Assessment of the cost production and pricing policies for the energy sector as a sustainable socio-economic enabler for doing business in Zimbabwe.

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Assessment of the cost production and pricing policies for the energy sector as a sustainable socio-economic enabler for doing business in Zimbabwe.

By

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PREFACE

The research in this thesis was completed while based in the discipline of Renewable Energy, Faculty of Engineering and Technology, AIU, USA. The content of this work has not been submitted in any form to any other university and, except where the work of others is acknowledged in the text, the results reported are due to collaborative investigations by the candidate.

Dr. Rene Tina Level

Signed:………………………………..(Academic Advisor)

Date………………………………….

Miriam James

Signed:………………………………..(Academic Tutor)

Date………………………………….

DECLARATION

I, Charles Kanyunga, declare that:

i. The research reported in this thesis, except where otherwise indicated or acknowledged, is my original work.
ii. The thesis has not been submitted in full or in part for any degree for examination at any other university.
iii. This dissertation does not contain other peoples' data, pictures, graphs or other information unless specifically acknowledged as being sourced from other persons.
iv. The dissertation does not contain other persons' writing unless specifically acknowledged as being sourced from other researchers. Where other written sources have been quoted, then;
    a. Their words have been re-written but the general information attributed to them has been referenced.
    b. Where their exact words have been used, their words have been placed inside quotation marks and referenced.
v. Where I have used materials for which publications followed, I have indicated in detail, my role in the work.
vi. This dissertation is primarily a collection of materials prepared by myself, published as journal articles or presented as a poster and oral presentation at conferences. In some cases, additional information has been included.
vii. This dissertation does not contain text, graphics or tables copied and pasted from the internet, unless specifically acknowledged and the sources being detailed in the dissertation and in reference sections.

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Date…25 July 2024………………..

As Research Supervisor I agree to the submission of this thesis for examination.

Dr. Rene Tina Level

Signed:…………………………………..(Academic Advisor)

Date………………………………….

Miriam James

Signed:…………………………………..(Academic Tutor)

Date………………………………….

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CHAPTER ONE

1.1 Introduction to the study.

Accurate, detailed, and up-to-date information on energy costs is crucial for energy management in manufacturing companies. Yet, to what extent is such energy costs information actually available and used? This study reviews empirical information provided in Quarterly and Annual Reports published for public consumption by ZERA, ZESA Holdings, REF, MoEPD, ZNCC, etc. The study aims to focus both on energy-intensive companies as well as non-energy-intensive companies, and also to distinguish between the practices of small and medium-size enterprises (SMEs) vs. large companies. The literature review covers a wide spectrum of publications in the fields of business, accounting, energy, and engineering, leading to the final sample that includes the National Energy Policy (2012), the National Renewable Energy Policy & the corresponding Statutory Instruments gazetted by the government of Zimbabwe from time to time. Most studies in this sample concern energy-intensive and large companies (some of which are currently under construction e.g. the Lithium Mine, the Iron & Steel Mine, Textile Processing Companies). The most striking result is that with only few exceptions, almost no studies provide a nuanced description of how measuring and allocating energy costs is being done. For example, almost no studies investigate specific cost allocation bases, the accuracy of cost allocations, or differentiation between first-stage allocation and second-stage allocation. Nevertheless, the overall impression is that many manufacturing companies resort to imprecise methods for measuring and allocating energy costs. They seem to lack much of the cost information necessary for energy management, such as information needed for improving energy efficiency, evaluating energy efficiency improvement investments, and holding managers accountable for energy efficiency.

Meanwhile, on the pricing policies implementation strategies by Zimbabwe in both the oil and electricity markets, for setting energy prices prove inconsistent across the country and region, spanning a full spectrum from discretionary price fixing to pure market-based approaches. In between sits a wide variety of other schemes such as (1) price stabilization funds; (2) regulation of commercial margins for refineries (GreenFuels in Chisumbanje) and wholesale and retail establishments; (3) price smoothing using the levers of taxation; and (4) direct price subsidies or vouchers targeting specific groups (exporters & those that receive foreign currency as a mode of payment for services and goods supplied). However, comparatively, price-setting processes may vary by commodity within countries. Governments can also influence final prices through tax policy. The international price of oil remains the one overriding factor governing domestic energy price policies, and because of the volatility of global oil prices over recent years, governments across the region have had to regularly adapt and refine domestic price-setting strategies, requiring a high level of policy flexibility.

1.2 Background for Analysis.

Russia's attack on Ukraine has added a new dimension to Germany's ambitious aims for ramping up the share of renewables in its energy system. Marking a "historic turning point," the fast elimination of fossil fuel imports for Germany practically overnight shifted from being a moral obligation and long-term environmental protection measure to a question of national security and short-term economic stability. Wind power, solar PV, bioenergy, hydropower and other renewable power sources since have become labeled "freedom energies" that can enable the country to vastly reduce its energy dependence and form the bedrock for de-carbonizing the economy. Comparatively, Zimbabwe is poised for an upper-middle income economy by 2030. Hence, given the impact on energy the Russia-Ukraine war has had on several countries in Europe including Germany, then how else has it affected Zimbabwe's drive for proficiency in access to energy.

Already before Russia's invasion, Germany's government coalition of the Social Democrats (SPD), the Green Party and the Free Democrats (EDP) had aimed to achieve 80 percent renewables in electricity consumption by 2030. Shortly after the war's outbreak on 24 February 2024, it raised the ambition to 100% by 2035, meaning the expansion rate of renewables will have to multiply. In a policy package in April 2022 presented as the "biggest energy policy reform in decades," the coalition proposed to lift the rollout of wind and solar power "to a completely new level." Renewables already provided about 54% of electricity consumption in early 2022 [28, 65, 85].

Installed onshore wind capacity should reach 115 gigawatts (GW), meaning annual capacity additions will have to reach 10 GW as of 2025. A total onshore turbine capacity of about 56 GW had been installed in the country by 2021. Solar installations will amount to 22 GW per year as of 2026 to achieve a total capacity of 215 GW by 2030, up from about 60 GW in 2021. Offshore wind additions are increased as well to reach a minimum of 30 GW by the end of the decade, 40 GW by 2035, and 70 GW by 2045. As ambitious as this sounds, much higher build out rates are not without precedent in the country. In 2017, Germany installed 5 GW of wind power and solar capacity expansion peaked at around 8 GW before 2012 [65, 85].

The government said it will introduce a second package of legislative reforms by the summer. These will include draft reforms of the Renewable Energy Act (EEG), the offshore wind law, the energy industry law and legislation to speed up power transmission grid development. It was due to be sent to parliament and could have been adopted still in the first half of 2022. Hence, in all this happening elsewhere, how is Zimbabwe performing given its target of reaching 11GW by 2030 as enunciated in the economic blue print, NDS1 [15, 27]. Hence, what could be the consequential challenges? As a result, the need to analyze the issue of cost as an investors', client's and government's tool for doing sound economic business.

Cost is the amount of resources sacrificed or given up to achieve a specific objective which may be the acquisition of goods or services. Efficient execution of any particular project depends considerably on the effective control of these costs such that costs can only be controlled if they have been identified and analyzed [1, 23, 40]. As a result, the conventional cost components of materials, labor and overheads are analyzed so as to unravel hidden aspects which are often overlooked by less skilled operational managers. Invariably within the energy sector in Zimbabwe, it is expected to supply energy on demand at a reasonable price, methods of recovery of overhead costs are deliberated on together with the depreciation accounting methods and rationalized equipment cost recovery techniques. The findings will then direct us on the mostcrucial aspects of inventory energy cost in Zimbabwe's habitually speculative industry. In real terms, the stored goods (potential energy) represent capital (money) which would have been yielding interest if invested in a bank but tied down as stock in natural resources and the energy company. The framework of the study is based on the knowledge of mathematical, experience and practice, which is applied with judgment to develop the ways to utilize economically the materials and other natural resources for profit making purpose. The study would be of significance to managers in terms of analytical decision making, inventory control policies and determination of the company's profit level.

The carbon market can guide the optimal allocation of carbon emission reduction resources through price signals, and it can reduce the cost of emission reduction in the entire society, promote investment in green and low-carbon industries, and then guide the capital flow. Therefore, the carbon pricing mechanism has encouraged the energy transition and effectively mitigating climate change. Additionally, the primary source of carbon emissions is the rapid growth of energy use, such as coal and crude oil. Therefore, carbon pricing plays a vital role in promoting energy transitions, such as the transition from high-carbon energy (coal and oil) to low-carbon energy (natural gas) and clean energy (renewable resources). Our study is devoted to finding out the impact of carbon pricing on the energy industry using bibliometric analysis and visual investigations. We analyze existing research trends on the impact of carbon pricing on the energy industry from different angles and review the effect of carbon pricing on various energy industries. We search for optimal carbon pricing models and pricing policies that impact the energy industry. Our study contributes to the literature by discussing the challenges and future study recommendations.

1.3 Problem statement.

Easing regulation on new renewable power projects and speeding up licensing procedures is one of the most urgent measures to achieve short-term gains in expansion. Many projects already have been planned but are still held up due to unresolved approval issues, lengthy licensing procedures, land tenure issues and investor confidence. In the case of urban settlements, these usually involve questions like minimum distances to residential areas and construction permits in ecologically sensitive areas. Solar IPPs seem to go through rigorous procedures that have to be streamlined and conflicts with nature conservation resolved through standard practices. Solar power projects on average are much easier to implement than the other renewable energy projects. But home owners and businesses willing to install solar power panels on their roofs are thinking otherwise. There could be District Development Administrators (DDA) in the conception of zonal installations that also could help improve on the local usage of solar power and quickly equip whole neighborhoods with renewable power in a coherent way.

A growing number of regulatory hurdles, more expensive licensing procedures and skewed off-taker agreements with ZETDC, have also hampered investor activity for solar PV power plants. In some cases, construction restraints influence the performance of some of the often small- and medium-sized suppliers who would even struggle to find their way through the required paperwork, and worse still to prepare a bankable marketing plan. Solar power is generally more accepted by neighboring residents, since even larger installations are less visible and attract less attention than the tall wind power turbines. In fact, many citizens not only tolerate but also want to take part in solar power expansion, as more and more homeowners mull installing panels on their roofs, often together with solar-powered batteries in their cellars. As late as 2021, power generation and heating have remained as the main drivers of a greater energy autonomy and rising prices, according to ZETDC.

Faltering investor confidence has long been a major impediment for Zimbabwe’s renewable energy industry, with negotiations stalling progress due to feed-in-tariff regime challenges. Binding commitments regarding build-out volumes and the required renewable power capacity could now offer a clear perspective for producers and grid operators to deliver the required hardware and provide corresponding logistics. Support rates for roof-mounted panels have to be adapted to higher expansion targets and attract investors irrespective of whether they primarily plan to market the power or use it for own consumption. The government agreed to split auctioned volumes equally between rooftops and open spaces and granting higher remuneration to small rooftop installations outside the tender scheme, including a halt to remuneration degression until the beginning of 2024. Installations on agricultural land or moorland receive a bonus payment to become competitive.

Solar power panels have a high degree of automatization in production, meaning that with corresponding investments in machinery, labor could become scarce for installation of the panels, which requires manual work on the ground. While some solar power installations and especially larger ones are made by internationally active teams, producers could benefit from a short-term influx of skilled domestic labor if only a fraction of the huge workforce in electrical trading is retrained to put their abilities to use for the energy transition. For this to happen, policymakers would have to ensure the expansion level boom will not be short-lived but offers business opportunities in the long run.

1.4 Purpose of the study.

With the rapid growth of renewables in Zimbabwe, comparing costs of different forms of power generation has become important for policymakers, investors and analysts. In these comparisons, the metric of LCOE (levelized cost of energy) is often used, but the U.S. Energy Information Administration (EIA) warns that this metric does not cover all the complexities involved. The EIA has written a short primer on comparing power generation costs. Cost is one of the key factors influencing the choice of fuels and technologies used to generate electricity. Capital, maintenance, operating, and financing costs often vary significantly across technologies and fuels. In addition, regional differences in construction, fuel, transmission, and resource costs mean that location also matters.

While simple metrics are sometimes used for cost comparisons, it is important to understand their limitations. Levelized Cost of Energy (LCOE), one common metric for cost comparisons across projects and technologies, considers a plant's expected lifetime and operation cycle and amortizes those costs over an assumed financial lifetime. Because LCOEs do not include contractual terms on price, duration, or price inflators, they should not be directly compared with the other price structures such as Power Purchase Agreements (PPA). PPAs may involve project- or corporate-specific finance terms, reflect differing contract terms with the power purchaser, or reflect the value rather than the cost of the energy.

LCOE comparisons have some notable limitations. For example, when comparing new capacity to existing capacity, some types of existing plants that may have been expensive to build but have relatively low operating costs can continue to operate competitively, even though the LCOE for new plants of these types may be higher than the LCOE for other technologies. Different generation technologies also operate in different ways: some are dispatchable, or can be scheduled, while others are dependent on energy sources, such as wind, water and solar, that are available intermittently. Some plants operate around the clock, while others are likely to operate only during times of high demand. Because electricity prices differ throughout the day, the timing of a plant's output affects its cost recovery. Also, dispatchable generating technologies (such as coal-fired steam plants, combined-cycle plants, and simple-cycle combustion turbines or internal combustion engines) provide both energy and capacity services to meet daily and seasonal fluctuations in demand.

Another cost concept, the Levelized Avoided Cost of Energy (LACE), attempts to measure the value to the electric system that certain technologies provide. LACE reflects the cost that would be incurred to provide the same supply to the system if new capacity using a specific technology were not added and used. A technology is generally considered to be economically competitive when its LACE exceeds its LCOE. Although EIA does not directly apply the LCOE and LACE in its modeling, EIA calculates both LCOE and LACE for several technologies for all regions to provide insight into factors driving capacity addition and dispatch decisions.

1.4.1 Primary Objective.

The primary objective of the research is to investigate the impact that the National Renewable Energy Policy (2019) vis-à-vis the production cost has had on the provision of renewable energy in Zimbabwe.

1.4.2 Secondary Objectives.

The secondary objectives are to:

1.4.2.1 Mobilize all government instruments that are used in monitoring and evaluating energy projects;

1.4.2.2 Collect data on registered and non-registered independent power producers;

1.4.2.3 Determine completed and pending PPAs;

1.4.2.4 Assess customer base structure for power in Zimbabwe;

1.4.2.5 Evaluate feed-in-tariff regime for each category of power suppliers;

1.4.2.6 Develop a rational LCOE for the Energy Market for Zimbabwe;

1.4.2.7 Ascertain the capacity of each renewable energy project in fulfilling with lead times and projections of National Development strategies.

1.4.3 Research Questions.

1.4.3.1 What are the current expansion goals for the renewable energy projects?

1.4.3.2 Will the planned expansion level allow an end to imports and satisfy climate change targets set through the MoEPD?

1.4.3.3 Are IPPs ready to deliver a fast expansion?

1.4.3.4 Which hurdles are obstructing a fast expansion? And how can they be overcome?

1.4.3.5 What about the parallel expansion of grids and storage capacity?

1.4.3.6 How can Zimbabwe's renewables push, be integrated in the regional framework of the SADC energy matrix?

1.4.4 Assumption of the study.

1.4.4.1 That there is a huge energy market both nationally & regionally;

1.4.4.2 That the business of electricity generation, supply, transmission and distribution is not well captured to make economic sense;

1.4.4.3 That tariff under-recovery is cause for concern in debt repayments;

1.4.4.4 That the customer base for electricity is bigger than what is in the order book.

1.4.5 Ethics Statement.

This research will make use of mostly secondary data on the international energy markets' historical trading prices, indices and volumes that already has ethical documentation and only require further analysis. Any sensitive listed firm, asset management, life/pension fund or individual specific data to be used will be treated with strict confidentiality and their specific experiences masked beyond identification by future researchers and users of this thesis.

1.5 Justification of the study.

This study unravels the basic concepts of energy economics and will add to the body of indigenous knowledge systems through the application of simple economic tools in the analysis of contemporary energy issues. It will give local players in the energy sector a high level and thorough grounding in various key aspects of the subject matter.

Since its modest beginning in the 1970s, the academic and research focus on energy has grown substantially and energy has established itself as an independent, interdisciplinary subject area. It attracts attention from people in a range of different fields including engineers, scientists, geologists, environmentalists, bankers, investors, policy makers and politicians. Hence, the study on cost price and their pricing policies will develop the local understanding on e*nergy economics* in six parts, i.e.:

- basic demand-related concepts (customers);
- supply-side economics (power producers);
- energy markets (both international & local such as VFSE, ZSE, SAPP.);

- the application of simple economic principles in analyzing contemporary energy issues;
- environmental aspects of energy use (EMA, ZERA, REF, ZETDC, etc.); and
- regulatory (ZERA) and governance issues (MoEPD).

1.6 Scope of the study.

Investment in the expansion of electric generation capacity requires an assessment of the competitive value of generation technologies in the future that is determined as part of a complex set of modeling systems. To better understand investment decisions in ZETDC, we use specialized measures that simplify those modeled decisions. Levelized cost of electricity (LCOE)refers to the estimated revenue required to build and operate a generator over a specified cost recovery period. Levelized avoided cost of electricity (LACE) is the revenue available to that generator during the same period. Beginning with Hwange 7 & 8 for instance, we include estimate for the levelized cost of storage (LCOS). Although LCOE, LCOS, and LACE do not fully capture all the factors considered in ZETDC, when used together as a value-cost ratio (the ratio of LACE to-LCOE or LACE-to-LCOS), they provide a reasonable comparison of first-order economic competitiveness among a wider variety of technologies than is possible using LCOE, LCOS, or LACE individually. In this study, we intend to present average values of LCOE, LCOS, and LACE for electric generating technologies entering service in 2024, 2027, up to 2030 as represented in ZETDC for ZERA as the Reference case. We shall present the costs for electric generating facilities entering service in 2027 in the body of the report, and will include the costs for 2024 and 2030, maybe through Appendixes. We will provide both a capacity-weighted average based on projected capacity additions and a simple average (unweighted) of the regional values across the 10 provinces of the electricity market in Zimbabwe, together with the range of regional values. Levelized cost of electricity (LCOE) and levelized cost of storage (LCOS); will represent the average revenue per unit of electricity generated or discharged that would be required to recover the costs of building and operating a generating plant and a battery storage facility, respectively, during an assumed financial life and duty cycle. LCOE is often cited as a convenient summary measure of the overall competitiveness of different generating technologies. Although the concept is similar to LCOE, LCOS it is however, different in that it represents an energy storage technology that contributes to electricity generation when discharging and consumes electricity from the grid when charging. Furthermore, LCOS is calculated differently depending on whether it is supplying electricity generation to the grid or providing generation capacity reliability. Given that we now have a Lithium Mine in Zimbabwe, we will also model battery storage in energy arbitrage applications where the storage technology provides energy to the grid during periods of high-cost generation and recharges during periods of lower cost generation, not as providing generation capacity reliability.

1.7 Delimitation

1.7.2 Energy Demand Analysis and Forecasting.

1.7.3 Economics Analysis of Energy Investments.

1.7.4 Energy Markets and Principles of Energy Pricing.

1.7.5 Impact of High Energy Prices.

1.7.6 The Economics of Climate Change & Clean Development Mechanism.

1.7.7 Regulation and Governance of the Energy Sector.

1.8 Conclusion

The execution of this research will have to be carried out in real time and in actual practical scenarios so as to gather the necessary experience and data associated with renewable energy projects' challenges. Production costs tend to differ in different jurisdictions due to legislative and regulatory frameworks and country perceptions on certain renewable energy technologies. In some cases, application of these technologies would require the acquisition of land and water, which are prime possessions of mankind. In other circumstances, the costs may be influenced by corrupt community leaders who may not value long term benefits associated with the technology. Hence, this research is carried out in Zimbabwe using various renewable energy technologies whose sources range from solar, water & biomass. The author left out waste to energy technology not that it could not be implemented but that at the time of compiling the document this work was in its infancy stage. The rigorous nature of waste management would require a whole separate examination profile that would produce conclusive results. However, it is also important to note that currently the most popular renewable energy technology is solar PV, whilst biofuels readily follow due to the presence of biodiesel and ethanol production plants, cases in which the author was involved from ideation to execution. Hence, the practical experience derived from these projects is immense.

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CHAPTER TWO

REVIEW OF THE SOCIO-ECONOMIC STATUS OF ZIMBABWE

2.0 Geography of Zimbabwe

Zimbabwe is a land locked country lying in the southern part of the African continent. It lies between latitudes 150 and 230S and latitudes 250 and 340E. It is bound by two rivers, the Zambezi to the North and the Limpopo to the South. The Zambezi River divides Zambia and Zimbabwe, whilst the Limpopo River marks its border with South Africa. To the East and North East of Zimbabwe lies Mozambique, whilst Botswana bounds the western side. In the North-West corner Zimbabwe is roughly 150 meters from Namibia, nearly forming a four-nation quadric-point. See Figure 2.1.

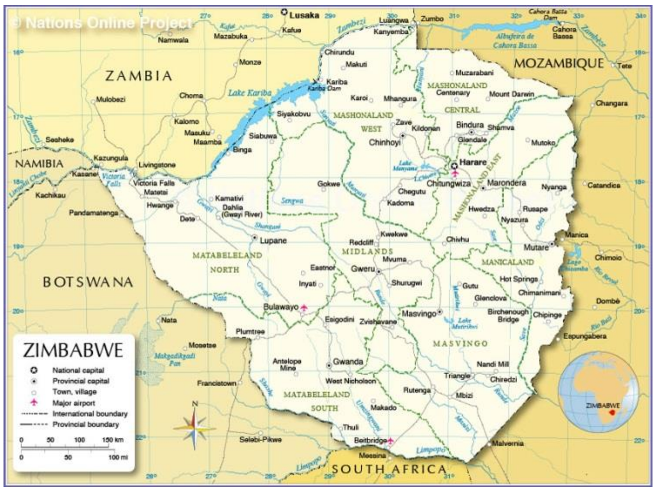


Fig. 2.1 Administrative map of Zimbabwe

Its land mass is 390 757 square kilometers with only one percent being occupied by water. Most of the country is elevated, consisting of a central plateau (high veld) stretching from the south west northwards with altitudes between 1000 and 1600 meters (m). The country's extreme east is mountainous and this area is known as the Eastern Highlands with Mount Nyanga peaking at 2 592 m. About 20 percent of the land consists of the low-lying areas, (low veld) under 900 meters above sea level. Zimbabwe has 32 Urban Councils and 60 Rural District Councils.

2.1 Energy and electricity sector brief

The Zimbabwe Electricity Transmission and Distribution Company (ZETDC) is responsible for the development, operation and maintenance of the transmission and distribution network (Figure 2.2). The transmission system consists of 420kV, 330kV, 220kV, 132kV, 88kV and 66kV lines and substations, with a total length of over 7,274 km. ZETDC intended to strengthen and extend the transmission and sub-transmission networks

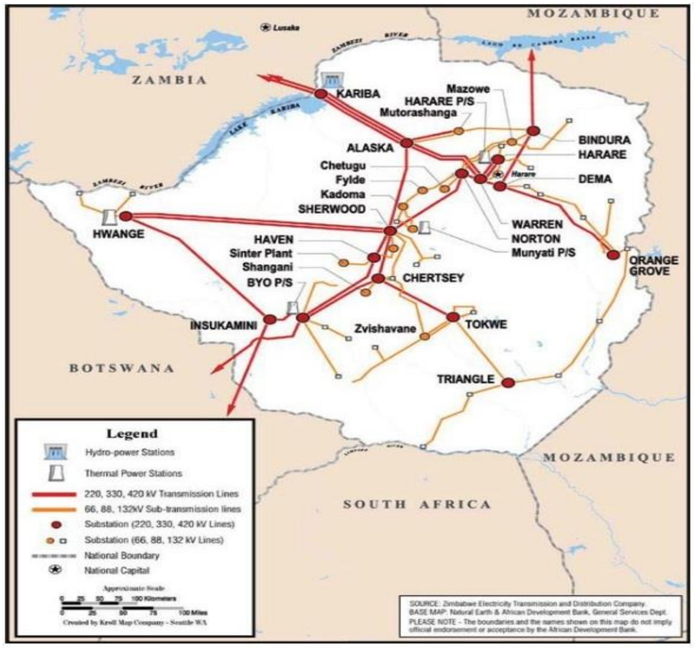


Fig. 2.2 Transmission and distribution network for Zimbabwe

up to the year 2020 in accordance to projections made in 2015. The country has over 119,784 km of distribution lines serving approximately 600,000 customers. ZETDC has prepared short, medium and long-term master plan studies with an aim to achieve greater reliability in the distribution system and ensure that it is capable of meeting future requirements. The studies outline the need to ensure reliable power supply, with a particular focus on the growing main cities. With this in mind, ZETDC planned to strengthen this existing distribution network a decade ago. Meanwhile, the entire energy sector in Zimbabwe is regulated by the Zimbabwe Energy Regulatory Authority (ZERA) whose regulatory structure is shown in Figure 2.3.

