*	*€/kWh*	*€*	*€/yr*	*€*	*kWh/yr*
Farmer 1	30%	2	0	2	1.5	0.089	4020	99	2290	818.1
	20%	2.5	0	2	1.5	0.094	4615	108	2723	511.91
	10%	2.5	0	3	2	0.1	5110	121	2983	269.53
Farmer 2	30%	0.3	0	1	0.3	0.122	876	21	504	108.4
	20%	0.4	0	1	0.3	0.125	1002	23	590	46.53
	10%	0.4	0	1	0.3	0.125	1002	23	590	46.53
Farmer 3	30%	3.5	0	1	2	0.067	5260	106	3408	1380.1
	20%	3.5	0	2	2.5	0.072	5798	122	3668	1042.5
	10%	4	0	3	2.5	0.078	6762	139	4320	507.15
Farmer 4	30%	1.5	0	3	1	0.114	3873	105	2038	698.19
	20%	2	0	3	1.5	0.118	4652	122	2510	213.19
	10%	2	0	3	1.5	0.118	4652	122	2510	213.19
Farmer 5	30%	4.5	0	9	4	0.132	12819	378	6193	2138.8
	20%	5	0	11	4	0.135	14512	425	7065	1365.3
	10%	5.5	0	14	4	0.14	16292	464	8158	711.71

	Capacity shortage	PV	MP-R	Battery	Converter	COE	NPC	O&M Cost	Initial Capital	Capacity shortage
	%	kW	qty	qty	kW	€/kWh	€	€/yr	€	kWh/yr
Farmer 6	30%	3.5	0	5	2	0.111	8273	227	4288	1470.1
	20%	3.5	0	7	3	0.117	9263	254	4808	1033.9
	10%	4	0	8	3	0.121	10294	276	5460	498.49
Farmer 7	30%	1.5	0	2	1	0.119	3517	97	1818	425.45
	20%	1.5	0	3	1	0.123	3939	108	2038	260.43
	10%	1.5	0	4	1.5	0.132	4375	119	2298	165.04
Farmer 8	30%	7	0	7	6	0.095	14139	346	8075	3236.7
	20%	8	0	8	9	0.101	16913	429	9400	2145.1
	10%	9	0	10	12	0.109	19851	493	10945	1086.2
Farmer 9	30%	9	0	3	6	0.068	12843	281	8925	3790.5
	20%	10	0	4	6	0.072	15325	303	10010	2672.2
	10%	11	0	6	8	0.078	17540	346	11475	1369.8
Farmer 10	30%	3.5	0	5	4	0.118	8699	243	4448	1542.2
	20%	4	0	6	3.5	0.12	9815	271	5060	1026.3
	10%	4.5	0	7	4	0.126	10975	298	5753	525.61
Farmer 11	30%	6	0	10	9	0.13	17012	508	8110	2900.5
	20%	7	0	11	9.5	0.132	19100	563	9235	1927.3
	10%	8	0	14	9	0.136	21504	615	10720	928.34
Farmer 12	30%	5.5	0	7	3	0.106	12070	316	6538	2443.4
	20%	6	0	8	4.5	0.108	13722	366	7310	1593
	10%	6.5	0	11	4.5	0.114	15422	400	8403	804.77
Farmer 14	30%	18	0	7	11	0.069	27890	565	17990	8258.4
	20%	20	0	8	14	0.072	31382	639	20180	5535.5
	10%	23	0	12	15	0.078	36156	709	23735	2818.9

	Capacity shortage %	PV kW	MP-R qty	Battery qty	Converter kW	COE €/kWh	NPC €	O&M Cost €/yr	Initial Capital €	Capacity shortage kWh/yr
Farmer 15	30%	9	0	11	5	0.099	19531	509	10605	4125.4
	20%	10	0	13	6	0.101	21907	566	11990	2749.3
	10%	12	0	13	8	0.107	24589	611	13880	1391.6

CONFIGURATION C

	Capacity shortage %	PV kW	MP-R qty	Battery qty	Converter kW	COE €/kWh	NPC €	O&M Cost €/yr	Initial Capital €	Capacity shortage kWh/yr
Cluster I	30%	5.5	0	4	2.5	0.085	8604	194	5838	2285.3
	20%	6	0	4	3.5	0.086	9331	209	6350	1694
	10%	6.5	0	8	4	0.097	11287	252	7703	869.69
Cluster II	30%	20	0	28	10	0.129	42199	1260	24260	8824.7
	20%	19	0	28	18	0.129	42620	1306	24035	8881.2
	10%	24	0	44	19	0.141	55310	1641	31960	2963.1
Cluster III	30%	33	0	20	16	0.086	51026	1180	34225	15421
	20%	39	0	24	20	0.093	60272	1381	40615	10130
	10%	41	0	48	25	0.102	71427	1644	48025	5157