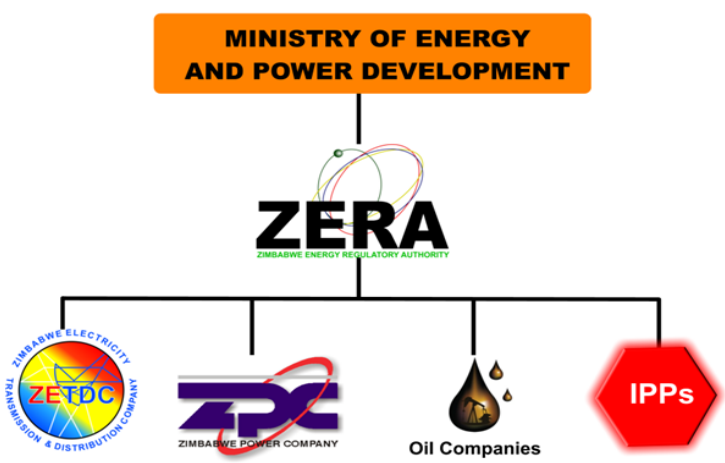


Fig. 2.3 ZERA Regulatory Structure

Zimbabwe’s renewable energy zones are illustrated in Figure 2.4.

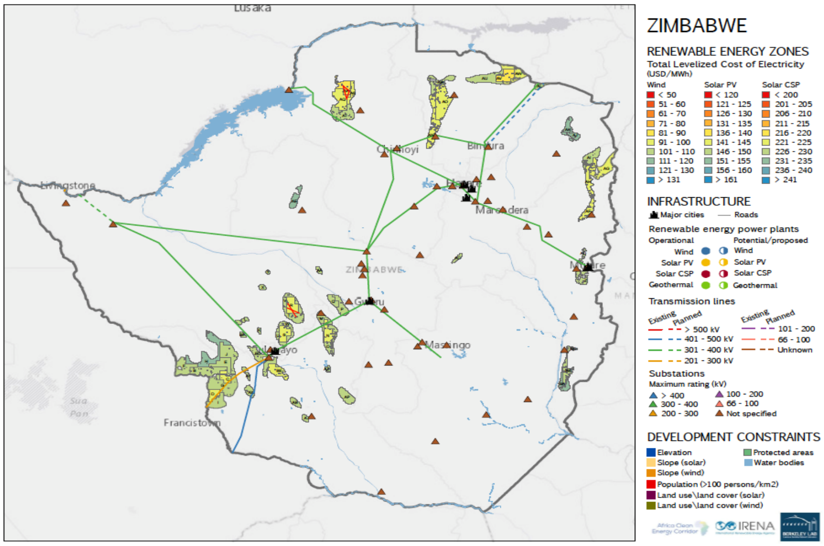


Fig. 2.4 Renewable energy zones for Zimbabwe

They are constituted by the following renewable resource potential:

- **Biomass, bagasse and bio-waste** – residue, sugarcane waste, timber waste;
- **Urban waste** – significant potential for waste to energy projects;
- **Geothermal** potential (about 50MW).
- **Hydro**- potential for more than 2GW along Zambezi River and mini-hydro sites and dams;

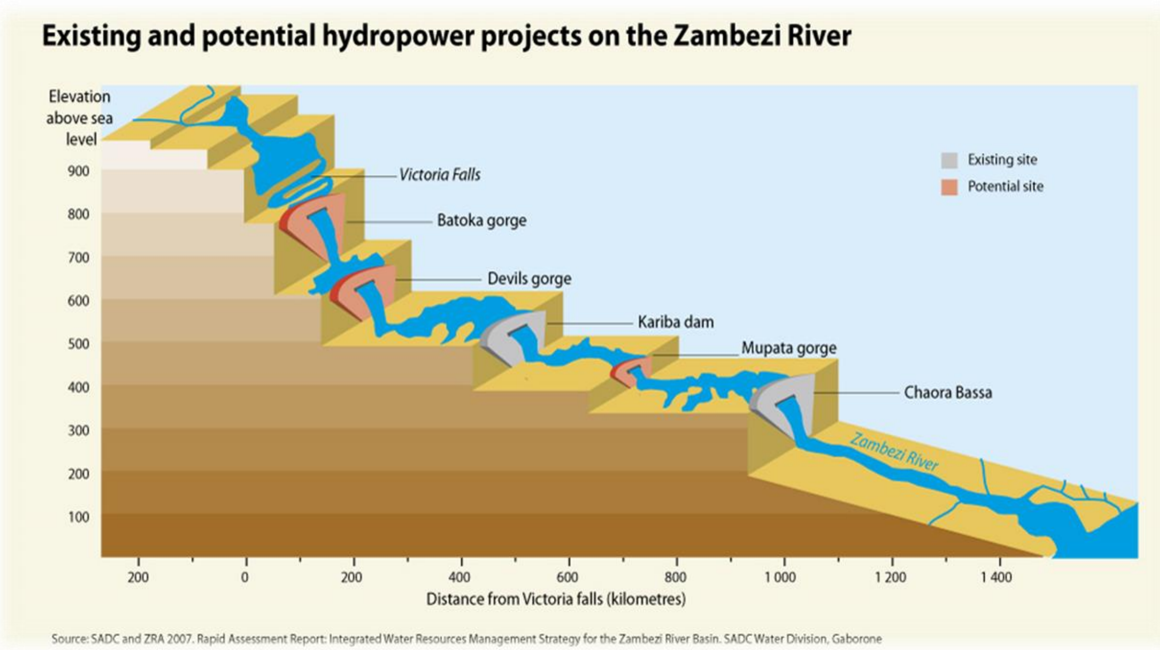


Fig. 2.5 Existing & potential hydropower projects on the Zambezi River

- **Solar**- irradiation averaging 20MJ per square metre and 3,000 hours of sunshine per year. (109 GW);
- **Wind** resource potential (39.3GW);

Table 1: Wind, Solar PV & Solar CSP Resource Potential

	Wind					Solar PV					Solar CSP				
Energy ϱ x10² W/m²	2	2.5	3	3.5	4	2.3	2.4	2.5	2.6	2.7	2.6	2.7	2.8	2.9	3
KWh/m²/day						5.5	5.8	6	6.2	6.5	6.2	6.5	6.7	7.0	7.2
~potential capacity x10³MW	39.3	5.96	0.4			109	77	62.2	42.3	5.28	40	35	31	19	4.4

However, results for potential wind sites in Zimbabwe as assessed by IRENA are indicated in Table 2.

Table 2: Potential wind sites in Zimbabwe; IRENA

IRENA MAP ZONE ID	**AV**	**AR**	**C**	**N**	**AO**
Area	**Mavhuradonha**	**Karoi**	**Plumtree**	**Shangani**	**Mutorashanga**
Site GPS Coordinates	-16.3347, 31.6200	-16.4742, 29.5048	-20.5243, 27.9466	-19.9174, 29.2895	-16.7097, 30.7748
Potential Capacity [MW]	40.8	34	23.8	34	88.4
P90 Annual Energy Production (MWh)	117,662	85,310	68,266	97,523	242,537
CAPEX [$/MW]	1,477,000	1,477,000	1,477,000	1,477,000	1,477,000
Tariff [$/MWh]	82	91.5	82.9	82.93	82.93
Average Wind Speed [m/s] at 100m Hub Height	7.2	6.5	7.4	7.4	7.3
Maximum Wind Speed [m/s] at 100m Hub Height	22	16.1	19.8	19.3	19.8
Area of Zone [km²]	362	294	207	296	776
Capacity Factor	39%	36%	40%	40%	38.3%
Mean Resource Quality [W/m²]	284	262	262	249	259
Distance from the nearest ZETDC Substation [km]	94	51	82	40	25
Name of nearest ZETDC Substation	Horse Shoe 132kV	Karoi 132kV	Bulawayo-Haven 330kV	Shangani 132kV	Mutorashanga 132Kv

Whilst the prioritized wind energy sites are shown in Table 3.

Table 3: Prioritized wind energy sites

#	Wind Site Location	Number of Wind Turbine Generators	Unit Wind Turbine Generator Capacity (MW)	Total Potential Installed Capacity (MW)
1	Mutorashanga (AO)	26	3.4	88.4
2	Karoi (AR)	20	1.7	34.0
3	Mavhuradonha (AV)	12	3.4	40.8
4	Plumtree (C)	7	3.4	23.8
5	Shangani (N)	10	3.4	34.0
	TOTAL			**221.0**

2.2 Water sector brief

Zimbabwe has a tropical climate with many local variations. The southern areas are known for their heat and aridity. The parts of the central plateau receive frosty winter. The Zambezi valley is also known for its extreme heat. The eastern highlands usually experience cool temperatures and the highest rainfall in the country. The country's rain season generally runs from November to March and the hot climate is moderated by increasing altitude. Severe storms are rare in Zimbabwe. The hottest month is December and the coolest month is June. Usually, the country experiences mid-season droughts in mid-January to early February. Normally, Zimbabwe's climate is characterized by distinct wet and dry seasons, with transitional periods. The country's main topographical features tend to influence both rainfall and temperature. Consolidated reviews indicate that rainfall average is 450mm per annum. Meanwhile, the average maximum monthly temperature recorded in October is 32.5^{0}C and the average minimum temperature recorded in July is 8.5^{0}C. Predominant wind direction is towards the North West.

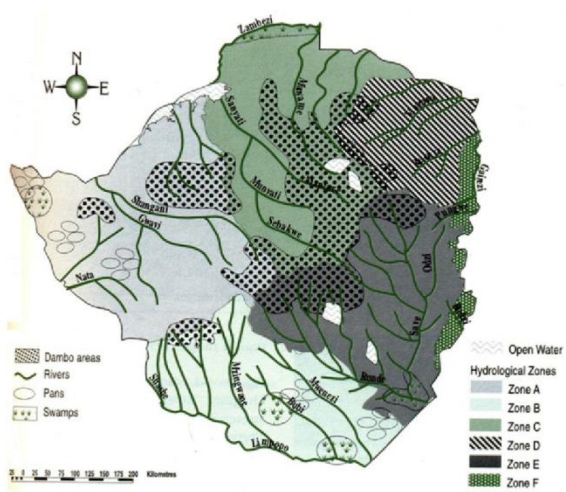


Fig 2.6 Water flow network in Zimbabwe

Most rivers, especially in the drier parts of the country, are not perennial. Only the major rivers such as Munyati, Manyame, Mazowe, Save and Runde are perennial. However, in dry years even these large rivers dry up in the months of August to November. An extensive network of dams has been constructed throughout the country. These range from small dams on commercial farms and in rural areas, to large dams for the purpose of supplying water to major cities and for irrigation. The water flow network is shown in Figure 2.6.

Studies carried out by ZINWA found out that the mean annual run-off for the whole of Zimbabwe is 19.910 billion m^3, with current shortage at 5.831 billion m^3, indicating that there is scope for storing more water. Current utilization is only 22% of mean annual run-off. Besides surface water storage, Zimbabwe also relies on underground water. Numerous boreholes and wells have been drilled throughout the country. Small, shallow, low yielding wells and boreholes in communal areas supply villages with drinking water, especially during the dry season and dry years. Deeper, high yielding wells are used for irrigation on commercial farms. The quality of both surface and groundwater supplies in Zimbabwe is generally good at present, since there is little overall use of chemicals in Zimbabwean agriculture. Localized pollution does, however exist. The eutrophication of Lake Chivero south of Harare is a case in point. In addition, the storage capacity of the major reservoir is threatened by siltation resulting from heavy soil losses in most of the catchment areas. However, the challenge to government and the development process is to ensure the provision of clean drinking water to the whole population.

2.3 Infrastructure and utilities brief

Infrastructure like road, rail, and air transport is very important for any economy. The Government of Zimbabwe currently has a 100% stake in air and rail transport. The railway operator is the National Railways of Zimbabwe (NRZ), whilst for air is Air Zimbabwe. The road network is controlled by the Zimbabwe National Road Authority (ZINARA) and the airports by the Civil Aviation Authority of Zimbabwe (CAAZ).

2.3.1 Road Network

Zimbabwe has close to 90 000 km of classified roads. Primary roads are composed of highways. About 5% of the entire road network is primary. Most of the primary roads are frequently used by SADC traffic since Zimbabwe is strategically positioned in the region. Secondary roads make up 14% of the network in Zimbabwe. Secondary roads link the major centers within the country. These form a dependable network for the movement of people and goods. Meanwhile, the roads otherwise known as tertiary feeder and access roads that link rural areas to both primary and secondary roads are managed by the District Development Fund (DDF) and by the Rural District Councils (RDC). These roads and tracks link rural communities to service centers, schools and health centers. Urban roads make 9% of the road network. Urban roads are managed by urban councils and municipalities.

2.3.2 **Pipelines**

A state-owned 270 km pipeline that runs from Beira in Mozambique to Mutare transports the bulk of petroleum imports. The pipeline is managed by a 100% state owned oil company, the National Oil Company of Zimbabwe which is a government owned company.

2.3.3 **Telecommunications**

This sector, a key to sustained economic development in Zimbabwe is controlled by the Postal and Regulatory Authority of Zimbabwe (POTRAZ) as well as the Broadcasting Authority of Zimbabwe (BAZ). Both organizations are state organizations established through acts of parliament. Currently, there are three mobile communications operators and one fixed operator registered. Radio transmission accounts for 8 operators whilst only one state TV station operates.

2.4 Country profile (population and economy) brief

National Flag	
Population, total (millions)	16,665,409 (2023)
Population growth (annual %)	1.48
Population density (people per sq. km of land area)	38
Median age (years).	18.4
GNI per capita, PPP (current international $)	1 390.00

Total Land area	390,797 km^2
Land	386,670 km^2
Water	3,910 km^2
Border countries and Length	Botswana 813 km, Mozambique 1,231 km, South Africa 225 km, Zambia 797 km
Climate	Tropical; moderated by altitude; rainy season (November to March)
Terrain	Mostly high plateau with higher central plateau (high veld); mountains in east
Natural Ore Resources	Diamonds, coal, chromium ore, asbestos,

	gold, nickel, copper, iron ore, vanadium, lithium, tin, platinum group metals
Zimbabwe Geographic coordinates	Zimbabwe is located at latitude -19.015438 and longitude 29.154857
Official Languages	English, Shona, Ndebele, Chewa, Chibarwe, Kalanga, Koisan, Nambya, Ndau, Shangani, sign language, Sotho, Tonga, Tswana, Venda Xhosa and Chikunda.
Key Economic sectors	Mining, Manufacturing, Agriculture, Energy, Tourism and Commerce.

Fig. 2.7 Provinces & Districts Map for Zimbabwe

2.5 Socioeconomic data

2.5.1 Energy and electricity sector

Table 4: ENERGY SUPPLY SITUATION (2018-2019)				
PROJECT	**2018 GWh**	**2019 GWh**	**Difference GWh**	**Variance %**
Kariba	5,377.3	4,095.6	-1,281.7	-24
Hwange	3,425.8	3,138.1	-287.7	-8
Bulawayo	88.0	51.7	-36.3	-41
Munyati	81.3	84.6	3.3	4

Harare	66.3	75.8	9.5	14
Nyamingura	5.6	4.0	-1.6	-28
Pungwe A	13.7	8.5	-5.2	-38
Duru	8.0	4.0	-4.0	-50
Pungwe B	86.4	35.9	-50.5	-58
Hauna	0.0	4.3	4.3	100
Riverside Solar	0.0	4.7	4.7	100
Pungwe C	13.4	8.2	-5.2	-39
Tsanga B	0.0	0.5	0.5	100
Claremont	1.7	1.6	0.0	-2
Dema	0.2	0.0	-0.2	-100
Chisumbanje	29.4	5.0	-24.4	-83
Kupinga	10.6	3.3	-7.3	-69
ZESCO	0.0	1.1	1.1	100
ESKOM	1,034.5	898.7	-135.8	-13
HCB	436.0	519.8	83.8	19
DAM Imports	17.0	235.0	218.0	1283
Total Supply	**10,695.1**	**9,180.5**	**-1,514.6**	**-14**
DAM & Nampower Exports	516.9	461.4	-55.5	-11
Net Supply	**10,178.2**	**8,719.1**	**-1,459.0**	**-14**

Table 5: Main Energy Sources

Energy Source	**%Ratio**	
	2009	**2012**
Biomass	66	61
Coal	19	8
Fuel	6	18
Electricity		13
Hydro	4	
Imports	5	

Table 6: Main power sources

Main Power Sources	**Qty MW**	**%Ratio**
Thermal (Coal)	750	36
Hydro	1050	45
Solar		1
Wind		Under review
Biomass		Under review
Imports		18
Deforestation		33
Hydrogen		0

Table 7.1a Cost of conventional electricity		
Mode	**Unit Cost (USc/kWh)**	
Commercial	10.53	
Domestic	9.86	

Table 7.1b Cost of green electricity

Source	**Estimated cost (USc/kWh)**	
Solar	10.3	100Kw to 10MW
Baggase	9.6	100KW to 10MW
Large Hydro	4.1	750MW
Small Hydro	12.5	1 to 10MW
Large coal	7.0	900MW
Small diesel	72	10 to 120KW
Large diesel	16.5	100MW
Hydrogen	0	0

Table 7.2: Tariffs in relation to technology used (2013/16/18)

Technology	Generation capacity range	Tariff (US$)/kWh 2013	Tariff (US$)/kWh 2016	Tariff (US$/kWh) 2018
Hydro	>100kW - 1MW	0.153	0.146	0.142[19]
Hydro	>1 - 5MW	0.134	0.134	0.132[19]
Hydro	>5 - 10MW	0.118	0.121	0.127[19]
Biomass	>100kW - 10MW	0.137	0.123	0.098
Bagasse	>100kW - 10MW	0.111	0.102	0.079
Biogas	>100kW - 10MW	0.127	0.114	0.106
Solar PV	>100kW - 1MW	0.186	0.140	0.130
Solar PV	>1 - 5MW	0.178	0.132	0.125
Solar PV	>5 - 10MW	N/A	0.123	0.119
Wind	>100kW - 5MW	0.148	0.112	0.100

Table 8: LEVELIZED COST OF ELECTRICTY (LCOE)			
Technology	**Qty**	**2013 USc/KWh**	**2016 USc/KWh**
Hydro	100KW to 1MW	15.3	19.2
Hydro	1 to 5MW	13.4	12.5
Hydro	5 to 10MW	11.8	11.1
Biomass	100KW to 10MW	13.7	11.5
Bagasse	100KW to 10MW	11.1	9.6
Biogas	100KW to 1MW	12.7	10.6
Solar PV	100KW to 1MW	18.6	13.8
Solar PV	1MW to 5MW	17.8	13.1
Solar PV	5MW to 50MW	n/a	11.8
Wind	100KW to 5MW	14.8	10.3

Table 9: National peak power demand

Indicator	2002	2003	2004	2005	2006	2007	2008
Maximum demand (MW)	2028	2028	2040	2045	2045	2040	2034
Energy Sales (GWh)	10225	10321	10367	10116	10408	10307	10028
Consumption per capita (kWh)	818	828	864	798	826	496	430
New Connections (domestic)	5248	6794	7453	10245	13926	12094	8162
Total Number of customers	201073	228465	245859	284562	338954	415667	500083

Table 10: CUSTOMER CONNECTIONS (2018/19)			
Category	**YTD 2018**	**YTD 2019**	**YTD Variances % 2018/19**
New Connections	27,247	22,665	-16.8
Active Customer Base	753,275	754,162	0.1
Connections Fees Paid but Customers not Connected	12,477	14,320	14.8

Table 11: Statistics of Institutional Connections 2019										
	Primary Schools	Secondary Schools	Clinics	Govt. Ext. Offices	Chiefs'	Business Centres	Farms	Villages	Others	**Total**
	30	11	7	8	5	21	19	11	22	**134**

Grid Extension Projects: Scope of Works Completed 2019			
33KV LINE (Km)	**11KV LINE (Km)**	**MV LINE (Km)**	**Capacity Installed (KVA)**
85.53	114.83	45.29	3,676

Table 12: ENERGY CONSUMPTION (2018/19)					
	YTD 2018 GWh	**YTD 2019 GWh**	**YTD Variance (%)**	**National Target GWh**	**National Demand Variance (%)**
Yearly Total Energy Transmitted/Delivered	10.178	8.719	-14	8.760	0.47
Demand Sales	8.505	7.751	-8.87	8.760	-11.52

Table 13: Energy Consumption Per Sector (GWh) 2018 to 2019			
Category	**2018**	**2019**	**Variance %**
Domestic metered	425.25	382.91	-9.96
Domestic Prepaid	1.940.841	1,604.31	-17.34
Mining & Industrial	3,731.994	3,684.47	-1.27
Commercial	1,871.1	1,603.69	-14.29
Agriculture	510.3	439.79	-13.82
Public Lighting	8.505	24.40	186.86
ZETDC Properties	17.01	12.31	27.63
TOTAL	**8,505.00**	**7,751.88**	**-8.87**

Fig. 2.8 Electricity Demand by Sector

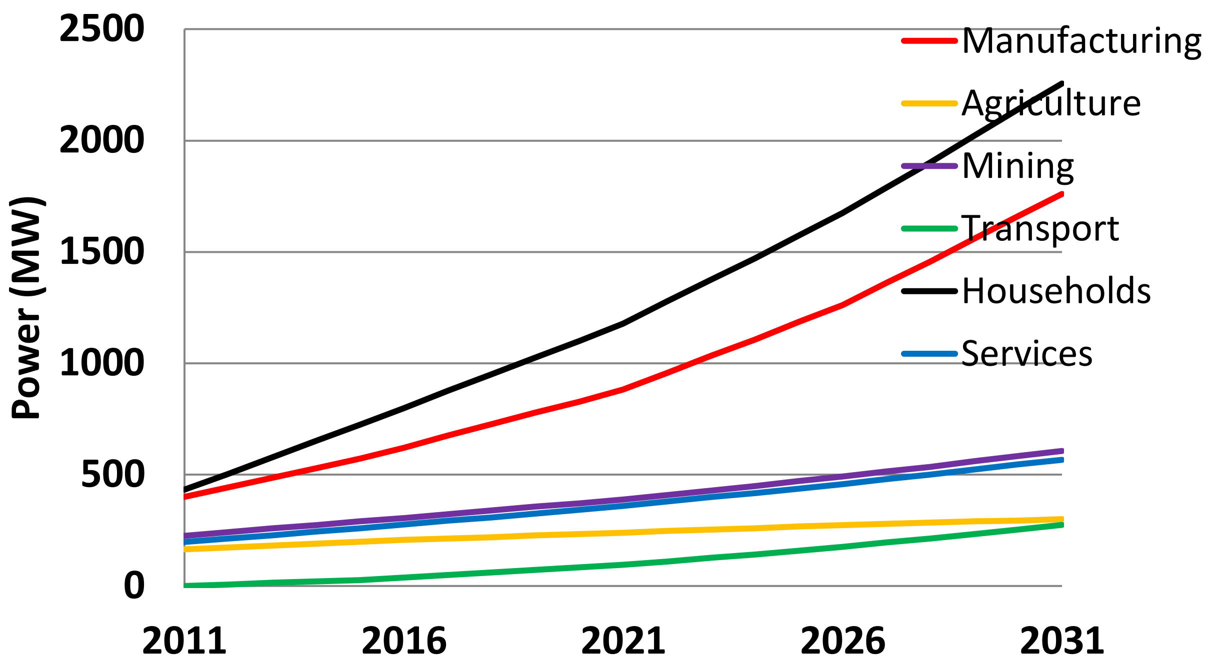


Table 14: POWER GENERATION CAPACITY

Station Name	Plant type	Installed capacity (MW)	Available capacity (MW) by 2000	*Available Capacity (MW) by 2009*
Hwange	Coal-fired	920	800	560
Kariba	Hydro-electric	750	470	420
Harare	Coal –fired	135	60	0
Bulawayo	Coal-fired	120	90	0
Munyati	Coal-fired	150	60	0
Kwekwe (Sable Chemicals)	Hydrogen	150	0	0
		2012	2019	
Mutoko	Biodiesel	0.25	0.25	
Dema	Diesel	120	0	
Chiredzi (sugarcane/woodwaste)	Bagasse	96.5	96.5	
Nyabira/Marondera	Solar	4.5	4.5	
Chiredzi	Ethanol	0	0	
Total		**2446.25**	**1581**	**1080**