Grid-connected scenarios

CONFIGURATION A

	Capacity shortage %	PV kW	Grid kW	Battery qty	Converter kW	COE €/kWh	NPC €	O&M Cost €/yr	Initial Capital €	Capacity shortage kWh/yr
	30%	300	150	240	150	0.085	632515	21075	332550	197253
	20%	300	200	360	200	0.09	735404	25974	365700	130851
	10%	400	200	440	300	0.097	867190	27357	477800	65667

CONFIGURATION B

	Capacity shortage %	*PV kW*	*Grid kW*	*Battery qty*	*Converter kW*	*COE €/kWh*	*NPC €*	*O&M Cost €/yr*	*Initial Capital €*	*Capacity shortage kWh/yr*
Farmer 1	30%	2	0	2	1.5	0.089	4020	99	2290	818.1
	20%	1	2.25	2	1	0.1	4613	177	1509	605.76
	10%	2.5	0	3	2	0.1	5110	121	2983	269.53
Farmer 2	30%	0.3	0	1	0.3	0.122	876	21	504	108.4
	20%	0.4	0	1	0.3	0.125	1002	23	590	46.53
	10%	0.4	0	1	0.3	0.125	1002	23	590	46.53
Farmer 3	30%	3.5	0	1	2	0.067	5260	106	3408	1380.1
	20%	3.5	0	2	2.5	0.072	5798	122	3668	1042.5
	10%	3.5	2.25	2	2.5	0.076	6740	168	3791	370.49
Farmer 4	30%	1.5	0	3	1	0.114	3873	105	2038	698.19
	20%	2	0	3	1.5	0.118	4652	122	2510	213.19
	10%	2	0	3	1.5	0.118	4652	122	2510	213.19
Farmer 5	30%	4.5	0	9	4	0.132	12819	378	6193	2138.8
	20%	5	0	11	4	0.135	14512	425	7065	1365.3
	10%	5.5	0	14	4	0.14	16292	464	8158	711.71
Farmer 6	30%	3.5	0	5	2	0.111	8273	227	4288	1470.1
	20%	3.5	0	7	3	0.117	9263	254	4808	1033.9
	10%	4	0	8	3	0.121	10294	276	5460	498.49
Farmer 7	30%	1.5	0	2	1	0.119	3517	97	1818	425.45
	20%	1.5	0	3	1	0.123	3939	108	2038	260.43
	10%	1.5	0	4	1.5	0.132	4375	119	2298	165.04
Farmer 8	30%	7	0	7	6	0.095	14139	346	8075	3236.7
	20%	8	0	8	9	0.101	16913	429	9400	2145.1
	10%	9	0	10	12	0.109	19851	493	10945	1086.2

	Capacity shortage	*PV*	*Grid*	*Battery*	*Converter*	*COE*	*NPC*	*O&M Cost*	*Initial Capital*	*Capacity shortage*
	%	*kW*	*kW*	*qty*	*kW*	*€/kWh*	*€*	*€/yr*	*€*	*kWh/yr*
Farmer 9	30%	3	6	4	5	0.071	12963	501	4178	4018
	20%	4	6	5	4	0.072	14599	537	5183	2713.2
	10%	6	6	5	6	0.074	16659	547	7073	1366.5
Farmer 10	30%	3.5	0	5	4	0.118	8699	243	4448	1542.2
	20%	4	0	6	3.5	0.12	9815	271	5060	1026.3
	10%	4.5	0	7	4	0.126	10975	298	5753	525.61
Farmer 11	30%	3	7.5	10	4.5	0.126	16256	610	5568	2885.3
	20%	2.5	7.5	10	8.5	0.129	18369	737	5455	1903.8
	10%	3.5	7.5	10	8.5	0.128	20262	770	6760	965.76
Farmer 12	30%	5.5	0	7	3	0.106	12070	316	6538	2443.4
	20%	6	0	8	4.5	0.108	13722	366	7310	1593
	10%	6.5	0	11	4.5	0.114	15422	400	8403	804.77
Farmer 14	30%	18	0	7	11	0.069	27890	565	17990	8258.4
	20%	20	0	8	14	0.072	31382	639	20180	5535.5
	10%	14	15	9	13	0.08	36817	1190	15955	2754.7
Farmer 15	30%	9	0	11	5	0.099	19531	509	10605	4125.4
	20%	10	0	13	6	0.101	21907	566	11990	2749.3
	10%	12	0	13	8	0.107	24589	611	13880	1391.6

CONFIGURATION C										
	Capacity shortage %	*PV kW*	*Grid kW*	*Battery qty*	*Converter kW*	*COE €/kWh*	*NPC €*	*O&M Cost €/yr*	*Initial Capital €*	*Capacity shortage kWh/yr*
Cluster I	30%	3	2.5	4	1.5	0.08	7858	290	3733	2361.4
	20%	4	2.5	4	2	0.083	8901	300	4638	1558.9
	10%	5.5	2.5	4	3	0.087	10106	287	6015	749.64
Cluster II	30%	14	6.5	28	9	0.122	39927	1446	19348	8909.4
	20%	15	10	36	11	0.129	46321	1686	22325	5842.2
	10%	19	10	40	18	0.133	52672	1788	27225	2960.8
Cluster III	30%	17	15	20	12	0.078	44935	1689	20890	15685
	20%	25	12	12	12	1	45406	1372	25885	15516
	10%	26	18	32	20	0.089	61533	2066	32120	5158.6

Grid-connected scenarios with random blackout

CONFIGURATION C										
	Capacity shortage %	*PV kW*	*MP-R qty*	*Battery qty*	*Converter kW*	*COE €/kWh*	*NPC €*	*O&M Cost €/yr*	*Initial Capital €*	*Capacity shortage kWh/yr*
Cluster IA	30%	4	3	4	3	0.081	7942	227	4718	2519.2
	20%	5	3	4	3	0.083	9023	242	5583	1568.4
	10%	6	5	4	4	0.09	10477	268	6665	866.23
Cluster IB	30%	4	3	4	3	0.08	7896	223	4718	2511.4
	20%	5	3	4	3	0.083	8997	240	5583	1550.5
	10%	6	5	4	4	0.09	10496	269	6665	825.66
Cluster IC	30%	4	3	4	2	0.082	7988	235	4638	2538.3
	20%	5	3	4	3	0.083	8871	231	5583	1731.9
	10%	7	3	4	3	0.094	10882	251	7313	865.53

	Capacity shortage *%*	*PV* *kW*	*MP-R* *qty*	*Battery* *qty*	*Converter* *kW*	*COE* *€/kWh*	*NPC* *€*	*O&M Cost* *€/yr*	*Initial Capital* *€*	*Capacity shortage* *kWh/yr*
Cluster IIA	30%	18	7	28	10	0.125	40852	1262	22888	8833.2
	20%	20	7	36	13	0.131	47133	1436	26700	5913.2
	10%	23	10	44	18	0.139	54606	1619	31565	2987.3
Cluster IIB	30%	17	10	28	9	0.125	40502	1290	22135	8888.2
	20%	19	8	36	14	0.129	46724	1462	25915	5928.7
	10%	23	13	40	18	0..137	54044	1631	30823	2969.9
Cluster IIC	30%	17	13	28	10	0.125	40828	1298	22353	8867.6
	20%	19	13	36	14	0.13	47073	1469	26163	5884.7
	10%	23	13	40	21	0.139	54409	1640	31063	2970.4
	Capacity shortage *%*	*PV* *kW*	*MP-R* *qty*	*Battery* *qty*	*Converter* *kW*	*COE* *€/kWh*	*NPC* *€*	*O&M Cost* *€/yr*	*Initial Capital* *€*	*Capacity shortage* *kWh/yr*
Cluster IIIA	30%	25	15	20	14	0.082	47422	1367	27970	15611
	20%	29	20	24	19	0.086	55392	1574	32985	10471
	10%	36	20	40	25	0.094	65302	1688	41280	5233.4
Cluster IIIB	30%	26	12	20	16	0.081	47120	1285	28830	15627
	20%	29	20	24	16	0.086	55093	1570	32745	10349
	10%	36	18	32	25	0.093	64959	1671	41170	5262
Cluster IIIC	30%	24	15	20	13	0.081	46808	1390	27025	15650
	20%	28	20	24	16	0.086	54409	1583	31880	10475
	10%	35	20	32	24	0.093	64584	1704	40335	5711

Scenarios with water tank

CONFIGURATION C										
	Capacity shortage *%*	*PV* *kW*	*MP-R* *qty*	*Battery* *qty*	*Converter* *kW*	*COE* *€/kWh*	*NPC* *€*	*O&M Cost* *€/yr*	*Initial Capital* *€*	*Water Tank* m^3
Cluster I	30%	6	0	0	3	0.094	9722	121	7993	8.3
	20%	7	0	0	4	0.104	11436	114	9811	16.6
	10%	8	0	0	4	0.122	11170	121	12454	24.9
Cluster II	30%	25	0	0	16	0.225	73096	146	71015	230
	20%	30	0	0	19	0.262	94205	116	92560	310.5
	10%	33	0	0	20	0.287	112754	152	112215	391.5
Cluster III	30%	42	0	0	22	0.101	61157	760	50340	61.6
	20%	46	0	0	24	0.114	75240	777	64460	114.4
	10%	53	0	0	27	0.132	92817	812	81225	167.2

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