Mini-Hydro sites

Name	Capacity (kW)	End Use
Svinurai	20	Electrification of households;
Mutsikira	25	Drives a hammer mill, irrigation water pump, saw and grinder;
Aberfoyle	25	Electrification of households;
Nyarufu	40	Electrification of households;
Kuenda	74	Irrigation water pumping;
Kwenda	80	Irrigation water pump, electrification of households;
Claremount	250	Electrification of households;
Rusitu	750	Electrification of households;

Sugar cane

Mill	Cane Crushing Capacity (TCH)	Available installed Capacity (MW)
Hippo Valley	480	26
Triangle	430	32

Table 15: Light handed regulation for off-grid renewable energy mini-grids:

NAME OF SCHEME	DATE INSTALLED	TECHNOLOGY	CAPACITY (kW)
1. Mashaba- Gwanda	2015	Solar	99
2. Himalaya	2013	Hydro	80
3. Hlabiso	2013	Hydro	30
4. Ngarura	2013	Hydro	30
7. Dazi	2011	Hydro	20
8. Chipendeke	2010	Hydro	25
9. Nyafaru	1996	Hydro	20

Table 16: Average electricity tariff (1998-2009)

Year	Av.Price (USc/kWh)	Year	Av.Price (USc/kWh)
1998	3.49	2004	4.67
1999	1.40	2005	4.78
2000	2.35	2006	4.92
2001	4.06	2007	5.20
2002	4.86	2008	5.05
2003	4.95	2009	3.45

Table 17: Electrification Access Statistics (1996 – 2009)

Year	Urban % of Total	ural % of Total	National % of Total
1996	72	12	27
1997	74	14	29
1998	78	16	31
1999	80	17	34
2000	81	18	36
2001	82	20	37
2002	84	22	39
2003	84	23	41
2004	85	25	41
2005	86	21	42
2006	85	22	41
2007	80	20	41
2008	80	20	40
2009	40	20	40

Table 18 National Supply Deficit (2000 – 2018)

Year	Supply deficit (MW)	Annual generated (MW)
2000	846	1 986
2001	661	2 013
2002	680	2028
2003	765	2007
2004	653	2069
2005	720	2066
2006	732	1904
2007	584	1758
2008	260	1429
2009	357	1403
2010	1 560	940
2011		

	2012		
	2013		
	2014		
	2015		
	2016		
	2017		
	2018	1355	845
	2019		

Total power generation	8 7125GWh (2019); 10718GWh (2018)
Total installed capacity	2 317MW
Total average available capacity	>1150
Percentage of power used for domestic purposes + others	Domestic-26%; Commerce/ Agriculture-27%
Percentage of power used in industry	47%

Table 19: Total capacity generated from other sources

Sources	Capacity (MW)	
Thermal (Coal)	1350	
Large Hydro	1050	
Small Hydro	31.26	
Solar	6.3	
Wind	Unknown	
Biogas	Unknown	
Hydrogen	0	
Ethanol	0	
Biodiesel	0.250	
Diesel Generators	120	(out of service)
Petrol Generators	Unknown	
Bagasse	96.5	Sugar cane; wood waste

Access to electricity (% of population)	44%
Consumption per capita (kWh/capita)	Unknown

Table 20: Main power providers (% distribution)

State	81	
IPPs	18	
PPPs	0	

Table 21: National Power Outages

Sector	*Average hours Of outage 2007*	*% of Work day Lost 2007*	*Average hours of outage in 2008*	*% of Work day Lost 2008*	*Average hours of outage in 2009*	**%of Work day Lost 2009**
Agriculture	2	25	4	50	6	75
Mining	0	0	0.5	6.25	1	12.5
Manufacturing	1	12.5	1	12.5	4	50
Commerce	1	12.5	1	12.5	4	50
Domestic: Urban	2	25	3	37.5	5	62.5
Domestic: Rural	2	25	4	50	6	75

Table 22: Major Power Producing Companies

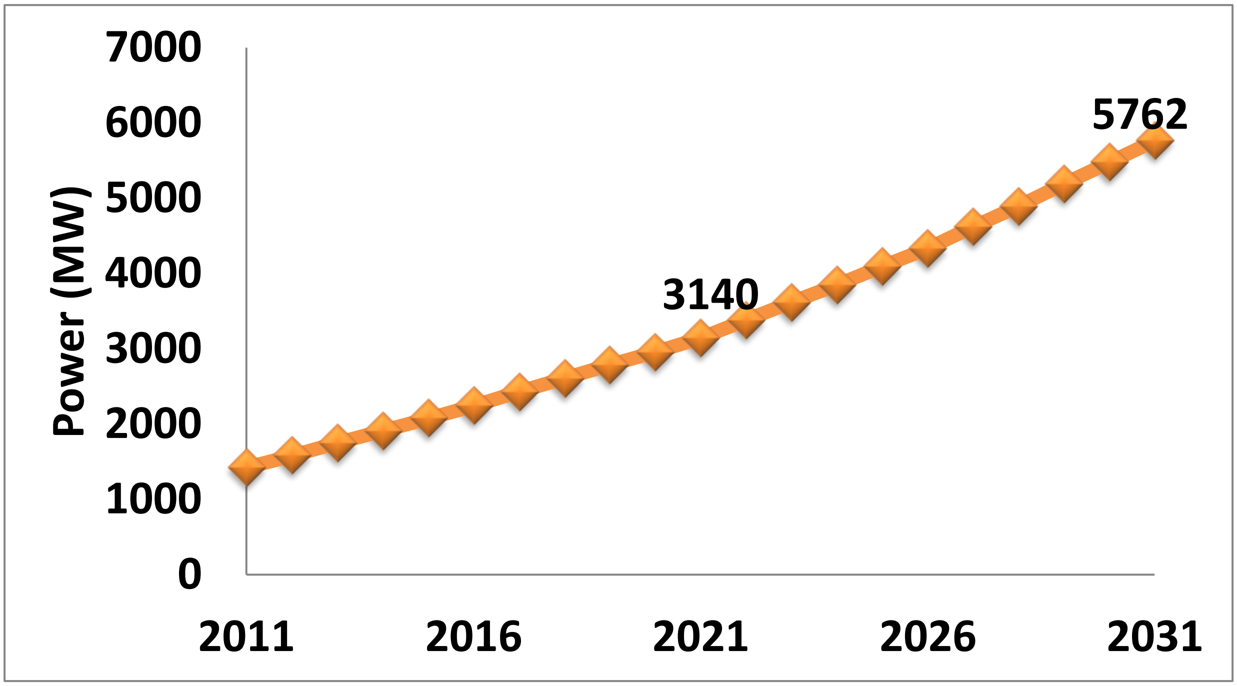
Power Stations	**Operating Company**
Kariba Dam	ZPC (state owned)
Hwange Thermal	ZPC (state owned)
Rusitu Hydro	Rusitu Power Corporation
Munyati (coal)	ZPC (state owned)
Bulawayo (coal)	ZPC (state owned)
Harare (coal)	ZPC (state owned)
Triangle (bagasse)	Triangle (Pvt) Ltd.

Hippo Valley Estates (Bagasse)	Hippo Valley Estates (Pvt) Ltd.
Green Fuel (bagasse)	Green Fuels (Pvt) Ltd.
Border Timbers (wood waste)	Border Timbers (Pvt) Ltd.

Table 23 Regional Electricity Imports.

Country	Inter-connection Voltage (KV)	Max. Cap. (MW)	Available Capacity (MW)	Available Capacity (MW) 2008	Available Capacity (MW) 2009
Mozambique	400	500	500	200	100
South Africa	400	500	150-500	100	0
Zambia	300	700	100-500	50	0
DRC	220	250	159	100	0
Botswana	220	100	60	0	0

Fig. 2.9 Electricity Demand Forecast.



2.5.2 Water Sector

In the 20 years from Zimbabwe's Independence in 1980, overall water coverage increased from 32% to 56% and overall sanitation access from 28% to 55%. Urban services had achieved well over 90% coverage by the late 1990s. Since then there has been a decline, the exact extent of which is not known. Zimbabwe has seven catchment areas namely Gwayi, Mazowe, Mzingwane, Runde, Sanyati, Save and Manyame.

Average annual precipitation in depth (mm/year)	657
Average annual precipitation in volume (billion cubic meters/year)	257
Surface water produced internally (billion cubic meters/year)	11
Groundwater produced internally (billion cubic meters / year)	6
Total internal renewable water resources (billion cubic meters / year)	19
Total internal renewable water resources per capita (m3/year)	741.7

Table 24 Main water sources

Rural	Boreholes, wells, rivers.
Urban	Boreholes, retail, harvested water.
Industry	Council, water bowsers, boreholes.
SMEs	Council, communal boreholes.
Agriculture	Water reservoirs (dams, lakes, storage facilities).
Mining	Rivers, underground and water reservoirs.

Table 25 % Distribution of water sources.

Borehole water	Unknown
Rain water	Unknown
Dam water	Unknown
Lake water	Unknown
Other water reservoirs	Unknown

Table 26: Major dam levels as at 17 March 2021

Dam	Installed Capacity ($x10^6$ m^3)	Current Capacity ($x10^6$ m^3)	%Full
Kariba	64800.00	33168.3	51.2
Tugwi Mukosi	1802.60	1809.1	100.4
Mutirikwi	1378.08	1348.9	97.9
Manyame	480.23	368.01	76.6
Osborne	401.64	260.7	64.9
Mazvikadei	343.82	253.8	73.8
Manyuchi	309.06.	275.1	89.0
Manjirenji	274.17	267.7	97.6
Sebakwe	265.73	265.7	100.0
Chivero	247.18	243.4	98.5
Insiza	173.49	138.1	79.6
Zhovhe	130.46	122.9	94.3
Siya	.105.45	105.2	99.8
Inyankuni	74.52	44.5	59.8
Mtshabezi	51.99	37.1	71.5
Upper Ncema	43.57	24.0	56.3
Mzingwane	42.17	13.2	31.5
Bubi Lupane	39.09	35.9	92.0
Silalabuhwa	23.22	20.8	89.8
Lower Ncema	14.87	11.0	74.6
Harava	9.02	8.8	97.6
Upper Insiza	7.81	6.8	88.1
Seke	3.38	1.8	55.1
Khami	Not measured		
Umguza	Not measured		
Darwendale	Not measured		
Biri	Not measured		

	Mazowe	Not measured			

Levels as at 21 March 2021 of national average dam levels gained 95.9%. The last highest gain recorded was in 1974 with a 55% gain. Below is the percentage distribution of water levels according to the seven catchment areas.

Table 27: %Water levels in catchment areas

Catchment Area	**%**
Gwayi	102.7
Manyame	81.1
Mazowe	80.4
Mzingwane	89.5
Runde	105.9
Sanyati	105.8
Save	78.7

Surface water : total flow of border rivers (billion cubic meters/year)	39.9
Surface water : accounted inflow (billion cubic meters/year)	7.7
Surface water : total external renewable (billion cubic meters/year)	19.0
Total external renewable water resources (billion cubic meters/year)	20.0
Total renewable surface water (billion cubic meters/year)	19.0
Total renewable groundwater (billion cubic meters/year)	6.0
Total renewable water resources (billion cubic meters/year)	12.0
Dependency ration (%)	38.7
Renewable internal water resources per capita (cubic meters / year)	1.210 (2017); 3 613 (1972)
Renewable water resources per capita (cubic meters / year)	742 (2017); 2 215 (1972)
Total exploitable water resources (billion cubic meters/year)	12.26
Interannual variability	Not given
Seasonal variability in main water source	Not given
Total dam capacity (km3)	99.93 (2015); 97.11 (1970)
Dam capacity per capita (cubic meters)	15 423 (2019); 17 542 (1970);

	6 045 (2015)
Agricultural water withdrawal (billion cubic meters/year)	2.92 (2007); 0.96 (1987)
Industrial water withdrawal (billion cubic meters/year)	0.22 (2007); 0.09 (1987)
Municipal water withdrawal (billion cubic meters/year)	0.43 (2007); 0.17 (1987)
Total water resources withdrawal (billion cubic meters/year)	3.6 (2007); 1.2 (1987)
Total water withdrawal per capita (cubic meters/year)	267.80 (2007); 131.30 (1987)
Freshwater withdrawal as % of total renewable water resources (%)	29.12 (2007); 9.95 (1987)
Total water consumed per capita (cubic meters)	Not given
% of land area covered by water (wetlands)	1.00
Environmental flow requirements (billion cubic meters/year)	14
Desalinated water produced (billion cubic meters/year)	None
Water stress (%)	28
Main source of drinking water	Dams, lakes, rivers, acquifers.
Total population with access to safe drinking water (%)	64.1 (2017); 71.1 (2003)
Rural population with access to safe drinking water (%)	49.8 (2017); 58.6 (2003)
Urban population with access to safe drinking water (%)	77.3
Cost of cubic meter of water US$	0.83 (2019); 0.70 (2018) CoH 0.40 ZINWA
Average groundwater depth meters	40
Aquifer productivity	Not given
Costs to pump groundwater per 1 meter ground water table depth USc	0.33

Table 28 Human water use

	Current	**Projection**
Irrigation	Not quantified	
Industrial	Not quantified	
Domestic (Rural)	Not quantified	
Domestic (Urban)	Not quantified	
Mining	Not quantified	

Main utility companies (% distribution)		
State	99	
IPPs	1	
PPPs	0	

Table 29: IPP ENERGY PRODUCTION (2015-19)

Project	Type	PRODUCTION LEVELS (GWh)				
		2015	2016	2017	2018	2019
Nyangani (NRE)	Hydro	51.4	69.8	111	112	65.3
Riverside Solar	Solar				4.79	4.7
Hippo Valley Estates	Biomass	34	53.1	0	63.2	56.2
Triangle	Biomass	87.5	181	3.33	83.9	115.2
Border Timbers	Biomass					
Chisumbanje	Biomass	6.5	2.72	10.8	39.5	5
Dema	Diesel		203	48.2	0.15	0
Kupinga	Hydro			7.9	13.1	3.3
Claremont	Hydro			0.4	1.68	1.6
Centrgrid	Solar					0.005
Total		179	509	182	311	251.4

2.5.3 Infrastructure

2.5.3.1 Rail

Available total rail line route (km)	2 627	
Available rail connection linking neighboring countries	Goods services readily available. Most passenger trains across borders were discontinued two decades except for Mozambique.	The passenger train to Mozambique starts from Bulawayo (Zimbabwe); Chicualacuala (500Km) 19Hrs then to Maputo (534Km) 17Hrs journey.
Effectiveness of the available rail line	9% under caution.	

Railways, goods transported (million ton-km)	2.6 (2020); 18 (1998); 4 (2015)
Access to railways (% of total population)	Not given
Railways, labour productivity (traffic units per employee/per locomotive)	17 000 employees (1980); 4500 employees (2019)
Rural Accessibility Index (percentage of population within 2 km of an all-weather rail line)	Unquantified

Table 30 Rail Operator Capacity

	NRZ	BBR
Operates on line		1
Locomotives	10	10
Freight wagons (flat bed) size	255	
Freight Wagons (high sided) size	3 560	
Freight Wagons (drop side) size	1 074	

Table 31 Linear of rail tracks on major passenger routes

	Route A Harare to Bulawayo	**Route B Bulawayo to Victoria Falls**	**Route C Harare to Mutare**	**Route D Beitbridge to Bulawayo**	**Route Byo to Chire**
Track gauge	1.067	1.067	1.067	1.067	1.067
Distance Km	450	440	280	317	523
Duration Hrs	13.5	13	20	Stopped in 2019	15
Repairs	Bad	Bad	Marginal	Marginal	Bad
Traffic frequency	Daily	Daily	Daily	Cancelled	daily
Main stations	Gweru, Kadoma, Kwekwe	Lupane, Hwange	Marondera, Rusape	Gwanda	Chicua

Number of public transport trains	8

Share of renewables energies in installed capacity	0

Table 32: RAILWAY KEY STATIONS

Location	**Harare**	**Bulawayo**	**Beitbridge**
Storage Capacity m^2	20 000	15 000	3 000
Handling Equipment	manual	manual	Manual
Handling Capacity metric tonnes	200	100	20
TEU/Hr	outsourced	outsourced	outsourced
Connection with other transport modes	road; air	road; air	Road

Table 33 Railways traffic, volumes and financial performance (1970 – 2002).

Year	**Operating Surplus/ deficit ($x10^3$)**	**Net Surplus/ deficit ($x10^3$)**	**Number of Passengers ($x10^3$)**	**Revenue Earning Tonnes-Km ($x10^6$)**	**Gross Tonne-Km ($x10^6$)**	**Net Tonne-Km (millions)**
1970	19 632	1 678	2 814	10 846	14 411	6 500
1971	17 380	(1 676)	2 782	10 768	14 283	6 293
1972	19 152	(1 926)	3 013	11 498	15 308	6 802
1973	12 255	(10 996)	3 236	11 598	15 194	6 623
1974	6 339	(19 139)	3 010	11 801	14 600	6 190
1975	8 483	(21 226)	3 127	12 018	14 686	6 141
1976	6 018	(29 119)	3 105	12 845	14 845	6 358
1977	1 102	(36 912)	2 613	12 108	13 957	6 104
1978	550	(35 697)	2 227	11 191	12 792	5 588
1979	13 441	(28 965)	1 574	11 621	13 391	6 149
1980	13 114	(32 151)	991	12 687	14 167	6 864
1981	20 277	(32 681)	1 580	13 153	13 540	6 610
1982	19 431	(39 730)	1 825	12 703	12 951	6 259

1983	21 793	(50 887)	2 050	13 071	13 008	6 289
1984	37 222	(45 976)	2 218	13 428	13 206	6 411
1985	37 339	(67 796)	2 471	13 088	13 029	6 200
1986	36 282	(87 389)	2 713	13 619	13 711	6 574
1987	7 520	(131 945)	2 650	13 200	11 239	5 451
1988	16 101	(116 666)	2 740	13 222	11 471	5 551
1989	6 217	(116 686)	3 126	13 215	10 592	5 287
1990	(36 427)	(227 913)	2 862	13 888	11 045	5 590
1991	163 834	515 158	1 975	12 928	10 930	5 413
1992	304 886	58 057	2 355	13 038	11 913	5 887
1993	228 649	(130 915)	2 200	10 464	9 649	4 581
1994	230 585	(161 658)	2 034	11 250	9 397	4 489
1995	335 740	(55 961)	1 670	18 448	13 440	7 180
1996	472 163	180 946	1 651	11 878	10 099	4 990
1997	467 580	(69 883)	1 461	10 163	9 989	4 100
1998	561 334	(71 522)	1 787	12 421	9 244	4 546
1999	1 263 080	153 501	1 896	11 028	8 962	4 381
2000	1 789 916	(351 369)	1 614	9 422	6 953	3 326
2001	346 655	(2 151 912)	1 334	8 843	6 667	3 100
2002	1 478 798	4 143 902	2 315	11 154	8 588	4 086

2.5.3.2 Available petroleum products pipeline

National length	261Km	Mutare to Harare

Ownership of pipe line distribution company	National Oil Company (NOIC) –

	state owned

2.5.3.3 Aviation:

Air-traffic freight 40.2 million tons; Passengers 0.5 million ferried (2019); Number of airports 17; Length of runways range from 914 to 3047 m.

2.5.3.4 Marine:

Marine population of registered boats: 1300

Table 34 Current RE activities in the country

Source	Location	Capacity (MW)
Mini-hydro	Svinurai	0.020
	Mutsikira	0.025
	Aberfoyle	0.025
	Nyarufu	0.040
	Kuenda	0.074
	Kwenda	0.080
	Claremont	0.250
	Rusitu	0.750
Sugar cane	Triangle	45
	Hippo Valley	33
	Green fuel (Chisumbanje)	18
Wood waste	Border Timbers	0.5
Solar	Mutoko	2.5
	Econet Msasa-Harare	0.1
	Natpharm rooftop-Masvingo (medical facility)	0.2
	Schweppes rooftop-Harare	1

		Liters (million)
Biodiesel	Mt Hampden	100 per annum
	Mutoko	1.1 per annum
Ethanol	Chisumbanje	380 000 per day (2019)

Table 35 Stages of development of licensed energy projects

	Project	Type	Size (MW)	Presumed Status
1	Wild Bush Investments	Solar PV	1.6	Stage 1 –Concept/ Pre-feasibility
2	Africa Oracle Solar Gen Company	Solar PV	25	
3	Sengwa Power Station	Coal	2400	
4	Parvalue Energy	Hydro	50	
5	Gombe Power Solutions	Solar PV	50	
6	Alliance Africa Energy	Solar PV	50	
7	Caledonia Mining Services	Solar PV	17.5	
8	Mvura Dam	Hydro	1	
9	Yellow Africa	Solar PV	50	Stage 1(b) – Feasibility/ Technical Studies
10	Acacia Energy Company	Solar PV	50	
11	Sinogy Power	Solar PV	175	
12	The Solar Group	Solar PV	50	
13	Solarwise Energy	Solar PV	50	
14	Pito Investments	Solar PV	25	
15	Energywise Equipment	Solar PV	30	
16	Custodian Energy Group	Solar PV	50	
17	Equinox Energy	Solar PV	10	
18	New Gloves Solar	Solar PV	10	
19	Planet Solar Park	Solar PV	50	
20	Shangani Renewable Energy	Solar PV	25	
21	Guruve Solar Park	Solar PV	5.5	
22	Sable Solar Energy	Solar PV	50	
23	Matshela Energy	Solar PV	100	
24	Lumigar Solar Energy	Solar PV	50	
25	ASPIRE	Solar PV	10	
26	Zhenje Solar Park	Solar PV	33	
27	Utopia Power Company	Solar PV	15	Stage 2 –Feasibility/ Proof of Bankability
28	Plum Solar	Solar PV	5	
29	De Green Rhino Energy	Solar PV	50	
30	Shilands Enterprises	Gas	345	
31	Great Zimbabwe Hydro	Hydro	5	

	32	PER Lusulu	Coal	2000	
	33	ZPC Gairezi Hydro	Hydro	30	
	34	Mopower Solar	Solar PV	50	
	35	Indo Africa Power	Solar PV	10	
	36	Centragrid	Solar PV	25	Stage 3 - Funding
	37	Tsanga A	Hydro	2.69	
	38	Tsanga C	Hydro	2.15	
	39	Rusitu Power Corporation	Hydro	1	
	40	Zimbabwe Zhongxin Electrical Energy	Solar PV	50	
	41	ZPC Hwange Expansion	Coal	600	
	42	Kefalos Cheese Products	Solar PV	0.6	
	43	Richaw Solar Tech	Solar PV	5	Stage 4- Construction
	44	Riverside Power Station Phase II	Hydro	7.5	
	45	TD Energy	Solar PV	40.8	
	46	Harava Solar Park	Solar PV	20	
	47	Solgas	Coal	5	
	48	Power Ventures	Solar PV	5	
	49	Nyakupinga Power Station	Hydro	0.6	
	50	Pelshong Investments	Solar PV	1	
	51	Tokwe Mukorsi	Hydro	15	
	52	Wild Bush	Hydro	1.6	
	53	Eastern Hydro	Hydro	1.4	
	54	Manako Power (Osborne Dam)	Hydro	2.5	
	55	Hippo Valley Estates	Co-Gen	33	
	56	Triangle Estates	Co-Gen	45	
	57	Greenfuel	Co-Gen	18.3	
	58	Riverside Power Station	Hydro	2.5	
	59	Nottingham Estates	Solar PV	1.5	
			Diesel	0.75	
	60	Padenga Holdings	Solar PV	0.33	
	61	Econet	Solar PV	0.1	
	62	SAZ	Solar PV	0.19	
	63	ZPC Kariba South Extension	Hydro	300	
	64	Schweppes Zimbabwe	Solar PV	0.2	
	65	Border Timbers	Biomass	0.5	Stage 5 – Commissioned
	66	Riverside Power Station	Solar PV	2.5	
	67	Duru	Hydro	2.2	
	68	Nyamingura	Hydro	1.1	
	69	Pfungwe A	Hydro	2.75	
	70	Pfungwe B	Hydro	15.25	
	71	Pfungwe C	Hydro	3.75	
	72	Hauna Power Station	Hydro	2.3	

73	Kupinga Power Station	Hydro	1.6	
74	Claremont Power Station	Hydro	0.3	
75	Tsanga B	Hydro	2.06	

Table 36 Licensed Projects

	PROJECT	TYPE	SIZE (MW)	LOCATION
1	Accelerated Sustainable Power in Renewable Energy (ASPIRE) (Pvt) Ltd..	Solar PV	10.2	ARDA Mkwasine Ranch, Chiredzi, MasP
2	Alliance Africa Energy Pvt Ltd	Solar PV	50	Chegutu, MWP
3	Bayrich Energy Pvt Ltd	Solar PV	50	Bikita, MasP
4	Caledonia Mining Pvt Ltd	Solar PV	17.5	Gwanda, MSP
5	Cam and Motor Solar Pvt Ltd	Solar PV	54	Kadoma, MWP
6	Chibani I Pvt Ltd	Solar PV	57.420	Sans Souci Farm, MasP
7	CoreZim Pvt Ltd	Solar PV	20	Goromonzi, MEP
8	Custodian Energy Group	Solar PV	50	Pun Farm, Alaska, MWP
9	Dalny Solar Pvt Ltd	Solar PV	20.6	Kwekwe, MidP
10	Dalny Solar Pvt Ltd	Solar PV	54	Kadoma, MWP
11	Equinox Energy (Pvt) Ltd.	Solar PV	10	Makaha, Mudzi District, MEP
12	Hapnust Investments	Solar PV	5.071	Magunje, MWP
13	Kefalos Solar Power Plant	Solar PV	0.6	Bhara Bhara Farm, Harare South
14	Kujoke Africa Pvt Ltd	Solar PV	6	Ward 33, Buhera South, ManP
15	Kusile Solar Park Pvt Ltd	Solar PV	24	Gweru, MidP
16	Lafrica Energy Pvt Ltd	Thermal	750	MNP
17	Lumiger Solar Pvt Ltd	Solar PV	50	Cactus Hill Farm, Chegutu, MWP
18	Matshela Energy Pvt Ltd	Solar PV	100	Timber Farm, Gwanda, MSP
19	Mopower Solar (Pvt) Ltd	Solar PV	50	Onent Farm, Somabhula, MidP
20	Murombedzi Solar Park Pvt Ltd	Solar PV	10.5	Zvimba, MWP
21	Murowa Solar Pvt Ltd	Solar PV	68.4	Zvishavane, MidP
22	New Glovers Solar (Pvt) Ltd.	Solar PV	10	Glovers Farm, Kwekwe, MP
23	Nyakupinga Power Station Pvt Ltd	Solar PV	0.6	Nyakupinga River, Nyanga, ManP
24	Padenga Holdings Limited	Hydro	1.2	Kariba, MWP

25	Parvalue Energy (Pvt) Ltd.	Solar PV	50	Donnington West, Westgate, Bulawayo
26	Parvalue Energy (Pvt) Ltd	Hydro	1	Odzani River, Mutasa District, ManP
27	Planet Solar Zimbabwe (Pvt) Ltd.	Solar PV	50	Eureka Farm, Chegutu, MWP
28	Power Ventures Pvt Ltd	Solar PV	25	Hwange, MNP
29	Renco Solar Pvt Ltd	Solar PV	38.04	Nyajena, Renco District, MasP.
30	Sable Solar Energy (Pvt) Ltd.	Solar PV	50	Kwekwe, MidP
31	Schweppes Zimbabwe Limited	Solar PV	1	Southerton, Harare
32	Shangani Renewable Energy (Pvt) Ltd.	Solar PV	25	Shangani, Insiza District, MSP
33	Shangani Renewable Energy (Pvt) Ltd.	Solar PV	5.5	Dunavet, Guruve District, MCP
34	Standards Association of Zimbabwe	Solar PV	0.5	Borrowdale, Harare North
35	Steam Team	Hydro	0.5	Silverstreams, Joppa Farm, Chipinge, ManP
36	T.D Energy (Pvt) Ltd.	Solar PV	20.002	Chivhu,MWP
37	TD Energy (Pvt) Ltd.	Solar PV	36	Lot 3 Stuhm, Goromonzi, MEP
38	Tokwe Mukorsi Hydroelectric (Pvt) Ltd.	Hydro	15	Tokwe Mukorsi Dam, Chivi, MasP.
39	Zhenje Solar Park Pvt Ltd.	Solar PV	33	Makokoro, Seke, MEP
40	Zimbabwe Zhongxin Electrical Energy	Thermal	50	Hwange, MNP
41	Zororo Energy Company (Pvt) Ltd	Solar PV	50	Bromley, MEP
42	ZPC Mutare Peaking Plant	Gas/Diesel	120	Orange Groove Farm, Feruka, Mutare, ManP
	SUB-TOTAL	**Solar PV**	**1102.933**	
		Thermal	**800**	
		Hydro	**17.7**	
		Gas/diesel	**120**	
TOTAL			**2040.633**	

Table 37: AMENDED LICENSES

	Project	Type	Size (MW)	Location	Nature of Amendment
1	Yellow Africa (Pvt) Ltd.	Hydro	1.0	Confluence of Odzi and Nyakupinga Rivers Minnehaha Area, Nyanga District Manicaland	Separation of Odzi and Nyakupinga River feeds into two separate power stations with two split licenses.
2	TD Energy (Pvt) Ltd.	Solar PV	40.8	Hunyani Business Park, Norton, Mashonaland West	Extension of dates for project completion.
3	Richaw Solar Tech (Pvt) Ltd.	Solar PV	5.0	Lot 16 of Capthal; Block 2A Gwanda, Matebeleland South	Revalidation of license conditions.
4	Yellow Africa (Pvt) Ltd.	Solar PV	50.0	Subdivision of 3 Broad Acres, Imbesu 3, Ward 8, Umguza RDC; Matebeleland North	Change of project site.
5	Sengwa Power Station	Coal	2400	Gokwe North; Midlands	Revalidation of license conditions.

Table 38 Operational small hydro projects:

#	Hydro Power Plant	Capacity (MW)
1	Nyamingura	1.1
2	Duru	2.2
3	Pungwe A	2.75
4	Pungwe B	15.25
5	Pungwe C	3.75

6	Hauna	2.3
7	Kupinga	1.6
8	Claremont	0.3
9	Tsanga B	2.06
	TOTAL	**31.26**

Other economic activities in the petroleum sector that also have an impact on access to power generation:

Table 39 Petroleum Licensing Statistics 2012-2019

Category	**YEAR**							
	2012	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**
Retail	229	411	496	594	569	609	638	709
Procurement	48	39	32	31	36	40	63	130
Wholesale	18	8	7	6	7	2	3	7
Blending	5	11	18	16	15	10	11	11
Production	1	2	4	4	3	4	2	1
TOTAL	**299**	**469**	**557**	**651**	**630**	**665**	**717**	**996**

Table 40 Geographical Distribution of Retail Service Stations 2019

Province	**Quantity**
Bulawayo	74
Harare	247
Manicaland	63
Mashonaland East	47
Mashonaland Central	35
Mashonaland West	78
Masvingo	51
Matebeleland North	28
Matabeleland South	32
Midlands	58
TOTAL	**713**

Table 41 Number of Licensed LPG Operators 2015-2019 (Biennial Licenses)

Category	**YEAR**			
	2015 to 2016	**2016 to 2017**	**2017 to 2018**	**2018 to 2019**
Retail	119	190	245	260
Wholesale	31	33	33	30
TOTAL	**160**	**223**	**278**	**290**

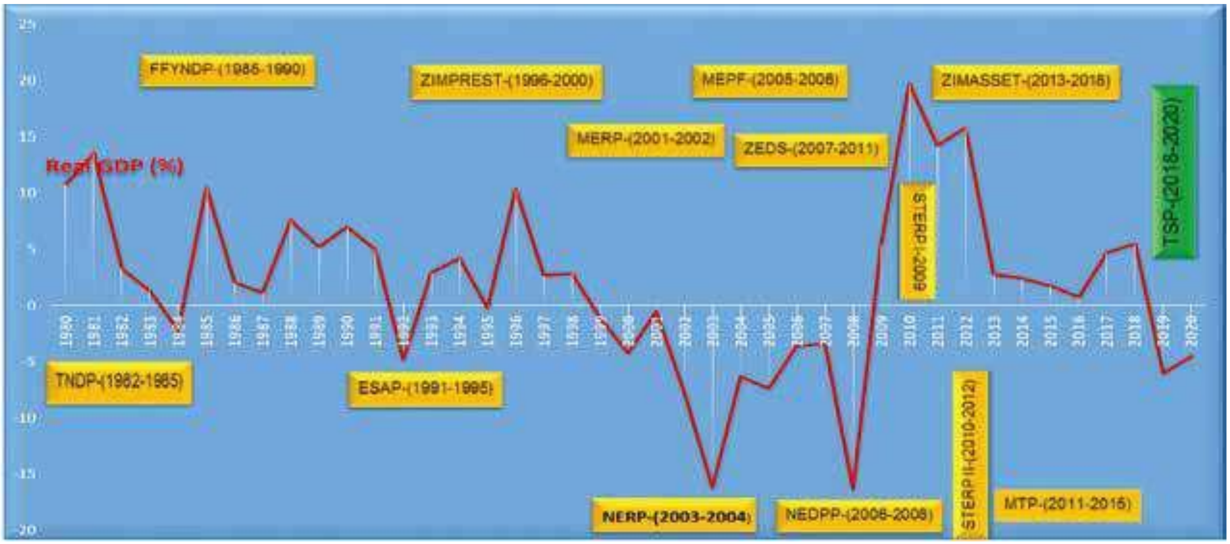
GDP growth (annual %)	-8.1 (2019)
Urbanisation Rate	32.21 (2019)
Total final Energy consumption GWh	8 631.81
Renewable energy consumption	87.19
Total electricity output	8 719
Access to electricity (% of rural population with access)	19
Access to electricity (% of urban population with access)	80
Access to electricity (% of total population)	40
Agriculture value added (%, of GDP)	8.3
Energy demand/consumption by agricultural sector	<250MW
Energy demand/consumption by industrial sector	>1300MW
Inflation, GDP deflator (annual %)	-4.0352
Agriculture, forestry, and fishing, industry services value added (% of GDP)	18.3 20.64 61.28
Industry (including construction), value added (% of GDP)	20.64

Table 42: 5 YEAR PLAN GDP PROJECTED GROWTH RATES

Year	**2020**	**2021**	**2022**	**2023**	**2024**	**2025**
Real GDP Growth %	-4.1	7.4	5.5	5.2	5.2	5.0
Average inflation %	654.9	134.8	28.7	10.5	7.5	5.8
%People in extreme poverty	38.9	24.5	19.2	15.4	12.3	10.1
Public Debt %GDP	78.4	64.5	64.8	64.5	63.6	61.5

*Budget presentation for 2021 by Minister of Finance & Economic Development in Nov-2020

Fig. 9.1 National Economic Blueprints & Real GDP Growth Rates: 1980-2020



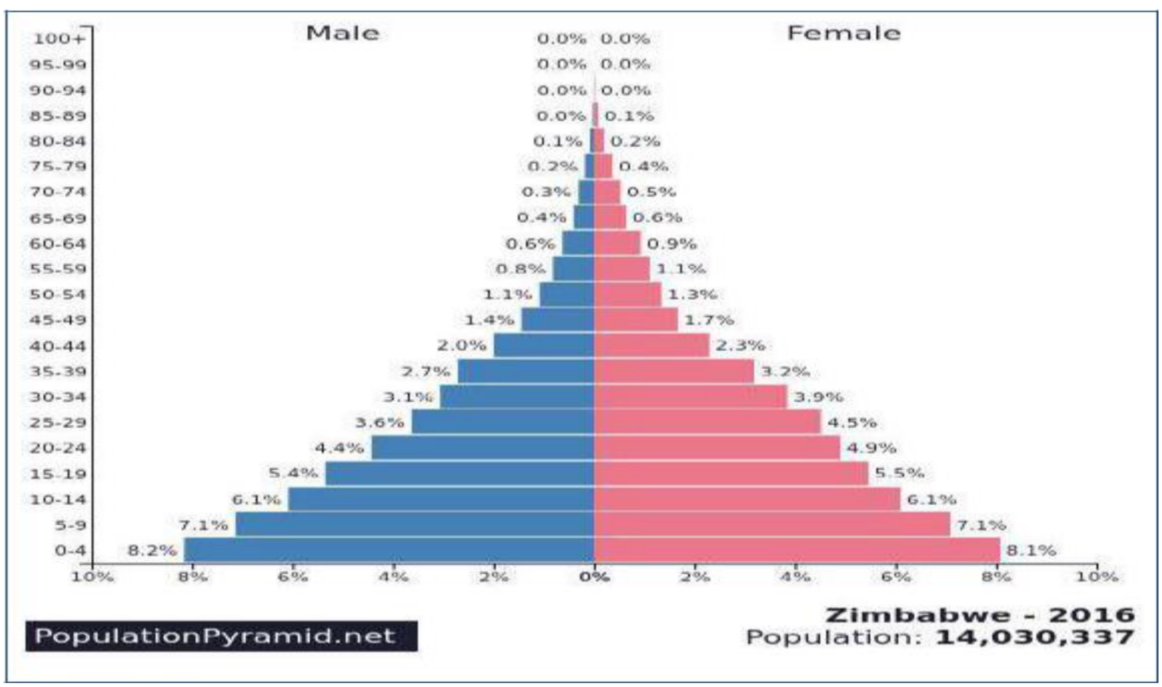
Exports of goods and services (% of GDP)	22.92 (2019); 19.0 (2018)
Imports of goods and services (% of GDP)	25.51 (2019); 31 (2018)
Revenue, excluding grants (% of GDP)	1.0976
Foreign direct investment, net inflows (BoP, current US$) (millions)	280
Government type	Republic with parliamentary democracy and presidential system.
Ease of doing business index	Table 43: Index Progression (below)

Table 43: Index Progression

YEAR	INDEX
2010	168
2011	171
2012	168
2013	170
2014	153
2015	157
2016	161
2017	159
2018	155

	2019 140
Adult (15+) literacy rate	0.96315GPI (2015)
Youth (15-24) literacy rate	1.0393GPI (2015)
Tertiary education gross enrolment ratio	0.83997%GPI (2016)
State expenditure ratio on education	5.8713%GDP (2018)
%Population under 24 years	62.9
%Population females under 24 years	31.7
Overall %population of females	52
%Females failing to proceed to secondary school	17.8
%Females failing to complete secondary school	30
%Primary schools practicing hot sitting	7.6
%Secondary schools practicing hot sitting	4.5
%Skills level availability	38
%Access to social care and support services	15
%Livelihoods support	3 (2020) to 17 (2025)
% Households supported	5 (2020) to 25 (2025)
%Households with livelihoods	2 (2020) to 15 (2025)

Fig 2.10 Zimbabwe Population Demographics



2.6 Conclusion

The analytical data captured here, is of paramount importance in that it serves as the foundation for investing into a well institutionalized socio-economic structure that has embraced to a certain extent the use and exploitation of renewable energy technologies. It is the experiences of this wide spectrum of independent power producers that gives an insight of the application of the various economic fundamentals in arriving at rationalized production costs. The nature of the population, literacy levels, demographic structure, energy resource base, licensed IPPs and those operationalized, renewable energy technologies acceptance levels, transport and communications infrastructure, land and water bodies, etc., all give rise to a high level of the cost-benefit analysis of making informed decisions. That can then build investor confidence and ease of doing business despite the overly institutionalized economic sanctions that are now currently and gradually being systemically reduced. The economic sanctions have played a significant role in the performance and operationalization of most of the registered and licensed IPPs. With these aspects we are now poised to look into some of the renewable energy technologies that the author participated in during implementation in-order to derive meaning of the challenges faced by IPPs and investors in cost build-ups to certainty of affordable tariff regimes that speak to Global Sustainable Goals. In the next chapter we review the legislative and regulatory framework of the renewable energy sector in Zimbabwe.

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CHAPTER THREE

EXECUTIVE REVIEW OF ENERGY POLICIES IN ZIMBABWE

3.0 Introduction

Zimbabwe currently has a national electrification rate of 42%. While electricity has reached 83% of the urban households, rural electrification is still around 13% as per the National Energy Policy of 2012.The country has an installed capacity of about 2300MW, with the Zimbabwe Power Company (ZPC), a power generation subsidiary of ZESA Holdings, owning around 95% of this. More than 50% of electricity is generated from hydropower whilst the remainder is from thermal power plants. Baggase, mini hydropower and small sized grid connected solar PV systems have an installed capacity of about 130MW. Against this background, the actual power generation capacity is about 1400MW against a peak demand of about 1700MW. The limited capacity is attributed to water availability issues, old equipment which needs rehabilitation and limited coal supplies.

The National Renewable Energy Policy (NREP) (2019) was developed under the overall framework laid out by the National Energy Policy of 2012. The policy also recognizes that an upper middle-income economy of 2030 needs to be driven by clean, sustainable energy sources. Apart from improving the share of renewable energy in the overall energy mix and addressing issues of Climate Change, this policy also focuses on driving cost-effective implementation of sustainable energy sources, social upliftment through community involvement, gender equality and employment generation as laid out in other various government acts and policies.

3.1 The basis of the renewable energy policy and regulation in Zimbabwe.

Renewable energy policy and regulation is set out in the National Energy Policy, 2012 (NEP) and the National Renewable Energy Policy, 2019 (NREP). The NEP recognized the importance of developing a comprehensive renewable energy policy in order to enhance the contribution of renewable energy to the overall energy supply in Zimbabwe. The NREP sets out in detail the ambitious targets of the government in the development of renewable energy and its contribution to the overall electricity supply in Zimbabwe. The NREP defines "renewable energy" as referring to "small hydro (equal to or less than 30MW), solar, wind, geothermal, biofuels and biomass and other such clean energy sources approved by the Ministry of Energy and Power Development (MoEPD)". The definition leaves room for the MoEPD to designate other energy sources as renewable energy at a future date. The Zimbabwe Energy Regulatory Authority Act (Chapter 13:23) (ZERA Act), which establishes the Zimbabwe Energy Regulatory Authority (ZERA), has a statutory definition of renewable energy. Renewable energy is defined in the ZERA Act as "energy generated from natural resources such as sunlight, wind, rain, water, tides, geothermal heat, plants and biomass which are naturally replenished, and "renewable energy source" shall be construed accordingly". The definition is comprehensive and seeks to identify renewable energy by having reference to the nature of its sources and the key characteristic of it being capable of replenishment. This naturally excludes from its scope energy derived from coal, for instance.

There are other regulations that have their own variant of what renewable energy is. For instance, the Electricity Solar Water Heating Regulations, 2019 (SI 235 of 2019) defines renewable energy as “all non-fossil sources including, biomass, geothermal, small hydro power, solar, wind, sewage treatment and plant gas”. There is no doubt that the various definitions all have common elements; namely, that the source of the energy is such that it cannot be depleted through use and is an alternative to the fossil fuel-based energy forms.

3.2 The main actors in the renewable energy sector.

The major actors are MoEPD, ZERA, the public utility Zimbabwe Power Company (ZPC), Zimbabwe Electricity Transmission and Distribution Company (Private) Limited (ZETDC), a number of Independent Power Producers (IPPs), Zimbabwe National Water Authority (ZINWA), and the Zambezi River Authority (ZRA). The MOEPD has overall responsibility for the energy sector in Zimbabwe. It is responsible for policy formulation and implementation, an oversight role over the government-owned utilities (ZETDC and ZPC), ZRA jointly with Zambia and the activities of ZERA. It is also responsible for regional and international cooperation on renewable energy issues. ZETDC and ZPC are subsidiaries of ZESA Holdings (Private) Limited (ZESA), which in turn is 100% owned by government. ZPC owns the electricity generation assets and is responsible for electricity generation. It also owns the Kariba Hydro-power stations, which presently generates approximately 20% of its installed capacity of 1050MW due to the persistent El Nino drought that has hit the SADC community of states. ZETDC is the utility that owns the transmission, distribution and net metering infrastructure in Zimbabwe. All hybrid renewable energy systems access off-takers through ZETDC. ZRA is the authority jointly set up by Zambia and Zimbabwe to manage the Kariba Dam water along the Zambezi River. It determines how much water can flow on either side of the power generating plants managed by ZPC and ZESCO. Meanwhile, ZINWA regulates all inland water bodies in Zimbabwe.

Several licensed IPPs are also playing a sizeable electricity generation role in the renewable energy space. They are either generating for self-use or for evacuation into the national grid through ZETDC. It is anticipated in the NREP that the IPPs will play a significant role in achieving the ambitious targets set for renewable energy.

The Rural Electrification Fund (REF) was established in terms of the Rural Electrification Fund Act (Chapter 13:20). The Rural Electrification Agency (REA) was established under this Act. Among other things, REA is responsible for ensuring that rural areas, with an electricity penetration rate of *circa* 13%, have access to electricity, especially through the deployment of off-grid solar solutions. REA is also responsible for developing the grid infrastructure in rural areas to ensure that electricity reaches even the most remote parts of the country.

Other significant players in the renewable energy sector are the Environmental Management Agency (EMA), established in terms of the Environmental Management Act (Chapter 20:27) (EMA Act) and the Standards Association of Zimbabwe (SAZ), who manage and facilitate in the development of national standards for renewable energy infrastructure component development using international best practices. Their roles are complimentary in ensuring that renewable energy projects, among other responsibilities, are carried out in a manner that ensures that the environment is protected and any other adverse effects on the environment are kept in check.

3.3 The role of government in the renewable energy sector.

The government, through the MoEPD, is responsible for policy formulation and ensuring that the policy is implemented by the organizations involved. The government is also responsible for ensuring that the necessary legislation enacted to give effect to the policies is put in place. As part of its policy formulation role, the government formulated the NEP in 2012 and then the NREP and NBP in 2019. The NREP and NBP took into account other policy measures and commitments of the government to the international community on the need to reduce greenhouse gases. Both the NREP and NBP were based on the Nationally Determined Contributions (NDCs) interventions that the government committed itself to and submitted to the United Nations Framework Convention on Climate Change (UNFCCC). The NDCs recognized the energy sector as a major greenhouse gas contributor, hence the need to develop policies that ensure that the energy sector reduces its greenhouse gas emissions by focusing on renewable energy and associated activities.

The NREP set the target of achieving an installed renewable capacity of 1,100MW, or 16.5% of the overall electricity supply in Zimbabwe, whichever is greater, by 2025. By 2030, the target is that the installed renewable energy capacity should be 2,100MW or 26.5% of the overall electricity supply. These targets exclude the large hydropower stations of more than 30MW. As indicated above, the NREP includes small hydropower stations of less than 30MW in the definition of renewables. Accordingly, any hydropower project that is more than 30MW will not be considered in determining whether the targets have been met. Most of the generation capacity to achieve these targets will therefore be anticipated to come from the IPPs. There is nothing, however, that stops ZPC from establishing its own renewable energy plants.

The NREP also aims to have installed 250,000 solar geysers by the year 2030 in new and old buildings, to increase the use of institutional and domestic biogas digesters, to deploy the use of solar mini-grids, off-grid solar solutions and solar water pumping solutions, and generally to increase the use of renewable technologies. The policy aim is to increase the electricity penetration rates in both rural and urban areas.

The government has also undertaken to increase the purchase of renewable energy-generated electricity by government-owned utilities in order to encourage further investments.

Investment incentives are also promised to investors in renewable energy to ensure that investment in renewable energy is profitable in order to attract more funding.

3.4 The market for renewable energy.

At present, the major hydropower station at Kariba Dam in Zimbabwe, which is owned by ZPC, supplies just over 20% of its total installed capacity of 1050MW. Its output has been affected by weather patterns. A poor rain season has the potential of reducing the power generated from it.

IPPs occupy the remainder of the renewable energy market. The combined output from the IPPs is, at present, only 130MW. These IPPs include Kupinga Renewable Energy, Guruve Solar Park (1.2MW), Solgas (Solar-5MW), Green Fuel (bagasse), Distributed Power Africa (solar), Centragrid (solar) and UK-based PGI Group Limited renewable energy projects run by Nyangani Renewable Energy (Private) Limited, which include Riverside Solar Power Station (Pvt) Ltd (2.5MW) (solar), Nyamingura Mini Hydro Station (1.1MW) (hydro), Dura Power Station (2.2MW) (hydro), Pungwe A Power Station (2.725MW) (hydro), Pungwe B Power Station (15MW) (hydro), Pungwe C Power Station (3.75MW) (hydro) and Hauna Power Station (2.3MW) (hydro). There are other companies that produce power mainly for their own consumption. These include Caledonia Mining (17.5MW), Nottingham Estate (1.5MW), Hippo Valley Estates (33MW) (bagasse), Triangle Estates (45MW) (bagasse) and Border Timbers (wood waste). There is also a trend for most mining companies to default to solar energy sources by constructing their own off-grid solar plants. This has been necessitated by the need to bridge the gap between their power needs and the supply from ZETDC.

The Electricity Act regulates the sale of power in Zimbabwe. The power is sold to ZETDC. A generator of renewable power would negotiate a PPA with ZETDC in advance of the construction of the generation facility. The PPA would then be approved by ZERA, provided its terms and the agreed tariff meets the requirements of ZERA. Generally, ZERA would be looking at ensuring that the generator receives a reasonable return on investment and ZETDC receives the power at a tariff that would ensure that it can be sold to the consumer at a reasonable tariff.

Meanwhile, the Electricity Act and the Electricity Licensing Regulations constitute the legal and regulatory framework for distributed/C&I renewable energy. The developer would be required to apply for the generation license and will typically be issued with a generation license for captive consumption of a particular buyer. The practice, however, is to have an open license that permits the developer to sell to more than one customer and to sell the excess power to the power utility. The same process of applying for the license as applies in non-distributed/C&I renewable energy would also apply. ZERA retains the power and authority to approve the prices at which the energy is sold.

However, there are no specific financial or regulatory incentives targeted at distributed/C&I investment. There is a power deficit in the market. The drive towards distributed/C&I is motivated by the need for corporate and industrial companies for guaranteed power and to plug the supply gap from the power utility. The importation of the equipment enjoys the same incentives as other imported equipment, particularly for solar power.

On the other hand, the government introduced mandatory carbon trading legislation for the first time on Friday the 18th of August 2023. The promulgated legislative instrument is identified as the Carbon Credits Trading (General) Regulations, 2023. Statutory Instrument 150 of 2023 provides the legal and regulatory framework for the control and management of carbon trading projects. It requires that any person desiring to engage in the voluntary carbon credit trading market, the Cooperative Approaches under Article 6.2 of the Paris Agreement or Article 6.4 Mechanism should apply for approval of the project. The project must meet the specified guidelines, which includes the requirement for the project to abate greenhouse emissions. Once the project is approved, the project proponent may undertake the project in the selected community.

3.5 The main drivers of the renewable energy transition in Zimbabwe.

The energy transition from fossil-based fuels is the major driver of the need to reduce carbon emissions in the government's commitment to policy changes in the energy sector. The government of Zimbabwe's NDCs submitted to the UNFCCC recognize the commitment to the decarbonization of the energy sector. The commitment of the government as set out in both the NREP and NBP, is to encourage investments in renewable energy, provide incentives to the investors, encourage the public utility to support the initiatives by procuring power from renewables, give priority dispatch from renewable energy generators and support off-grid renewable energy projects in rural areas. While the commitment expressed in the NREP has ambitious targets of getting at least 16.5% of all electricity supplied from renewables by 2025 and 26.5% by 2030, the actual investment is expected to be driven by the private sector. Faced with acute power shortages, the government encouraged the use of solar technologies and removed import duties on solar products.

The government at present has limited resources and it is unlikely to invest on its own. It is hoped, however, that sufficient incentives will be put in place in order to make it worthwhile for private investors to put money into such projects. It is also expected that as and when the Batoka hydrological project is commissioned, an additional 800MW of power will be added to the national grid and will provide an incentive to the retirement of the old 1 to 5 coal-fired power plants at Hwange. However, new 600MW of coal fired 6 and 7 power plants were recently commissioned at Hwange and were funded by a bank of China.

3.6 Civil society role in the promotion of renewable energy acceptance.

Civil society organizations have played a part in promoting the renewable energy agenda. Organizations involved in the protection of the environment and the climate change agenda have been at the forefront of pushing for the adoption of renewable energy. The message became easy to promote in the face of acute power shortages, as most businesses and households were forced to adopt alternative technologies as a way of accessing energy.

3.7 The legal and regulatory framework for the generation, transmission and distribution of renewable energy.

The legal and regulatory framework for the generation, transmission and distribution of energy has not yet been made specific to renewable energy. The process of acquiring the generation license is still largely the same as that for fossil fuel-based energy generators. The principal law governing the construction and operation of generation facilities is section 42 of the Electricity Act (Chapter 13:19), as well as the Electricity Licensing Regulations, 2008 as amended by SI 55/2015 and SI 101/2021.

Under section 42(1) of the Electricity Act, a generation license authorizes the licensee to construct, own, operate and maintain a generation station for the purposes of the generation and supply of electricity, subject to any terms and conditions imposed by ZERA and without contravention of the other provisions in the Electricity Act.

In terms of section 42(2) of the Electricity Act, the holder of a generation license may supply electricity to any transmission, distribution or supply licensee who purchases electricity for resale and, with the approval of the Commission, to any one or more consumers, subject to the terms and conditions imposed by ZERA and without prejudice to any other provisions in the Electricity Act.

In terms of section 11 of the Licensing Regulations, anyone who operates an electric generator (including stand-alone generators) that is capable of generating, distributing or transmitting in excess of 100kW must obtain a license under section 40 of the Electricity Act, unless they can demonstrate to ZERA that the generator in question is for the sole use of their household or business. The notification must occur within 60 days of acquiring the generator. ZERA may order and conduct an inspection and, if it determines that the generator is for personal use, will issue an indefinite permit with conditions to comply with public safety standards and to permit further inspection by ZERA.

The principal laws are as follows:

- the Electricity Act (Chapter 13:19);
- the ZERA Act;
- the Electricity Licensing Regulations; and
- the SI 55 of 2015 Electricity Licensing Regulations Amendment.

The Electricity (Net Metering) Regulations, 2018 permit consumers with excess power generated from renewable energy to feed in the excess power into the grid. The excess power will then be set-off against the power consumed by the customer from the utility during the period when the customer's power generation is below its demand.

3.8 The main challenges that affect investment in developing renewable energy projects.

The major challenges in investing in renewable energy have been the lack of clear and coherent policies that necessarily should encourage investments in Zimbabwe. Investments in generation plants are long-term decisions and require policies that guarantee to the investors that their investments are secure and that the utilities will honor their obligations, and if that fails, then the government will have to issue guarantees. This has been lacking in Zimbabwe. The government itself has defaulted on many of its obligations to international institutions, which has meant that there is no comfort in any such guarantees. Zimbabwe is generally regarded as a high-risk investment destination. This has also meant that borrowing for projects in Zimbabwe will command a high premium for those investors willing to take the risk. This has meant that many of the licensed IPPs have not been able to attract investors for their projects. The never-ending changes in the policies, particularly relating to exchange control, have made it difficult for investors to keep pace and develop proper models for funding. Many IPPs are now threatened with cancellation of their licenses as the investment climate continually changes, and parties are forced to go back to the drawing board to restructure their plans in the face of policy changes.

Another major limitation is the acute shortage of foreign currency in Zimbabwe. There is no guarantee for most investors that they will be able to repatriate their profits and capital from

Zimbabwe due to foreign currency shortages. The policy inconsistencies in this area have also meant that it is impossible to plan with any degree of certainty.

While limited funding could be sourced from local funders such as pension funds, the failure to convert such funding into foreign currency to import much of the equipment required has resulted in this not being a viable option. The NREP proposes a number of schemes aimed at granting Prescribed Asset Status to qualifying projects to enable pension funds and insurance companies to invest in such projects.

In February 2023, the government announced the introduction of Government Implementation Agreements for IPPs that would have passed the screening stage. This is meant to ensure that IPPs are guaranteed economic tariffs, have foreign currency convertibility and transferability and that government guarantees on the investment. In that regard, the ZIDA Act offers guarantees and assurances that, in respect of all investments for which licenses have been secured under the Act, the investors may, without restriction or delay in freely convertible currency, transfer funds into and out of Zimbabwe in respect of contributions to capital, such as:

- principal and additional funds to maintain, develop or increase the investment;
- proceeds, profits from the asset, dividends, royalties, patent fees, license fees, technical assistance and management fees, shares and other current income resulting from any investment under this Act;
- proceeds from the sale or liquidation of the whole or part of an investment or property owned by an investment;
- payments made under a contract entered into by the investor or investment, including payments made pursuant to a loan agreement;
- payments resulting from any settlement of investment disputes pursuant; and
- earnings and other remuneration of foreign personnel legally employed in Zimbabwe in connection with an investment subject to any laws in force at the time.

In cases of serious balance-of-payments or external financial difficulties, the government may temporarily restrict payments or transfers related to investments, provided that such restrictions are imposed on a non-discriminatory and good faith basis.

However, utility-scale projects are generally accorded National Project Status, which will enable them to import much of the equipment duty-free. Once such a project is granted National Project Status, import duties on the capital goods would be waived in terms of sections 140 and 141 of the Customs and Excise (General) Regulations. It would also be possible to negotiate specific waivers of certain taxes and other government levies.

Due to high duties, an exemption from the payment of the duties can make a huge difference to the profitability of a project. Power generation projects are also exempted from income tax for the first five years of commencing their operations. The income would be taxable at a lower rate of 15% for the next five years thereafter, compared to the general tax rate of other companies at 25%. In addition, the government announced the introduction of Government Implementation Agreements for IPPs that would have passed the screening stage.

3.9 The tender processes of large-scale renewable power projects.

The present regulatory environment does not have specific tendering procedures for energy projects. What has typically been happening is that an entity, after being issued with a generation license, will approach ZETDC to negotiate for a Power Purchase Agreement (PPA). Due to shortages of power, ZETDC has invariably accommodated such unsolicited offers. Tendering has, however, been undertaken for contracts to construct the power plants for ZPC as the power generation unit of ZESA.

The Public Procurement and Disposal of Public Assets Act (Chapter 22:23) (PPDPA Act) regulates the tendering process in Zimbabwe. The utility concerned, through its procurement unit, would prepare the tender documents and invite bids. After the bids are received and adjudicated, the successful bidder would be announced. The unsuccessful bidders are given the right to challenge such awards in the event that it is believed that the process was not carried out properly.

3.10 The primary consents and permits for developing a renewable power project.

The licensing process required for renewables in order for one to construct, commission and operate utility-scale renewable energy facilities is similar to the process for non-renewables, with minor variations in relation to the specific requirements for the energy type proposed. Essentially, one must obtain a generation license issued by ZERA in terms of section 42 of the Electricity Act as read together with the ZERA Act and the Electricity Licensing Regulations. In order for ZERA to consider the application for a generation license, one would need to also have satisfied other requirements. These include the requirements of the EMA Act by securing the Environmental Impact Assessment Certificate; a Grid Impact Assessment Study would need to have been commissioned providing details of the connection that can be permitted to the national grid; land lease/ownership or land use permit; and water extraction permit. The permitting regime is the same for all types of renewable energy facilities.

Invariably, distributed/C&I renewable energy facilities also require the same consents and permits as utility-scale renewable facilities. One requires a generation license issued by ZERA. In terms of section 40 of the Electricity Act as read together with section 11 of the Licensing Regulations, anyone who operates an electric generator (including standalone generators) that is capable of generating, distributing or transmitting in excess of 100kW must obtain a license under section 40 of the Electricity Act. The practice is to acquire the license in the name of the C&I entity while a third party provides the funding to set up the facility.

Since ZETDC currently owns and controls the national transmission network. Any generation facility intending to connect to the network would be required to first commission ZETDC to undertake a Grid Impact Assessment Study that will determine the impact of the intended connection to the national grid and what can be done to ensure the continued integrity of the national network. ZETDC determines the maximum power connection that it can offer from a particular location and may determine that the generator must construct a transmission line to the nearest connection point that may offer a stable connection as required in terms of the Grid Code, 2017. Once the connection parameters are agreed upon, the generator and ZETDC will then sign a Transmission Connection Agreement.

On the other hand, most of the equipment and materials for developing renewable energy projects are imported into Zimbabwe. Hence, they are required to comply with the national standards. For this purpose, goods and materials with a value of more than USD1,000 are required to be subjected to a pre-shipment conformity assessment and to be issued with a Certificate of Conformity in terms of the Control of Goods Act Open General Import License (Standards Assessment) Notice, 2015 (SI 132 of 2015). If the pre-shipment is not carried out in the country of origin, it will be subject to such assessment prior to customs clearance at the port of entry and will be subject to a penalty equivalent to 15% of the cost, insurance and freight (CIF) value of the goods. The Minister of Industry and Commerce may, on application, grant an exemption.

In terms of human capital resources for developing the project, the ZIDA Act permits an investor to appoint, regardless of their nationality, any qualified individual as a senior manager, technical and operational expert or advisor with respect to the investment in accordance with the laws of Zimbabwe. Work permits would be required for such employees. Outside of the employees permitted in terms of the ZIDA Act, work permits are issued on the basis that the skills or expertise possessed by the person being employed are not available in Zimbabwe. There are certain fields that may have additional requirements in the field. One such example is the Engineering Council Act (Chapter 27:22). Furthermore, the by-laws prescribe that locals must be involved in the project as a condition of the issuance of the registration and the practitioners' certificate to the foreign firm. This would therefore affect engineers involved in an Engineering, Procurement, and Construction (EPC) capacity. The Engineering Council would need to be satisfied that the skills being brought in are not available in Zimbabwe.

3.11 Conclusion

The regulatory and legislative framework of Zimbabwe in the Renewable Energy sector is intertwined with other peripheral policies within the general context of doing business. The two policies, namely the National Renewable Energy Policy (NREP) and the National Biofuels Policy (NBP) firmly confirm the high acceptance level of commitment by the government of Zimbabwe to the exploitation of renewable energy resources. However, the policies tend to speak more to solar PV, the production of biodiesel and ethanol, which have been the most popularized renewable energy technologies. However, all other technologies are implied through these policies. Whenever the need arises for addendums and adjustments the government often addresses these through the promulgation of statutory instruments. Land and water availability and eligibility depends on a number of factors that tend to affect the appropriate technology to be implemented given that these two resources are not directly managed by the relevant parent ministry that deals with energy and power development. On the other hand, government has facilitated this nugget through in some instances the awarding of National Project Status that then alleviates the challenges. The next chapter looks at Green Hydrogen which is not directly addressed in the policies, but its implementation by the author in collaboration with others in Zimbabwe commenced with the development of a Green H_2 Atlas, a process which was co-funded by Julich and the Ministry of Federal Education in Germany and was facilitated by the Southern African Science Service Center for Climate Change & Adaptive Land Management (SASSCAL) based in Namibia. The Green H_2 Atlas was published in April of 2023 and is now available on internet.

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CHAPTER FOUR

GREEN HYDROGEN

4.0 Introduction

This project proposal was part of the implementation of the Green H_2 Atlas carried out in Zimbabwe by me with the help of other Team Experts who are identifiable in the chapter in context of their participatory role in achieving the set goals. The intention for doing this project was as part of the renewable energy mix in understanding the cost production ingredients that influence the ultimate tariff to off-takers in Zimbabwe. It is of prime importance to note that the first stage of establishing the Green H_2 Atlas for Zimbabwe was successfully done through funding advanced by Julich & the Ministry of Federal Education in Germany. Hence, the Southern African Science Service Center for Climate Change & Adaptive Land Management (SASSCAL) based in Namibia facilitated in the provision of this funding.

Title	Green Ammonia Production in SADC (Zimbabwe)
SASSCAL Team	Dr. Jane Olwoch
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Required funding	Zimbabwe: USD85,123,845
Project duration **Proposed starting date**	4 Years 09.01.2023

4.1 Project brief

The need for increased production of ammonia and consequently nitrogen-based fertilizer has never been more topical than it is today. Fertilizer ensures food security and thus answering to the energy-water-food nexus discourse. Currently, the Russia-Ukraine conflict has affected the food supply chain as the two countries are leading exporters of important agricultural products such as wheat, barley and sunflower seeds. The conflict has exposed the world and prices of particularly cooking oil have shot up. It is no surprise that the two countries are leading producers of fertilizers as well. In order for the rest of the world to be independent, the production of fertilizer is the first step towards food security. The production of ammonia however contributes 1% of all the greenhouse gases that cause global warming that lead to climate change. As new ammonium nitrate fertilizer plants go up it is imperative that they be decarbonized so that nations such as Zimbabwe can manage to achieve their NDCs to global decarbonization. Against this background, a proposal is presented here for the production of ammonium nitrate fertilizer from ammonia at pilot scale that achieves zero carbon emissions. It is proposed that ammonia be produced from hydrogen produced from the electrolysis of water powered by electricity produced by solar PV power plant. In a similar manner nitrogen shall be produced from air separation. The hydrogen produced is further used in the production of ammonia and in a fuel cell responsible for producing electricity that powers the other unit processes in the plant up to the production of ammonium nitrate plant. It is forecasted that building the pilot plant will cost USD85.2 million over a period of four years.

4.2 Scientific Reference

Green ammonia is the term that refers to ammonia that is produced and associated with zero carbon footprint. The unit processes involved in the production are all powered by electricity produced from renewable sources, thus making the entire ammonia manufacturing process carbon-free (Royal Society). Green ammonia production consists of two major plants, namely, the power generation plant and the chemical production plant. Firstly, electricity is produced from the power plant from renewable sources such as solar as in the case of Zimbabwe, since wind potential is low. Figure 4.1 shows the proposed process flow schematic diagram. The process plant is an ammonia and ammonium nitrate fertilizer-producing plant.

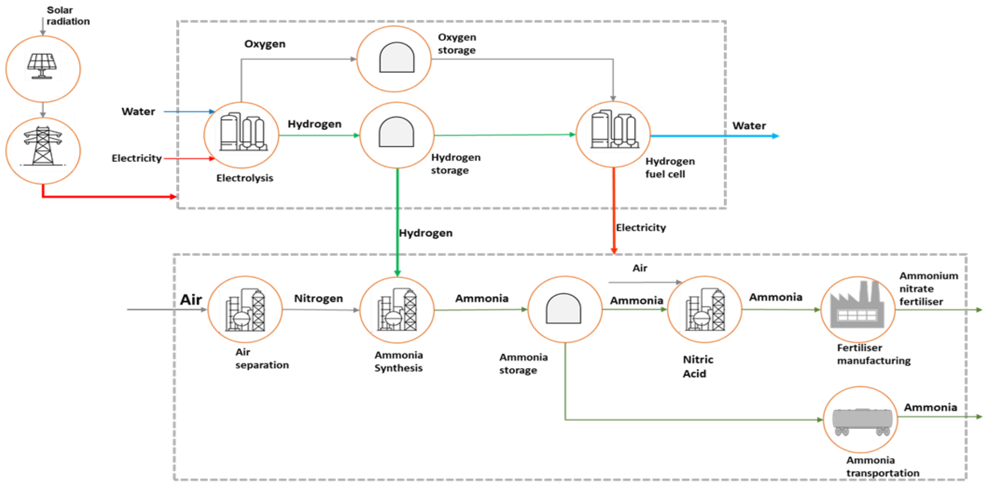


Fig. 4.1 Schematic process flow diagram of green ammonia.

The process plant would initially include a renewable source such as solar, wind or hydroelectric. In the case of Zimbabwe, it is considered that a solar power plant would suffice given the high solar radiation received at the proposed location. The solar power plant would need battery storage as back up to address intermittence. Hydrogen will be produced in the electrolysis plant through the electrolysis of water. Water is split into its constituents i.e. hydrogen and oxygen using electrical energy. Alkaline Water Electrolysis is the more mature technology and is proposed in this process flow sheet. The feasible location for the plant is therefore close to a source of water. The produced hydrogen and oxygen is then stored. (Brauns and Turek, 2020).

Hydrogen and oxygen from the storage vessels is then sent to the hydrogen fuel cell plant where they are both used to produce water and electricity. The proposed fuel cell in this study is the solid oxide fuel cell since it is suitable for large electricity utility application (Cigolotti et al., 2021). The electricity produced by the fuel cell is used to power the other process units of the pilot.

Ammonia production also includes an air separation plant. Air is comprised of 70% nitrogen, and thus, it is also a natural source of nitrogen. Air is separated through cooling. The Air separation to produce highly pure nitrogen involves several steps. Firstly, the air is pumped and passed through a filter to remove dust. It is then cooled and purified to remove dust and other soluble impurities such as carbon dioxide and is further cooled in a different cooling heat exchanger (refrigeration) and then the products are separated in liquid /vapor separators and finally warmed by the heat exchangers (Stamicarbon, 2022).

The hydrogen gas produced at the electrolysis plant is combined with the nitrogen produced at the air separation plant and supplied to the ammonia production plant. The gasses react in the presence of an iron catalyst in the reactor to form ammonia. The ammonia is then sent to the ammonia storage spheres. Nitric acid is produced from the oxidation of ammonia. Ammonia is vaporized and heated and then combined with air. The mixture is sent to a converter basket where the reactants react to give nitric oxide, which in turn converts to nitrogen dioxide. The nitrogen oxides are absorbed by pure water in an absorption column to produce nitric acid. The nitric acid is stored in stainless steel vessels (Starmicarbon, 2022).

Ammonium nitrate solution is produced by neutralizing ammonia with nitric acid. The solution is concentrated through evaporation. Drying and granulation follow if solid fertilizers are required. In detail, the production of ammonium nitrate involves four steps. Evaporation technology is used to increase the concentration of the solution to 99%. Firstly, nitric acid is made to react with ammonia, resulting in an 83% ammonium nitrate solution. The solution is passed through spraying to transform the solution into pills or granules. These granules are passed through sieving for size control. The granules that do not meet the size requirements are fed back into the system for further processing. The granules are sent for bagging and storage before shipping.

4.3 Work schedule 1

Responsible Person:

Dr. Chipo Shoniwa

(BUSE)

Activities:

Figure 2 shows the project design. The activities to be done are listed below:

1. Prefeasibility.

   This includes developing the project business plan involving site selection, budget, time scheduling and a draft design. Environmental impact assessment, stakeholder engagement and risk analysis will be done.

2. Feasibility study.

   The project logistics and tendering and contracting strategies will be developed. A detailed business plan will be developed.

3. Permitting Process.

   Before the project rolls on, a land use permit, water extraction permit and the energy generation permit needs to be obtained.

4. Project implementation.

This involves work package 3 to 9 following after permit is granted.

- Work package 3: Hydrogen (H2) production Plant and Ammonia (NH3) Plant.
- Work package 4: Ammonium Nitrate (NH4NO3) Plant.
- Work package 5: Project Management.
- Work package 6: Capacity Building.
- Work package 7: Policy & Institutional Framework.
- Work package 8: Dissemination & Communication.
- Work package 9: Green Ammonia Uptake (Local & International).

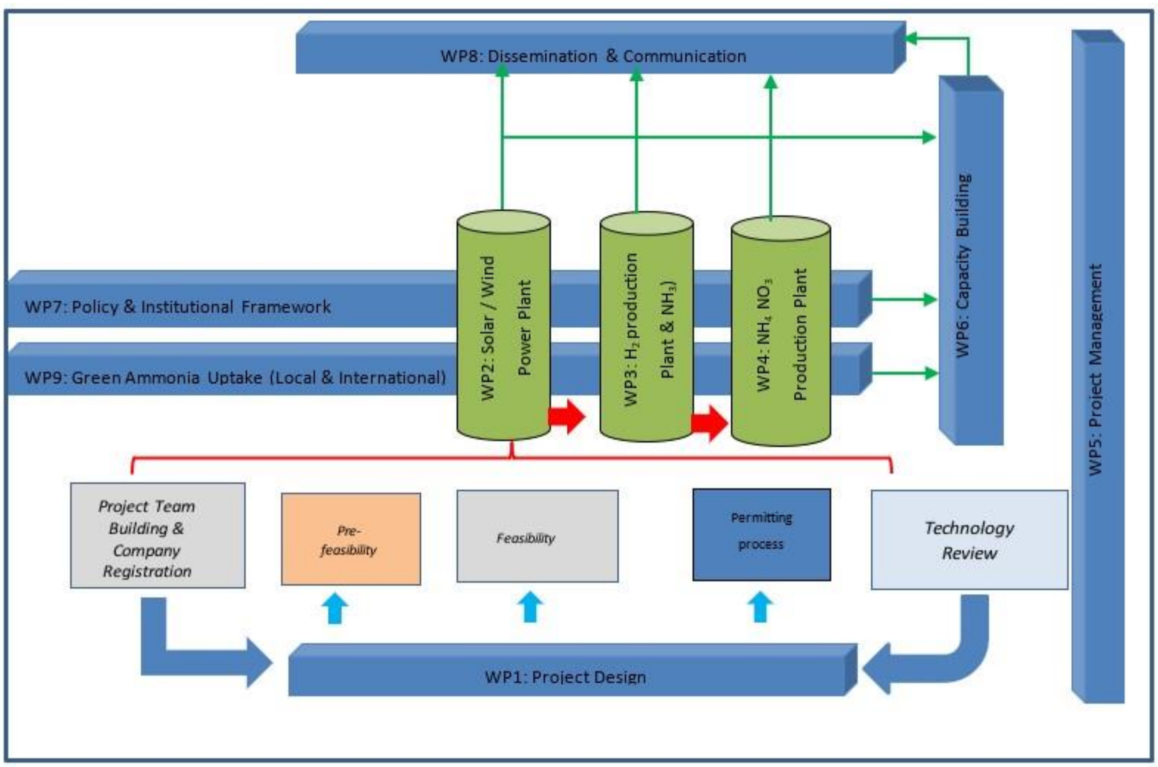


Fig. 4.2 Project Design

4.4 Work Schedule 2	Solar PV Power Plant
Name of Responsible person: Engineer Tobias Mudzingwa (ZERA)	

Activities:

To develop a 10 MW solar PV power plant to power an electrolyser that produces 1,166 tons/year of hydrogen. Such a solar PV power plant requires about 20 ha of land to accommodate the power generation plant only. More land is required however to accommodate the other plants such as the ammonia production, hydrogen storage, hydrogen fuel cell plant and fertilizer production plant. The plant is to be located at a site close to a water body such as a river or a reservoir. The estimated cost to install the solar PV plant is estimated to be USD16.35 million assuming a capital investment cost of USD1.64/MW. The capacity factor of the solar PV plant is assumed to be 20% as benchmarked with other existing solar PV power plants in Zimbabwe.

Solar PV power plants are most preferred over wind as Zimbabwe has abundant solar resources. Solar PV- irradiation averaging 20 MJ per square meter and 3,000 hours of sunshine per year. The estimated installed capacity potential for the country is 109 GW. The wind resource potential for Zimbabwe is estimated to be 39.3 GW. However, this resource is more specific than the solar PV resource. Wind power projects can only be considered on sites with wind energy resources i.e. with a minimum wind power density of 200 W/m^2.

The pilot project of the 10 MW solar PV plant is required by the Electricity Act to have a generation license which is issued by ZERA as it exceeds the licensing threshold of 100 kW. A license application fee of US$ 2,500 is required as shown in Figure 4.3. It is important to note that this project qualifies to be exempted from the licensing fees as it is deemed to be non-commercial as well as a pilot project.

. RENEWABLE ENERGY POWER PLANTS

Fee description	US$
Generation Licence Application fee Green Field Brown Field	 2 500 2 000
Generation Licence fee	
Projects for own consumption	No licence fees
Commercial Projects	

Technology	Capacity			
		Capacity (Above 100kW and up to 10 MW)	Capacity above 10 MW	
		Fixed	Fixed	Variable per 25 MW
Solar PV	0.23	2 875	5 750	2 875
Biomass	0.6	7 500	15 000	7 500
Small Hydro	0.55	6 875	13 750	6 875
Geothermal	0.72	9 000.	18 000	9 000
Wind	0.3	3 750	7 500	3 750

Fig. 4.3 ZERA Licensing Fees (as extracted from SI 92 of 2021)

The Following General Requirements are required on application:

a) ZERA Application Form

b) Business Plan.

c) Certificate of Incorporation.

d) Memorandum and Articles of Association.

e) Company registration documents – CR5, CR6, CR11, Share Certificates, Share Transfer Instruments, Register of Shareholders.

f) Shareholding Structure, Of Shareholders and Shareholders' Agreement.

g) Board Profile including nationality, qualifications and experience of Directors.

a) Proof of Financial capability (Equity, Debt Financing/loan/grant/etc) in the form of Irrevocable financing commitments or agreements with both equity and loan providers.

h) Audited Financial Statements for past three years (if any).

i) Zimbabwe Investment and Development Agency license (where applicable).

j) Zimbabwe Revenue Authority Tax Clearance Certificate for the current year.

k) Technical capacity to carry out the project in the form of a Memorandum of Understanding or Letter of Intent from a credible technical organization.

l) Proof of payment of license application fee.

The Generation License Requirements are as follows:

a) Generation Capacity.

b) Buyer/Off-taker arrangements.

c) Electricity Generation Cost.

d) Zimbabwe Electricity Transmission and Distribution Company Grid Impact Assessment.

e) Fuel Supply Arrangement(s)/Agreement(s) (where applicable).

f) Proposed Power Purchase Agreement.

g) Proposed interconnections point to the transmission system.

h) Prefeasibility study report.

i) Memorandum of Understanding with or Letter of Intent from Engineering Procurement Contract (EPC) Contractor.

j) Maps indicating the location of the generating plant.

k) Land Use Permit.

l) Water Extraction Permit (where applicable).

m) ZIA Investment and Development Agency endorsement (where applicable).

n) Environmental Impact Assessment (EIA) Prospectus.

o) Project Timeline /Gantt Chart/Implementation Schedule.

The project licensing preparatory costs are estimated to be USD 103,500.00 as indicated in the Table 4.1.

Table 4.1 Project licensing preparatory costs.

	Activity	**Estimate Cost (USD)**
1	ZERA Generation License Application	2,500.00
2	Environmental Impact Assessment Prospectus	1,500.00
3	Environmental Impact Assessment Certificate (0.8% of total project cost)	60,000.00
4	Full Feasibility Study Report	5,000.00
5	ZETDC Grid Impact Assessment Study	6,000.00
6	Land lease permit/Agreement	10,000.00
7	Water extraction permit	5,000.00
	Sub-total	**90,000.00**
	Contingency @ 15%	13,500.00
	TOTAL	**103,500.00**

On the other note, the project may be exempted from licensing fees as the project stands to be a national Green Hydrogen and Ammonia pilot project supported by the Government of Zimbabwe. The Government through the Ministry of Energy and Power Development and Zimbabwe Energy Regulatory Authority (ZERA) strongly supports this initiative.

4.5 Work Schedule 3	Hydrogen (H2) production Plant and Ammonia (NH3) Plant

Name of Responsible person: Eng. Charles Kanyunga

Activities:

The determination of;

1. The operating characteristics of the electrolyser;
2. The capital and operating costs;
3. The optimal location for a renewable electricity generation plant;
4. Grid stabilisation requirements and benefits;
5. The optimal electrolyser load factor;
6. The optimal hydrogen storage requirements and
7. The vendor readiness.

Table 4.2 Detailed description of WP3

Key interface	**Description**
Renewable energy generation assets	Power will be generated from the Solar PV system developed on the site. The renewable energy assets are planned to have significantly larger generation capacity than the plant electricity off-take. This difference between generation capacity and off-take enables a high load factor to be achieved.
Location of renewable energy assets	Options for placing the renewable energy generation assets behind the meter were explored. The project will provide grid stabilisation and response services to the network.

Connection of facilities to the national electricity grid.	The existing 132 kV network at the Norton substation has the capacity to accommodate the increase in power demand associated with the green ammonia project.
Target plant Availability.	The green ammonia plant is expected to achieve a very high utilisation rate through a pragmatic design with limited redundancy. Early discussions with vendors confirmed that targeting 98% availability for both the electrolyser and ammonia synthesis plants would yield an overall 96% availability with minimal sparing.
Target plant load factor	Higher load factors reduce the size of electrolysers, hydrogen storage and power infrastructure required for the project, but this reduces power provision optionality, and demands a higher cost of power. Evaluation of different load factors determines that NPV was similar for different load factors, hence a high load factor of 80% was chosen to minimise capital expenditure. .
Raw water supply	Raw water will be sourced from Darwendale Dam.
Filtered water supply	Additional filtered water capacity will be achieved through the installation of tube settler units.

Demineralised water processing	The plant facility must have sufficient demineralised water treatment capacity to accommodate the proposed plant.
Hydrogen generation	Alkaline electrolysers were selected as the preferred technology since they have sufficient speed of response to provide "FCAS services", whilst being safe, lowest cost and highest efficiency. The target availability of this facility is >98%.
Hydrogen storage	Two different hydrogen storage models are under consideration, namely: ● Containerised storage with storage pressure of 300 bars; ● Vertical carbon steel storage with storage pressure of 100 bars.
Ammonia synthesis plant	Small-scale ammonia synthesis plant. This deployment of Haber- Bosch technology adopts a scale used in the 1940s whilst taking advantage of modern catalysts and reactor bed designs. The target availability of this facility is >96%.
Electrolyser and ammonia synthesis bulk cooling requirements	The bulk cooling requirements for the electrolyser plant are considerably smaller than the ammonia plant and of a scale that can be accommodated with standard sized adiabatic cooling. The ammonia synthesis plant will independently use bulk cooling with either air cooling or adiabatic cooling.

Electrolyser and ammonia synthesis chilling requirements.	Chiller requirements for the electrolyser plant vary considerably between vendors. When chilling requirements are less than 200 kW this will be integrated into the ammonia plant chiller. When chiller demand is greater than this, both units will provide chilling services separately.	
Electrolyser to ammonia synthesis plant transfer pressure.	The transfer pressure between electrolyser and ammonia synthesis depends on the selected electrolyser technology, purification system size and compressor rationalisation. 30 barg is standard pressure which yields cost effective purification systems and accommodates atmospheric alkaline systems. If a pressurised alkaline system with 15 barg operating pressure were to be selected, then a 15 barg transfer pressure could be adopted.	
Nitrogen supply	The air separation unit (ASU) will provide nitrogen for the ammonia synthesis unit. It will also supply nitrogen to the electrolysers for use as a purging agent if required.	
Plant and instrument air supply	The green ammonia plant is to operate with an instrument air system installation.	
SCADA and monitoring	The power switch room will provide a convenient hub for aggregation of instrumentation and MCC associated with the plant. A fibre-optic linkage between the ancillary buildings and the control room will enable primary control of the facilities.	

Rationalization of compression	The plant will have four compression services, namely: 1. Electrolyser product to transfer pressure; 2. Hydrogen storage compression; 3. Ammonia synthesis plant feed (i.e. hydrogen and nitrogen) compression; 4. Syngas recycle compression; 5. Services 3 and 4 are regularly aggregated into a single compression. Some design options consider aggregating services 1 and 2.
Ammonia plant production flexibility	Installing an ammonia plant with some over-capacity and ability to turndown could reduce the hydrogen storage requirements and potentially overall project cost depending on the increased ammonia plant costs.
Waste management	All wastes and effluents generated by the plant will be catered for by solid and liquid handling and disposal mechanisms which will be on site.

For further analysis and information please refer to the Principal Researcher of this project proposal document in which technical descriptions and the potential economic viability assumptions which would also require significant government support in the form of policy direction, land and possibly off-taker agreements with public utilities responsible for electricity distribution, environment, farming and local government authorities, are expressed. The important stakeholders include Zimbabwe Electricity Supply Authority (ZESA), Zimbabwe Energy Regulatory Authority (ZERA), Environmental Management Agency (EMA), Agricultural Marketing Agency (AMA), Zimbabwe Water Authority (ZINWA) and the Ministry of Energy & Power Development (MoEPD) as the custodian of the National Renewable Energy Policy and the National Biofuels Policy.

Results: The production of "green" ammonia is undertaken in two key processing steps, water electrolysis to produce hydrogen followed by ammonia production, with key inputs to the process being water	Total cost: USD38.15 million.
and renewable electricity. Key metrics associated with this project are: a) Water (~25 ML/y) is to be sourced from the Darwendale Dam. b) 10 MW alkaline electrolyser which uses ~70 GWh of electricity to produce 1,200 T/y of hydrogen; d) Production of 7,000 T/y of Ammonia in a small scale ammonia synthesis plant using the Haber- Bosch process; e) The hydrogen production rate will vary in response to electricity price and network requirements, while the ammonia synthesis plant will operate continuously. To balance these operating modes, hydrogen storage is required.	

4.6 Work Schedule 4	Ammonium Nitrate ($NH_4 NO_3$) Plant
Name of Responsible person: Dr Natsayi Chiwaye	

Activities:

To install ammonia storage tanks, nitric acid synthesis plant and the ammonium nitrate plant with the aim of producing 10 900 T/y of ammonium nitrate. It is assumed that the plant is sourced from vendors based on the required tonnage. Installation of the plant on site is assumed to be five months assuming and it has been assumed that there are four weeks in a month. Full-scale plants take 9 months. The specific activities include;

1. Detailed pilot nitric and ammonium nitrate plant design for the production of the specified ammonium nitrate tonnage.
2. Installation and commissioning of the plants as outlined below

a) Installation of ammonia storage tanks

-Order ammonia tanks (84 days)

-Order refrigeration material and components (84days)

-Shipping of material (7days)

-Installation and building (140 days)

-Commissioning (84 days)

-Safety inspection (7days)

-Hazard and Hazop (3days)

-Training of operators

-The ammonia storage facility would need 1 operator per shift

b) Installation of nitric acid synthesis plant

-Order the plant materials **(**Air compression, Converter basket, Absorption) (84 days)

-Shipping(14)

-Assembly and fixing onsite (140)

-Pre-Commissioning (84 days)

-Commissioning (7 days)

-Safety and environmental inspection (3)

-Plant operator training (7 days)

The nitric acid plant would need 2 operators per shift

c) Building of ammonium nitrate plant

-Order of materials (neutraliser, evaporators, prilling, size controller) (84 days)

-Shipping of materials to the site (Neutraliser, evaporators, prilling, size controller) (14 days)

-Installation on site (140 days)

-Building bagging shed (21 days)

-Pre-Commissioning (84 days)

-Commissioning (7 days)

-Safety inspection (3 days)

-Training of operators -The ammonium nitrate section would need 2 operators per shift. The three sections would need 15 operators, assuming 3 shifts a day no special capacity building is required since the three sections are already operational and personnel is sourced locally with suitable skills. The two plants will be sourced and shipped simultaneously as a single unit, and hence the building and installation will occur at the same time. Equipment to be purchased or installed: Reactor; Concentrator; Prilling tower; Slurry tank & Evaporator

Results: The result will be functioning nitric acid and ammonium nitrate-producing plants. Assuming that 7000 ton/year of ammonia is available for ammonium nitrate production and 5% is lost in losses. The sum cost of the nitric acid and the cost of the ammonium nitrate plant 21.5 million euro.	Budget/cost: USD23.44 million

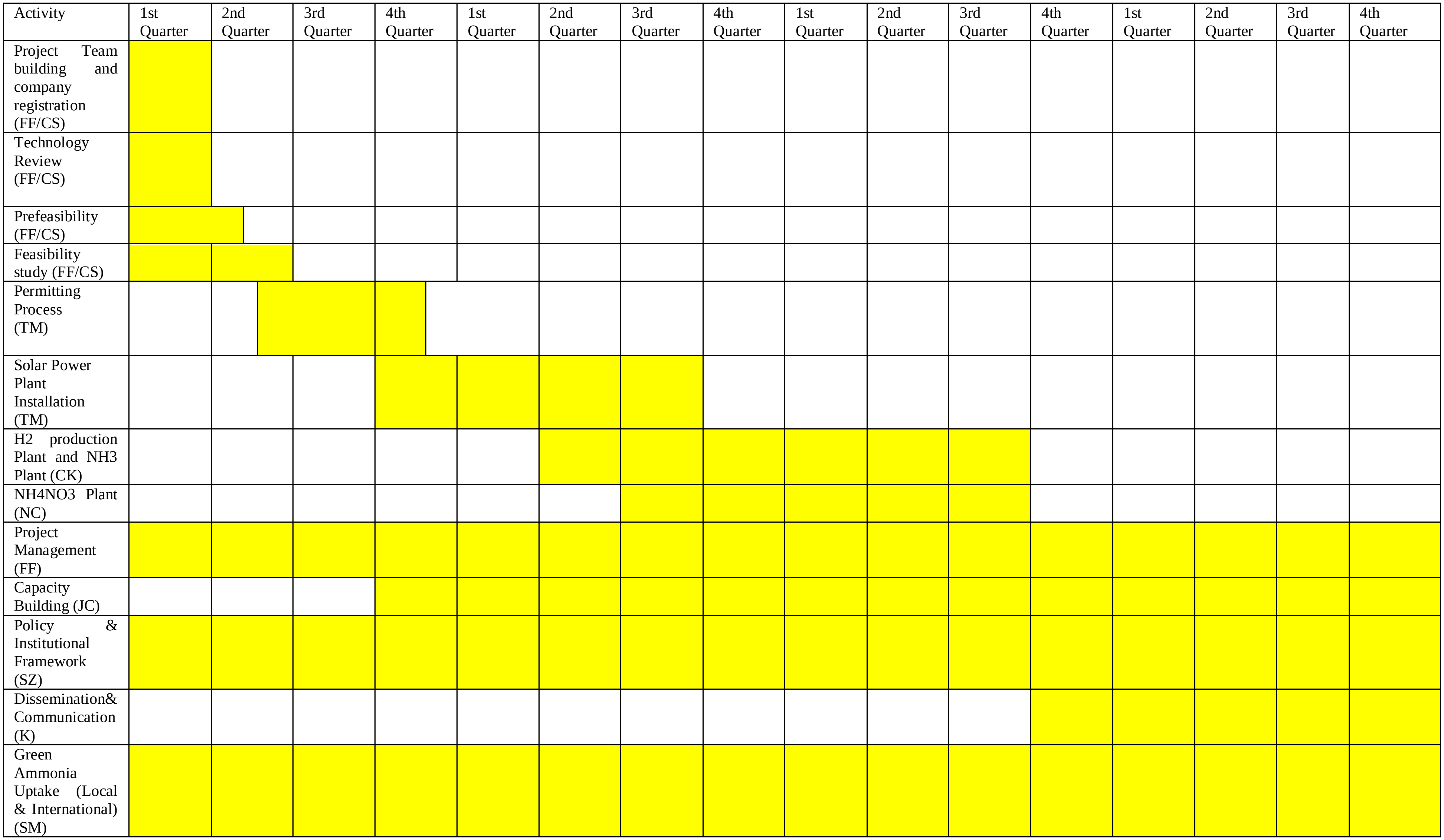
4.7 Work Schedule 5	Project Management
Name of Responsible person: Dr. Fortunate Farirai	

Activities:

- This project's objective is to ensure that the project is a success by installing and successfully operating green ammonia and ammonium nitrate plant production of the fertiliser. Regular monitoring of partner and project funder communication will occur, avoiding glitches so that the project advances in managing activities that encompass financial transactions and other administrative tasks carried out in matters, including legal, handled to a distinctive and following the funds' terms. Preparations, strategies and evaluations are some of the project objectives in ensuring that the board reports to the work leader for financial and administrative operations. The Project Steering Committee will be appointed to be responsible for day-to-day operational, financial and administrative tasks to review, control, and report budget and costs to the team.
- Project management cost is estimated at 9% on average of the total project cost, hence it is calculated from the other work package sum.

Results:	
• Smooth communication flow • Financial transparency • A successful project • Division of labour for a smooth flow of the project	Budget/cost: USD6.99 million

GANT PLAN AND MILESTONES PLAN



.Fig. 4.4 Gant Chart

Key for resource persons

FF- Fortunate Farirai; CS- Chipo. Shonhiwa; TM- Tobias Mudzingwa, CK- Charles Kanyunga; NC- Natsayi Chiwaye; JC- Jennifer Chigerwe; SZ- Sosten Ziuku; CK- Cassandra Kadenha and SM-Swinage Matonhodze.

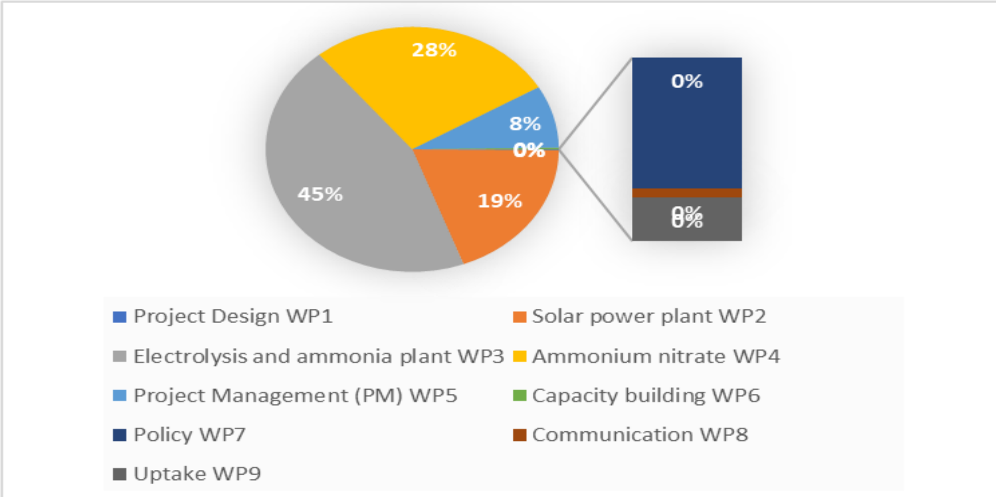


Fig 4.5 Resource share of the work package

Table 4.3 Budgetary Estimates

Area of application	**Cost (USD) X10^6**
Solar Power Plant	16.35
Electrolysers (Alkaline)	8.01
Hydrogen storage and compression	3.82
Ammonia Plant	9.92
High voltage transmission line	3.05
Balance of Plant (EPCM)	3.82
Civils	1.91

Ancillary buildings	3.05
Contingency	4.58
Ammonium Nitrate plant	23.33
Other WP1+6+7+8+9	0.24

Table 4.4 Key Aspects

Item	Category	Topics	Observations
1	Technical	Ammonia synthesis technology is evolving	The preferred architecture for an ammonia synthesis plant fed with electrolytic hydrogen is still evolving, as are technologies that seek efficiencies in novel hydrogen and nitrogen coupling approaches.
2	Technical	Electrolyser technology evolution	Our assessment of the cost of alkaline technologies demonstrates that costs are already following cost reduction trajectories that were forecast in 2017. Alkaline technology appears to be the incumbent (at least as relates to the requirements of this project). Next generation technology offers are emerging with potential cost reductions.

3	Technical	Vendor saturation	Vendors of electrolysers, small ammonia synthesis plants and hydrogen storage systems are all straining under the surge in hydrogen development interest and therefore are rationalising their response effort. Vendors are assessing project outcome likelihoods when evaluating the effort to direct to prospective projects.

4	Technical	Electrolyser power demand response speed	Based on vendor submissions, alkaline systems are slower in power response speed than PEM systems, but many vendors offer units capable of "regulatory" FCAS (i.e.> 3% load shift / second). Vendors can achieve different response speeds though modifications to separation system and rectifier design. The economic value of response speed will be unique to each project.

5	Technical	Hydrogen technology storage	Power demand responsive facilities either require the entire process system to modulate capacity (with associated cost for additional capacity) or have a storage system that can cycle in response to flow variation. In the case of the proposed electrolyser- based system, up to 6 cycles per day are anticipated. It has not been possible to refine the nomination of preferred hydrogen storage technology. Key trade-offs and costs are well understood, but the integration of plant footprint and safety considerations is still evolving. High pressure carbon steel pressure vessels are designed to cope with a defined number of pressure cycles, and costs escalate significantly with pressures >200 barg. The use of high-pressure carbon steel pressure vessels which can be blown down in the case of a fire have lower capital cost but will require more maintenance / replacement. Composite overwound pressure vessels (COPV) is an evolving technology which supports mobile transport and high levels of pressure cycling. These vessels can cope with many more pressure cycles and become cost effective with pressures >300 barg. However, emergency blow down of these vessels is more challenging, hence passive protection systems may need to be adopted. The higher-pressure systems challenge conventional compression design, but novel compression has not evolved sufficiently to have value for this project.

			Two different hydrogen storage models are under consideration as the project progresses, namely: § Containerised storage with storage pressure of 300 barg; Vertical carbon steel storage with storage pressure of 100 barg.
6	Technical	Process safety for COPV based hydrogen storage containers	A continuous focus on safety in design identified that the best industry practice for hydrogen storage safeguarding involves passive fire protection of all bottles and installation of blast panels mounted in the roof of the containers.

7	Technical	Developed an understanding of turndown considerations	The maximum level of turndown that an electrolyser can achieve is often highly contentious. The client seeks the maximum turndown range in order to minimise “fixed” power costs. Vendors recognise that there are capital cost and safety implications of greater turndown ranges. Achieving greater turndown range often requires more complex transformer/rectifier systems and modulation of the ancillary systems. The capacity to provide “hot standby” appears to be a costeffective alternative to straining for turndown capability. Pilot plant demonstrations are considered to be key qualifiers of vendor cl**aim**s.
8	Commercial	Cost of electrolytic ammonia synthesis plants	Compared with conventional ammonia synthesis plants, the level of complexity of an electrolytic ammonia synthesis plant is low. Unfortunately, based on vendor cost submissions the removal of complexity does not significantly reduce cost. Net energy efficiency of a “green” ammonia plant is lower than the conventional ammonia plants.

9	Commercial	Developed an understanding of key electrolyser CAPEX, / OPEX, trade-off.	Electrolyser vendors have several key CAPEX vs OPEX trade-offs to balance when submitting an offer, e.g. · Pushing unit operating capacity at expense of efficiency and electrolyser life; · Complexity of rectification system relative to desired rate of response and AC system (i.e. harmonics) impacts; Having an understanding of key trade-offs enables a client to set preferences and reduces the range of options that vendors must negotiate.
10	Commercial	Flexibility of a diverse renewable energy portfolio	The electrolysers will be operated to ensure that the amount of hydrogen in the hydrogen tank is always maintained between minimum and maximum thresholds to ensure continuous operation of the ammonia plant. In addition, the plant needs a certain level of firm electricity to operate. In order to meet these operational constraints and provide a high capacity factor, hence an oversized solar asset which means the project can leverage a renewable energy supply without being exposed to the intermittent nature of renewables.

11	Commercial	Target load factor	The project determined that a similar NPV was obtained at a range of load factors (for this project). Hence the highest load factor and lowest capital solution is optimal. Electrolyser units come in standard sizes and hence will be "over-sized" to some extent. This leaves the possibility for higher generation / lower load factor, or operation at target load factor with higher efficiency. Operating with the higher generation rate (and marginally lower efficiency) was found to be preferable.
13	Commercial	Value of ammonia synthesis plant flexibility	Increasing the capacity of a small-scale ammonia synthesis plant has a small economic penalty. If this plant can modulate production capacity relatively quickly, i.e. 20% shift in capacity within an hour, then the capacity of hydrogen storage (and associated cost) can be reduced significantly. Collective design development between plant operator and electricity supplier is required to determine the optimal hydrogen storage capacity.

14	Commercial	Project commercial viability	The green ammonia production pathway has not achieved cost parity with conventional ammonia production (at the proposed scale). The project is commercially viable with funding assistance. The major driver of project economics is the margin between electricity costs and the value of the ammonia. Electricity costs must fall or carbon pricing / green premium increase in order that ‘green” projects achieve cost parity with conventional ammonia production.
15	Commercial	Identifying a contracting strategy that balances risk Vs certainty. contracting “commercial tension” approach	Considering the relative immaturity of electrolyser technology and optimisation considerations with an ammonia synthesis plant, there is a continued need for technical development. Conventional engineering practices do not allow for design fluidity (and learning) whilst maintaining competitive market tension. This approach will engage multiple contractors to enable continued technical advancement (e.g. sharing of IP within a safe environment) whilst maintaining “commercial tension” for ultimate design.

16	Regulatory	Regulatory advances	The implementation of hydrogen projects will need to support / advance the application of Zimbabwe national standards as they relate to high pressure tubing, low ignition energy instrumentation, hydrogen storage vessel inspection requirements and the hydrogen safety case.

RISK MANAGEMENT

.**Table 4.5** Risk assessment

Risk description	Mitigation strategy
Business case assumptions not delivered during delivery and commissioning phase (e.g. capital cost exceeded)	"Feasibility study /detailed design risk transfer strategy. Performance guarantee.
Reduction in global ammonia price	Obtain independent review of forecast global ammonia prices
Sufficient grant funding concession not and/or available.	Early engagement the Heads of Agreement and funding negotiations.
Inability to resolve grid connection	Early engagement with ZETDC
Poor plant integration	Rigorous engineering change management. Rigorous overview of detailed design and construction.

Electricity supply not confirmed	Execute PPA
Pandemic	Zimbabwean health measures. Close management of project and vendor timelines.
Potassium Hydroxide (10-15%, 30%) rundown mixes with ammonium nitrate, sodium hydroxide and sulphuric acid rundown.	Review Potassium Hydroxide disposal options with vendors.
High pressure and large quantity hydrogen storage	Complete hazardous area classification study.
Dissimilar materials resulting in corrosion.	Conduct dissimilar metals study and include carbon fiber to aluminium and stainless steel
Lack of secondary egress	Ensure secondary emergency egress is included in emergency response
Loss of containment of ammonia	Project to consider methods to avoid or mitigate ammonia loss of containment (Minimisation of leak sources, alarms, trips, emergency inventory)
Ammonia storage	Complete hazardous area classification study.
Hydrogen embrittlement of piping during start-up resulting in crack /fracture	Project to confirm likelihood of embrittlement with different materials and choose appropriate material

Project Stakeholder Groups' Likely Interests and Key Considerations

Table 4.6: Stakeholder mapping

Stakeholder group	Likely interests and key considerations
Key customers	Potential opportunity to reduce the carbon footprint of the supply chain.
Key suppliers	Potential employment and business opportunities.
Zimbabwean Government, including § Renewable Energy Association; § Rural Electrification Fund (REF); § Department of Energy Conservation and Renewable Energy; § Department of Infrastructure, Transport, Provincial Development and Communications; § Office of the President & Cabinet.	Various Zimbabwean government agencies will be interested in promoting the benefits of the project because it relates to the renewable hydrogen industry.

Zimbabwean Government, including § Department of Environment (EMA) and Tourism. § Workplace Health and Safety (NSSA) § State Development, Manufacturing, Infrastructure and Economic Planning. § Industry Development § Natural Resources, Mines and Energy § Economic Development § Department of Transport and Communications	Zimbabwean government agencies will be interested in promoting the benefits of the project because it relates to the renewable hydrogen industry and also for the potential employment opportunities. Liaison is also required with the government regarding regulatory approvals.
Local Members of Parliament	Local Members of Parliament will be interested in understanding how the project will benefit the local economy and community.
Local Government	The project will require approvals and planning support from Local Council. Norton Town Council will be interested in understanding how the project will benefit the local economy and community.
Local community, including: § Neighbouring landholders § Norton community residents § Local businesses § Local Indigenous groups	Neighbouring landholders will be interested in understanding project benefits and impacts.

Local regional development groups, including:	Various regional development groups will be interested in understanding the potential project benefits (such as supplier opportunities) and how they can facilitate consultation with key stakeholders regarding this matter.
Infrastructure and utility providers/groups, including:	Infrastructure and utility providers/groups will likely be primarily interested in project-related infrastructure and service delivery requirements.
Relevant unions	Relevant unions will be interested in understanding employment opportunities and impact on the existing workforce.
Neighbouring industry, including: • Mining conglomerates • Agricultural field corporate • Marine	Neighbouring industry will likely be interested in obtaining hydrogen (e.g. for mine haul trucks), understanding project timeframes and logistics.
Media	The media will be interested in any newsworthy stories regarding the project – which in this case will likely relate to hydrogen technology.

4.8 Fiscal incentives for Green Hydrogen in the renewable energy sector.

In general, Zimbabwe has no specific hydrogen strategy or hydrogen policy as is the case elsewhere, however the general outlook on the current policies gives a very good opportunity and universal approach as is applicable to all known forms of renewable energy harnessing. As a result, green hydrogen is not specifically defined in the latest policy framework. At the same time, there is no 'corona recovery package' which would include investment incentives for green hydrogen applications. For most industries as well as government, the green hydrogen technologies and their applications are relatively new or are regarded as futuristic promises. Despite the fact that Zimbabwe had one of the biggest green hydrogen facilities operating until 2015 (100 MW electrolyzer for ammonia, fertilizer production). Meanwhile, Zimbabwe possesses Africa's 2nd largest (after South Africa), and the World's 3rd largest (after South Africa and Russia) deposits of Platinum Group Metals (PGMs) which are essential in most of the hydrogen, ammonia, fuel cell and electrolyzer applications, next to many other minerals besides PGMs.

The PGM mining industry is one of the few sectors clearly aware of the hydrogen economy and its applications and is following the developments closely. Parent companies outside Zimbabwe are trailing the technology and will decide when the technology will apply in their Zimbabwean operations. As far as the PGM mining industry is aware of, there are no clear roadmaps from the government regarding any value chain creation of the PGMs into hydrogen and fuel cell related products and applications, as is the case in South Africa.

As electricity is at the source of green hydrogen production via water electrolysis, investment incentives for renewable electricity development are a prerequisite for green hydrogen production. There is definitely support from the Zimbabwean government for (large scale) solar and biofuels plants. Whilst the incentives are primarily fiscal, there are no duties on importing solar related equipment. The first 5 years there is no corporate tax, after that period there is a reduced corporate tax tariff of 15%. Although green hydrogen production is not specifically mentioned in the tax code, it is very clear that green hydrogen production and applications would receive the same level of benefits as with solar PV and biofuels. This trend has also been felt by other renewable energy technology developers like those for solar and biofuels.

4.9 Conclusion

The discovery with Green H_2 is such that the cost of establishing the plant is higher than that of establishing a solar PV plant of similar size. In this case for a 10MW green hydrogen plant about USD85 million is required compared to that of 10MW solar PV of about USD8 million. However, in both cases construction costs have been decreasing due to improvements in the technical components of each technology. It is also important to note that for green hydrogen there are also co-products that generate revenue streams other than energy itself. However, infrastructure for solar PV requires a large land area as compared to green hydrogen that requires far much less land. Invariably, with the advent of solar PV technologies that can be laid on water body surface, the two technologies can be installed to compliment each other. Meanwhile, globally in some quarters, green hydrogen is also being produced from harvesting atmospheric air. Which further reducing the costs associated with electrolyzers.

On the other hand, Zimbabwe is one of the few countries in the world that host an electrolysis plant. The production of hydrogen is not a new technology in Zimbabwe. From 1972 to 2015, Sable Chemicals, current Zimbabwe's sole manufacturer of ammonia, used to generate hydrogen from the electrolysis of water. The process demands a lot of power (close to 100 MW) which has not been available, leading to the shutting down of the electrolysis plant. Hence, the author's participation in the Green H_2 Atlas Africa project and especially for Zimbabwe was in tandem with this realization of enabling such big industrial companies in developing green energy technologies that can generate affordable power for own consumption and evacuation into the national grid market. Sable Chemicals has the advantage that it has been producing hydrogen as a by-product but without exploiting it further as a renewable energy source.

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11. Levelized costs of hydrogen refers to the total of the discounted CAPEX and OPEX divided by annual hydrogenproduction, and is expressed in Euro/kg H2.
12. For a 1-GW green-hydrogen facility, the SEVESO III Directive 2012/18/EU is not applicable, because the \ quantity of H2 involved is below the threshold of 5,000 kg.
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15. Low Voltage Directive 2014/35/EU.

16. Thyristor is a semiconductor low-frequency switching device that can operate like a rectifying diode once it is “ON”.
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CHAPTER FIVE

BIOFUELS

5.0 Introduction

Traditional biomass, including fuelwood, charcoal and animal dung, continues to provide important sources of energy in many parts of the world. Bioenergy is the dominant energy source for most of the world's population who live in extreme poverty and who use this energy mainly for cooking. More advanced and efficient conversion technologies now allow the extraction of biofuels – in solid, liquid and gaseous forms – from materials such as wood, crops and waste material.

A wide range of biomass sources can be used to produce bioenergy in a variety of forms. For example, food, fiber and wood process residues from the industrial sector; energy crops, short-rotation crops and agricultural wastes from the agriculture sector; and residues from the forestry sector can all be used to generate electricity, heat, combined heat and power, and other forms of bioenergy. Biofuels may be referred to as renewable energy because they are a form of transformed solar energy. Biofuels can be classified according to source and type. They may be derived from forest, agricultural or fishery products or municipal wastes, as well as from agro- industry, food industry and food service by-products and wastes. They may be solid, such as fuelwood, charcoal and wood pellets; liquid, such as ethanol, biodiesel and pyrolysis oils; or gaseous, such as biogas. A basic distinction is also made between primary (unprocessed) and secondary (processed) biofuels:

- Primary biofuels, such as firewood, wood chips and pellets, are those where the organic material is used essentially in its natural form (as harvested). Such fuels are directly combusted, usually to supply cooking fuel, heating or electricity production needs in small- and large- scale industrial applications.
- Secondary biofuels in the form of solids (e.g. charcoal), liquids (e.g. ethanol, biodiesel and bio-oil), or gases (e.g. biogas, synthesis gas and hydrogen) can be used for a wider range of applications, including transport and high-temperature industrial processes.

Liquid biofuels for transport, on the other hand, are generating the most attention and have seen a rapid expansion in production. However, quantitatively their role is only marginal: they cover 1% of total transport fuel consumption and 0.2–0.3% of total energy consumption worldwide. In spite of their limited overall volume, the strongest growth in recent years has been in liquid biofuels for transport, mostly produced using agricultural and food commodities as feedstocks. The most significant are ethanol and biodiesel.

5.1 Ethanol

Any feedstock containing significant amounts of sugar, or materials that can be converted into sugar such as starch or cellulose, can be used to produce ethanol. Ethanol available in the biofuel market today is based on either sugar or starch. Common sugar crops used as feedstocks are sugar cane, sugar beet and, to a lesser extent, sweet sorghum. Common starchy feedstocks include maize, wheat and cassava. The use of biomass containing sugars that can be fermented directly to ethanol is the simplest way of producing ethanol. In Brazil and other tropical countries currently producing ethanol, sugar cane is the most widely used feedstock. In OECD countries, most ethanol is produced from the starchy component of cereals (although sugar beet is also used), which can be converted fairly easily into sugar. However, these starchy products represent only a small percentage of the total plant mass. Most plant matter is composed of cellulose, hemicellulose and lignin; the first two can be converted into alcohol after they have first been converted into sugar, but the process is more difficult than the one for starch. Today, there is virtually no commercial production of ethanol from cellulosic biomass, but substantial research continues in this area.

Ethanol can be blended with petrol or burned in its pure form in slightly modified spark-ignition engines. A liter of ethanol contains approximately 66 percent of the energy provided by a liter of petrol, but has a higher-octane level and when mixed with petrol for transportation it improves the performance of the latter. It also improves fuel combustion in vehicles, thereby reducing the emission of carbon monoxide, unburned hydrocarbons and carcinogens. However, the combustion of ethanol also causes a heightened reaction with nitrogen in the atmosphere, which can result in a marginal increase in nitrogen oxide gases. In comparison with petrol, ethanol contains only a trace amount of Sulphur. Mixing ethanol with petrol, therefore, helps to reduce the fuel’s Sulphur content and thereby lowers the emissions of Sulphur oxide, a component of acid rain and a carcinogen.

5.2 Biodiesel

Biodiesel is produced by combining vegetable oil or animal fat with an alcohol and a catalyst through a chemical process known as transesterification. Oil for biodiesel production can be extracted from almost any oilseed crop; globally, the most popular sources are rapeseed in Europe and soybean in Brazil and the United States of America. In tropical and subtropical countries, biodiesel is produced from palm, coconut and *jatropha curcas* oils. Small amounts of animal fat, from fish- and animal-processing operations, are also used for biodiesel production. The production process typically yields additional by-products such as crushed bean “cake” (an animal feed) and glycerin. Because biodiesel can be based on a wide range of oils, the resulting fuels can display a greater variety of physical properties, such as viscosity and combustibility, than ethanol.

Biodiesel can be blended with traditional diesel fuel or burned in its pure form in compression ignition engines. Its energy content is 88–95 percent of that of diesel, but it improves the lubricity of diesel and raises the cetane value, making the fuel economy of both generally comparable. The higher oxygen content of biodiesel aids in the completion of fuel combustion, reducing emissions of particulate air pollutants, carbon monoxide and hydrocarbons. As with ethanol, diesel also contains only a negligible amount of Sulphur, thus reducing Sulphur Oxide emissions from vehicles.

5.3 Straight vegetable oil

Straight vegetable oil (SVO) is a potential fuel for diesel engines that can be produced from a variety of sources, including oilseed crops such as rapeseed, sunflower, soybean and palm. Used cooking oil from restaurants and animal fat from meat-processing industries can also be used as fuel for diesel vehicles.

5.4 Second-generation liquid biofuels

Second-generation biofuels currently under development would use lignocellulosic feedstocks such as wood, tall grasses, and forestry and crop residues. This would increase the quantitative potential for biofuel generation per hectare of land and could also improve the fossil energy and greenhouse gas balances of biofuels. However, it is not known when such technologies will enter production on a significant commercial scale. Current liquid biofuel production based on sugar and starch crops (for ethanol) and oilseed crops (for biodiesel) is generally referred to as first-generation biofuels. A second generation of technologies under development may also make it possible to use lignocellulosic biomass. Cellulosic biomass is more resistant to being broken down than starch, sugar and oils. The difficulty of converting it into liquid fuels makes the conversion technology more expensive, although the cost of the cellulosic feedstock itself is lower than for current, first-generation feedstocks. Conversion of cellulose to ethanol involves two steps: the cellulose and hemicellulose components of the biomass are first broken down into sugars, which are then fermented to obtain ethanol. The first step is technically challenging, although research continues on developing efficient and cost-effective ways of carrying out the process. The lack of commercial viability has so far inhibited significant production of cellulose-based second-generation biofuels.

As cellulosic biomass is the most abundant biological material on earth, the successful development of commercially viable second-generation cellulose-based biofuels could significantly expand the volume and variety of feedstocks that can be used for production. Cellulosic wastes, including waste products from agriculture (straw, stalks, leaves) and forestry, wastes generated from processing (nut shells, sugar- cane bagasse, sawdust) and organic parts of municipal waste, could all be potential sources. However, it is also important to consider the crucial role that decomposing biomass plays in maintaining soil fertility and texture; excessive withdrawals for bioenergy use could have negative effects.

Dedicated cellulosic energy crops hold promise as a source of feedstock for second-generation technologies. Potential crops include short-rotation woody crops such as willow, hybrid poplars and eucalyptus or grassy species such as miscanthus, switchgrass and reed canary grass. These crops present major advantages over first- generation crops in terms of environmental sustainability. Compared with conventional starch and oilseed crops, they can produce more biomass per hectare of land because the entire crop is available as feedstock for conversion to fuel. Furthermore, some fast- growing perennials such as short-rotation woody crops and tall grasses can sometimes grow on poor, degraded soils where food- crop production is not optimal because of erosion or other limitations. Both these factors may reduce competition for land with food and feed production. On the downside, several of these species are considered invasive or potentially invasive and may have negative impacts on water resources, biodiversity and agriculture.

Second-generation feedstocks and biofuels could also offer advantages in terms of reducing greenhouse gas emissions. Most studies project that future, advanced fuels from perennial crops and woody and agricultural residues could dramatically reduce life-cycle greenhouse gas emissions relative to petroleum fuels and first- generation biofuels. This stems from both the higher energy yields per hectare and the different choice of fuel used in the conversion process. In the current production process for ethanol, the energy used in processing is almost universally supplied by fossil fuels (with the exception of sugar- cane-based ethanol in Brazil, where most of the energy for conversion is provided by sugar-cane bagasse). For second-generation biofuels, process energy could be provided by left-over parts of the plants (mainly lignin).

While cellulosic biomass is harder to break down for conversion to liquid fuels, it is also more robust for handling, thus helping to reduce its handling costs and maintain its quality compared with food crops. It is also easier to store, especially in comparison with sugar-based crops, as it resists deterioration. On the other hand, cellulosic biomass can often be bulky and would require a well- developed transportation infrastructure for delivery to processing plants after harvest.

Significant technological challenges still need to be overcome to make the production of ethanol from lignocellulosic feedstocks commercially competitive. It is still uncertain when conversion of cellulosic biomass into advanced fuels may be able to contribute a significant proportion of the world's liquid fuels. Currently, there are a number of pilot and demonstration plants either operating or under development around the world. The speed of expansion of biochemical and thermochemical conversion pathways will depend upon the development and success of pilot projects currently under way and sustained research funding, as well as world oil prices and private-sector investment.

In summary, second-generation biofuels based on lignocellulosic feedstocks present a completely different picture in terms of their implications for agriculture and food security. A much wider variety of feedstocks could be used, beyond the agricultural crops currently used for first- generation technologies, and with higher energy yields per hectare. Their effects on commodity markets, land-use change and the environment will also differ – as will their influence over future production and transformation technologies.

The main liquid biofuels are ethanol and biodiesel. Both can be produced from a wide range of different feedstocks. The most important producers are Brazil and the United States of America for ethanol and the EU for biodiesel.

- Current technologies for liquid biofuels rely on agricultural commodities as feedstock. Ethanol is based on sugar or starchy crops, with sugar cane in Brazil and maize in the United States of America being the most significant in terms of volume. Biodiesel is produced using a range of different oil crops.
- Large-scale production of biofuels implies large land requirements for feedstock production. Liquid biofuels can therefore be expected to displace fossil fuels for transport to only a very limited extent.
- Even though liquid biofuels supply only a small share of global energy needs, they still have the potential to have a significant effect on global agriculture and agricultural markets because of the volume of feedstocks and the relative land areas needed for their production.

5.5 Biofuel feedstocks

There are many supply sources of biomass for energy purposes, scattered across large and diverse geographical areas. Even today, most energy derived from biomass used as fuel originates from by-products or co-products of food, fodder and fiber production. For instance, the main by- products of forest industries are used to produce fuelwood and charcoal, and black liquor (a by-product of pulp mills) is a major fuel source for bioelectricity generation in countries such as Brazil, Canada, Finland, Sweden and the United States of America. A considerable amount of heat and power is derived from recovered and/or recycled woody biomass and increasing amounts of energy are recovered from biomass derived from cropland (straw and cotton stalks) and forest land (wood chips and pellets). In sugar- and coffee-producing countries, bagasse and coffee husks are used for direct combustion and to produce heat energy and steam.

In terms of bioenergy, however, the big growth area in recent years has been in the production of liquid biofuels for transport using agricultural crops as feedstocks. The bulk of this has taken the form of ethanol, based on either sugar crops or starchy crops, or biodiesel based on oil crops. A range of different crops can be used as feedstock for ethanol and biodiesel production. However, most global ethanol production is derived from sugar cane or maize; in Brazil, the bulk of ethanol is produced from sugar cane and in the United States of America from maize. Other significant crops include cassava, rice, sugar beet and wheat. For biodiesel, the most popular feedstocks are rapeseed in the EU, soybean in the United States of America and Brazil, and palm, coconut and castor oils in tropical and subtropical countries, with a growing interest in jatropha.

5.6 Biofuels and Agriculture

The current expansion and growth of energy markets, as a result of new energy and environment policies enacted over the past decade in most developed countries and in several developing countries, is reshaping the role of agriculture. Most significant is the sector's increasing role as a provider of feedstock for the production of liquid biofuels for transport – ethanol and biodiesel. Modern bioenergy represents a new source of demand for farmers' products. It thus holds promise for the creation of income and employment. At the same time, it generates increasing competition for natural resources, notably land and water, especially in the short run, although yield increases may mitigate such competition in the long run. Competition for land becomes an issue especially when some of the crops (e.g. maize, oil palm and soybean) that are currently cultivated for food and feed are redirected towards the production of biofuels, or when food-oriented land is converted to biofuel production.

Currently, around 85 percent of the global production of liquid biofuels is in the form of ethanol. The two largest ethanol producers, Brazil and the United States of America, account for almost 90 percent of total production, with the remainder accounted for mostly by Canada, China, the EU (mainly France and Germany) and India. Biodiesel production is principally concentrated in the EU (with around 60 percent of the total), with a significantly smaller contribution coming from the United States of America. In Brazil, biodiesel production is a more recent phenomenon and production volume remains limited. Other significant biodiesel producers include China, India, Indonesia and Malaysia.

Table 5.1 Biofuel production by country, 2007

COUNTRY/ GROUP	**ETHANOL**		**BIODIESEL**		**TOTAL**	
	(Million litres)	(Mtoe)	(Million litres)	(Mtoe)	(Million litres)	(Mtoe)
Brazil	19 000	10.44	227	0.17	19 227	10.60
Canada	1 000	0.55	97	0.07	1 097	0.62
China	1 840	1.01	114	0.08	1 954	1.09
India	400	0.22	45	0.03	445	0.25
Indonesia	0.00	0.00	409	0.30	409	0.30
Malaysia	0.00	0.00	330	0.24	330	0.24
USA	26 500	14.55	1 688	1.25	28 188	15.80
EU	2 253	1.24	6 109	4.52	8 361	5.76
Others	1 017	0.56	1 186	0.88	2203	1.44
World	**52 009**	**28.57**	**10 204**	**7.56**	**62 213**	**36.12**

Source: FAO, The State of Food and Agriculture, Biofuels: Prospects, Risks and Opportunities (2008), Chapter 2, Section Biofuels and agriculture, p. 15

Different crops vary widely in terms of biofuel yield per hectare, both across feedstocks and across countries and production systems, as illustrated in Table 5.2. Variations are due both to differences in crop yields per hectare across crops and countries and to differences in conversion efficiency across crops. This implies vastly different land requirements for increased biofuel production depending on the crop and location. Currently, ethanol production from sugar cane and sugar beet has the highest yields, with sugar-cane-based production in Brazil topping the list of in terms of biofuel output per hectare and India not far behind. Yields per hectare are somewhat lower for maize, but with marked differences between yields, for example, in China and in the United States of America. The data reported in Table 5.2 refer only to technical yields. The cost of producing biofuels based on different crops in different countries may show very different patterns.

Table 5.2 Biofuel yields for different feedstocks and countries.

CROP	GLOBAL/ NATIONAL ESTIMATES	BIOFUEL	CROP YIELD	CONVERSION EFFICIENCY	BIOFUEL YIELD
			(Tons/ha)	(Litres/ton)	(Litres/ha)
Sugar beet	Global	Ethanol	46.0	110	5 060
Sugar cane	Global	Ethanol	65.0	70	4 550
Cassava	Global	Ethanol	12.0	180	2 070
Maize	Global	Ethanol	4.9	400	1 960
Rice	Global	Ethanol	4.2	430	1 806
Wheat	Global	Ethanol	2.8	340	952
Sorghum	Global	Ethanol	1.3	380	494
Sugar cane	Brazil	Ethanol	73.5	74.5	5 476
Sugar cane	India	Ethanol	60.7	74.5	4 522
Oil palm	Malaysia	Biodiesel	20.6	230	4 736
Oil palm	Indonesia	Biodiesel	17.8	230	4 092
Maize	USA	Ethanol	9.4	399	3 751
Maize	China	Ethanol	5.0	399	1 995
Cassava	Brazil	Ethanol	13.6	137	1 863
Cassava	Nigeria	Ethanol	10.8	137	1 480
Soybean	USA	Biodiesel	2.7	205	552
Soybean	Brazil	Biodiesel	2.4	205	491

Source: FAO, The State of Food and Agriculture, Biofuels: Prospects, Risks and Opportunities (2008), Chapter 2, Section Biofuels and agriculture, p. 16

The technical and economic potential for bioenergy should be discussed in the context of the increasing shocks and stress on the global agriculture sector and the growing demand for food and agricultural products that is a consequence of continuing population and income growth worldwide. What is technically feasible to produce may not be economically feasible or environmentally sustainable. This section discusses in more detail the technical and economic potential of bioenergy.

Because bioenergy is derived from biomass, global bioenergy potential is ultimately limited by the total amount of energy produced by global photosynthesis. Plants collect a total energy equivalent of about 75 000 Mtoe (3 150 Exajoule) per year (Kapur, 2004) – or six to seven times the current global energy demand. However, this includes vast amounts of biomass that cannot be harvested. In purely physical terms, biomass represents a relatively poor way of harvesting solar energy, particularly when compared with increasingly efficient solar panels.

A number of studies have gauged the volume of biomass that can technically contribute to global energy supplies. Their estimates differ widely owing to different scopes, assumptions and methodologies, underscoring the high degree of uncertainty surrounding the possible contribution of bioenergy to future global energy supply. The last major study of bioenergy conducted by the International Energy Agency (IEA) assessed, on the basis of existing studies, the range of potential bioenergy supply in 2050 from a low of 1 000 Mtoe to an extreme of 26 200 Mtoe. The latter figure was based on an assumption of very rapid technological progress; however, the IEA indicates that a more realistic assessment based on slower yield improvements would be 6 000–12 000 Mtoe. A mid-range estimate of around 9 500 Mtoe would, according to the IEA, require about one- fifth of the world's agricultural land to be dedicated to biomass production.

More important than the purely technical viability is the question of how much of the technically available bioenergy potential would be economically viable. The long-term economic potential depends crucially on assumptions concerning the prices of fossil energy, the development of agricultural feedstocks and future technological innovations in harvesting, converting and using biofuels.

A different way of looking at the potential for biofuel production is to consider the relative land-use requirements. In its "Reference Scenario" for 2030 in World Energy Outlook 2006, the IEA projects an increase in the share of the world's arable land devoted to growing biomass for liquid biofuels from 1% in 2004 to 2.5% in 2030. Under its "Alternative Policy Scenario", the share in 2030 increases to 3.8%. In both cases, the projections are based on the assumption that liquid biofuels will be produced using conventional crops. Should second-generation liquid biofuels become widely commercialized before 2030, the IEA projects the global share of biofuels in transport demand to increase to 10 percent rather than 3% in its Reference Scenario and 5% in the Alternative Policy Scenario. Land-use requirements would go up only slightly, to 4.2% of arable land, because of higher energy yields per hectare and the use of waste biomass for fuel production.

Nevertheless, this illustrates that, even under a second-generation scenario, a hypothetical large-scale substitution of liquid biofuels for fossil-fuel-based petrol would require major conversion of land.

The potential for current biofuel technologies to replace fossil fuels is also illustrated by a hypothetical calculation by Rajagopal et al. (2007). They report theoretical estimates for global ethanol production from the main cereal and sugar crops based on global average yields and commonly reported conversion efficiencies. Conversion of the entire crop production to ethanol would correspond to 57% of total petrol consumption. Under a more realistic assumption of 25% of each of these crops being diverted to ethanol production, only 14% of petrol consumption could be replaced by ethanol. The various hypothetical calculations underline that, in view of their significant land requirements, biofuels can only be expected to lead to a very limited displacement of fossil fuels. Nevertheless, even a very modest contribution of biofuels to overall energy supply may yet have a strong impact on agriculture and on agricultural markets.

TABLE 5.3: Voluntary and mandatory bioenergy targets for transport fuels in G8+5 countries

COUNTRY/GROUP	TARGETS [1]
Brazil	Mandatory blend of 20–25 percent anhydro ethanol with petrol; minimum blending of 3 perce biodiesel to diesel by July 2008 and 5 percent (B by end of 2010
Canada	5 percent renewable content in petrol by 2010 a 2 percent renewable content in diesel fuel by 201
China	15 percent of transport energy needs through use biofuels by 2020
France	5.75 percent by 2008, 7 percent by 2010, 10 perce by 2015 (V), 10 percent by 2020 (M = EU target
Germany	6.75 percent by 2010, set to rise to 8 percent 2015, 10 percent by 2020 (M = EU target)
India	Proposed blending mandates of 5–10 percent f ethanol and 20 percent for biodiesel
Italy	5.75 percent by 2010 (M), 10 percent by 2020 (= EU target)
Japan	500 000 kilolitres, as converted to crude oil, 2010 (V)
Mexico	Targets under consideration
Russian Federation	No targets
South Africa	Up to 8 percent by 2006 (V) (10 percent targ under consideration)
United Kingdom	5 percent biofuels by 2010 (M), 10 percent by 20 (M = EU target)
United States of America	9 billion gallons by 2008, rising to 36 billion 2022 (M). Of the 36 billion gallons, 21 billion to from advanced biofuels (of which 16 billion fro cellulosic biofuels)
European Union	10 percent by 2020 (M proposed by E Commission in January 2008)

[1]M=mandatory;V=voluntary.Sources: GBEP, 2007, updated with information from the United States Department of Agriculture (USDA, 2008a), the Renewable Fuels Association (RFA, 2008) and written communication from the EU Commission and Professor Ricardo Abramovay, University of São Paulo, Brazil.

TABLE 5.4: Applied tariffs on ethanol in selected countries

Country/group	Applied MFN tariff	At pre-tariff unit value of US$ 0.50/litre		Exceptions/Comments
	Local currency or ad valorem rate	Ad valorem equivalent	Specific-rate equivalent	
		(Percentage)	(US$/litre)	
Notes: Ethanol is classified for trade purposes as HS 2207.10, undenatured ethyl alcohol. Tariffs indicated are rates as of 1 January 2007. MFN = most-favoured nation; FTA = Free Trade Association; EFTA = European Free Trade Association; GSP = Generalised System of Preferences; CBI = Caribbean Basin Initiative. Steenblik, 2007.				
Australia	5%+A$0.38143/L	51 %	0.34	USA, New Zealand
Brazil	0%	0 %	0.00	From 20% in March 2006
Canada	Can$ 0.0492/litre	9 %	0.047	FTA partners
Switzerland	SwF35/100 kg	46 %	0.232	EU, GSP
USA	2.5%+US$0.54/gal	28 %	0.138	FTA partners, CBI partners
EU	€ 0.192/litre	52 %	0.26	EFTA, GSP

TABLE 5.5: Energy demand by source and sector: reference scenario

	ENERGY DEMAND (Mtoe)						**SHARE (Percentage)**		
	1980	**1990**	**2000**	**2005**	**2015**	**2030**	**2005**	**2015**	**2030**
Total primary energy supply by source	7 228	8 755	10 023	11 429	14 361	17 721	100 %	100 %	100 %
Coal	1 786	2 216	2 292	2 892	3 988	4 994	25 %	28 %	28 %
Oil	3 106	3 216	3 647	4 000	4 720	5 585	35 %	33 %	32 %
Gas	1 237	1 676	2 089	2 354	3 044	3 948	21 %	21 %	22 %
Nuclear	186	525	675	714	804	854	6 %	6 %	5 %
Hydro	147	184	226	251	327	416	2 %	2 %	2 %
Biomass and waste	753	903	1 041	1 149	1 334	1 615	10 %	9 %	9 %
Other renewable	12	35	53	61	145	308	1 %	1 %	2 %
Total energy consumption by sector	..	6 184	..	7 737	9 657	1 1861	100 %	100 %	100 %
Residential, services and agriculture	..	2 516	..	2 892	3 423	4 122	37 %	35 %	35 %
Industry	..	2 197	..	2 834	3 765	4 576	37 %	39 %	39 %
Transport	..	1 471	..	2 011	2 469	3 163	26 %	26 %	27 %
Oil	..	*1 378*	..	*1 895*	*2 296*	*2 919*	*94 %*	*93 %*	*92 %*
Biofuels	..	*6*	..	*19*	*57*	*102*	*1 %*	*2 %*	*3 %*
Other fuels	..	87	..	*96*	*117*	*142*	*5 %*	*5 %*	*4 %*

Note: .. = not available. Data presented are subject to rounding.Source: IEA, 2007.

Source: FAO, The State of Food and Agriculture, Biofuels: Prospects, Risks and Opportunities (2008) , Chapter 4, Section Long-term projections for biofuel development, p.44

Source: FAO, The State of Food and Agriculture, Biofuels: Prospects, Risks and Opportunities (2008) , Chapter 3, Section policy measures affecting biofuel development, p.29

5.7: Biofuel policies in Brazil

Around 45% of all energy consumed in Brazil comes from renewable sources, reflecting the combined use of hydroelectricity (14.5%) and biomass (30.1%); the use of sugar cane in the internal renewable energy supply in 2006 represented 32.2% of renewable energy and 14.5% of total internal energy supply (GBEP, 2007).

Brazil has been a pioneer in national regulatory efforts for the bioenergy sector and has accumulated significant experience and expertise in the area of biofuels, particularly concerning the use of ethanol as a transport fuel. The Brazilian experience of using ethanol as a petrol additive dates back to the 1920s, but it was only in 1931 that fuel produced from sugar cane officially began to be blended with petrol. In 1975, following the first oil crisis, the Government launched the National Ethanol Program (ProAlcool), creating the conditions for large-scale development of the sugar and ethanol industry. The program was aimed at reducing energy imports and fostering energy independence. Its main goals were to introduce into the market a mixture of petrol and anhydrous ethanol and to provide incentives for the development of vehicles that were fueled exclusively with hydrated ethanol. Following the second major oil shock, in 1979, a more ambitious and comprehensive program was implemented, promoting the development of new plantations and a fleet of purely ethanol-fueled vehicles. A series of tax and financial incentives was introduced. The program induced a strong response, with ethanol production rising rapidly along with the number of vehicles running exclusively on ethanol.

Subsidies provided through the program were intended to be temporary, as high oil prices were expected to make ethanol competitive with petrol in the long run. However, as international oil prices fell in 1986, the elimination of subsidies became problematic. In addition, rising sugar prices led to scarcity of ethanol, and in 1989 severe shortages in some of the main consuming centers undermined the credibility of the program.

The period from 1989 to 2000 was characterized by the dismantling of the set of government economic incentives for the program as part of a broader deregulation that affected Brazil’s entire fuel supply system. In 1990, the Sugar and Ethanol Institute, which had regulated the Brazilian sugar and ethanol industry for over six decades, was extinguished, and the planning and implementation of the industry’s production, distribution and sales activities were gradually transferred to the private sector. With the end of the subsidies, the use of hydrated ethanol as fuel diminished drastically. However, the mixture of anhydrous ethanol with petrol was boosted with the introduction in 1993 of a mandated blending requirement specifying that 22% of anhydrous ethanol must be added to all petrol distributed at retail petrol stations. The blending requirement is still in place today, with the Inter-Ministerial Board for Sugar and Ethanol establishing the required percentage, which can range from 20 to 25%.

The most recent phase of the Brazilian ethanol experience began in 2000 with the revitalization of ethanol fuel and was marked by the liberalization of prices in the industry in 2002. Ethanol exports increased further as a result of high oil prices in the world market. The dynamics of the sugar and ethanol industry began to depend much more on market mechanisms, particularly in the international markets. The industry has made significant investments, expanding production and modernizing technologies. An important factor in domestic market development in recent years has been the investment of the automobile industry in bi-fuel or dual-fuel alcohol–petrol cars, also referred to as flex-fuel vehicles, which are able to run on a blend of petrol and ethanol.

Biodiesel, by contrast, is still an infant industry in Brazil, and biodiesel policies are much more recent. The biodiesel law of 2005 established minimum blending requirements of 2 percent and 5 percent to be accomplished by 2008 and 2013, respectively. Reflecting social inclusion and regional development concerns, a system of tax incentives was established for the production of raw materials for biodiesel on small family farms in the north and northeast regions of Brazil. Under a special scheme, the “Social Fuel Seal” (Selo Combustível Social) program, biodiesel producers who buy feedstocks from small family farms in poor regions pay less federal income tax and can access finance from the Brazilian Development Bank. The farmers are organized into cooperatives and receive training from extension workers.

Current bioenergy policies in Brazil are guided by the Federal Government’s Agro-energy Policy Guidelines, prepared by an interministerial team. Linked to the overall policy of the Federal Government, the Ministry of Agriculture, Livestock and Food Supply has prepared a program to meet the bioenergy needs of the country. The goal of the Brazilian Agro-energy Plan 2006–2011 is to ensure the competitiveness of Brazilian agribusiness and support specific public policies, such as social inclusion, regional development and environmental sustainability.

5.8: Biofuel policies in the European Union

Over the past decade, the production and use of biofuels has increased substantially in the European Union (EU). In 2007, 9 billion liters of biofuel were produced, dominated by biodiesel (6 billion liters). The sector has undergone very rapid growth, with Germany accounting for more than half of EU biodiesel production. The main feedstock used is rapeseed (about 80 percent), with sunflower oil and soybean oil making up most of the rest. The EU industry has been slower to invest in ethanol production, which totaled almost 3 billion liters in 2007. The main ethanol feedstocks are sugar beet and cereals.

EU biofuel legislation consists of three main Directives. The first pillar is Directive 2003/30/EC for promotion of a biofuels market in the EU. To encourage biofuel use, in competition with less costly fossil fuels, the Directive sets a voluntary "reference target" of 2 percent biofuel consumption (on the basis of energy content) by 2005 and 5.75 percent by 31 December 2010. It obliges Member States to set national indicative targets for the share of biofuels, in line with reference percentages of the Directive, although it leaves them free to choose a strategy to achieve these targets.

The second pillar is Directive 2003/96/EC, which allows for the application of tax incentives for biofuels. Taxation not being within the sphere of action of the European Community, each Member State can decide on a level of taxation for fossil fuels and biofuels. However, these tax exemptions are considered as environmental state aid and therefore their implementation by Member States requires authorization from the European Commission in order to avoid undue distortions of competition.

The third pillar of the EU biofuel legislation concerns environmental specifications for fuels indicated in Directive 98/70/EC amended by Directive 2003/17/EC. The Directive contains a 5 percent limit on ethanol blending for environmental reasons. The Commission has proposed an amendment that includes a 10 percent blend for ethanol.

Bioenergy support has also been introduced as part of the Common Agricultural Policy, especially following its reform in 2003. By cutting the link between payments made to farmers and the specific crops they produce, the reform allowed them to take advantage of new market opportunities such as those offered by biofuels. A special aid of €45 per hectare is available for energy crops grown on non- set-aside land (traditional food crop areas). In addition, while farmers cannot cultivate food crops on set-aside land, they can use this land for non-food crops, including biofuels, and are eligible to receive compensatory payments per hectare.

Support to bioenergy comes also from the new EU rural development policy, which includes measures to support renewable energies, such as grants and capital costs for setting up biomass production.

In March 2007, the European Council, based on the Commission's Communication An energy policy for Europe, endorsed a binding target of a 20 percent share of renewable energies in overall EU energy consumption by 2020, as well as a 10 percent binding minimum target for the share of biofuels in overall EU petrol and diesel consumption for transport by 2020. The latter target is subject to production being sustainable, second-generation biofuels becoming commercially available and the fuel- quality Directive being amended to allow for adequate levels of blending (Council of the European Union, 2007). A proposal for a renewable energy Directive including both these targets and sustainability criteria for biofuels was put forward by the European Commission to the Council and the European Parliament on 23 January 2008.

5.9: Biofuels and the World Trade Organization

The World Trade Organization (WTO) does not currently have a trade regime specific to biofuels. International trade in biofuels falls, therefore, under the rules of the General Agreement on Tariffs and Trade (GATT 1994), which covers trade in all goods, as well as other relevant WTO Agreements such as the Agreement on Agriculture, the Agreement on Technical Barriers to Trade, the Agreement on the Application of Sanitary and Phytosanitary Measures and the Agreement on Subsidies and Countervailing Measures. Agricultural products are subject to the GATT and to the general rules of the WTO insofar as the Agreement on Agriculture does not contain derogating provisions.

Key trade-related issues include the classification for tariff purposes of biofuel products as agricultural, industrial or environmental goods; the role of subsidies in increasing production; and the degree of consistency among various domestic measures and WTO standards.

The Agreement on Agriculture (AoA) covers products from Chapters 1 to 24 of the Harmonized System, with the exception of fish and fish products and the addition of a number of specific products, such as hides and skins, silk, wool, cotton, flax and modified starches.

The discipline of the AoA is based on three pillars: market access, domestic subsidies and export subsidies. One of the main features of the AoA is that it allows Members to pay subsidies in derogation from the Agreement on Subsidies and Countervailing Measures.

The Harmonized System classification affects how products are characterized under specific WTO Agreements. For example, ethanol is considered an agricultural product and is therefore subject to Annex 1 of the WTO AoA. Biodiesel, on the other hand, is considered an industrial product and is therefore not subject to the disciplines of the AoA. Paragraph 31(iii) of the Doha Development Agenda has launched negotiations on “the reduction or, as appropriate, elimination of tariff and non-tariff barriers to environmental goods and services”. Some WTO Members have suggested that renewable energy products, including ethanol and biodiesel, should be classified as “environmental goods” and therefore subject to negotiations under the “Environmental Goods and Services” cluster.

5.10: Biofuels and preferential trade initiatives

For developing countries, the challenges associated with producing bioenergy for the international market are particularly acute. Trade opportunities may be reduced by measures that focus exclusively on enhancing production in developed countries, or by protectionist measures designed to limit market access. Tariff escalation on biofuels in developed-country markets can restrict developing countries to exporting feedstocks, such as unprocessed molasses and crude oils, while the actual conversion into biofuels – with its associated value-added – often occurs elsewhere.

A number of European Union (EU) and United States preferential trade initiatives and agreements have been introduced that offer new opportunities for some developing countries to benefit from the increasing global demand for bioenergy. Preferential trade with the EU for developing countries falls under the EU's Generalised System of Preferences (GSP). In addition, the Everything But Arms (EBA) initiative and the Cotonou Agreement contain provisions of relevance to the bioenergy sector. Under the current GSP, in effect until 31 December 2008, duty-free access to the EU is provided to denatured and undenatured alcohol. The GSP also has an incentive programme for ethanol producers and exporters who adhere to sustainable development principles and good governance. The EBA initiative provides least-developed countries with duty-free and quota-free access to ethanol exports, while the Cotonou Agreement provides duty-free access for certain imports from African, Caribbean and Pacific countries. The Euro-Mediterranean Association Agreements also contain provisions for preferential trade in biofuels for certain countries in the Near East and North Africa. In the United States of America, ethanol may be imported duty-free from certain Caribbean countries under the Caribbean Basin Initiative, although there are specific quantitative and qualitative restrictions depending on the country of origin of the feedstocks. Provisions for duty-free ethanol imports have also been proposed in the US-Central America Free Trade Agreement negotiations.

However, while such preferential access can provide opportunities for beneficiaries, it also creates problems of trade diversion, to the disadvantage of the developing countries not benefiting from the preferential access.

5.11: Jatropha curcas

As an energy crop, Jatropha curcas (L.(jatropha) is making a lot of headlines. The plant is drought-tolerant, grows well on marginal land, needs only moderate rainfall of between 300 and 1 000 mm per year, is easy to establish, can help reclaim eroded land and grows quickly. These characteristics appeal to many developing countries that are concerned about diminishing tree cover and soil fertility and are looking for an energy crop that minimizes competition with food crops. At the same time, this small tree produces seeds after two to five years containing 30% oil by kernel weight – oil that is already being used to make soap, candles and cosmetics and has similar medicinal properties to castor oil, but is also useful for cooking and electricity generation.

A native of northern Latin/Central America, there are three varieties of jatropha: Nicaraguan, Mexican (distinguished by its less- or non-toxic seed) and Cape Verde. The third of these varieties became established in Cape Verde and from there spread to parts of Africa and Asia. On Cape Verde it was grown on a large scale for export to Portugal for oil extraction and soap-making. At its peak, in 1910, jatropha exports reached over 5 600 tons (Heller, 1996).

The many positive attributes claimed for jatropha have translated into numerous projects for large-scale oil and/or biodiesel production as well as small-scale rural development. International and national investors are rushing to establish large areas for jatropha cultivation in Belize, Brazil, China, Egypt, Ethiopia, the Gambia, Honduras, India, Indonesia, Mozambique, Myanmar, the Philippines, Senegal and the United Republic of Tanzania. The largest- scale venture is the Indian Government's "National Mission" to cultivate jatropha on 400 000 hectares within the period 2003–07 (Gonsalves, 2006). By 2011–12, the goal is to replace 20 percent of diesel consumption with biodiesel produced from jatropha, cultivated on around 10 million hectares of wasteland and generating year-round employment for 5 million people (Gonsalves, 2006; Francis, Edinger and Becker, 2005). The original target may well be ambitious, as Euler and Gorriz (2004) report that probably only a fraction of the initial 400 000 hectares allocated to jatropha by the Indian Government is actually under cultivation.

The plant also grows widely in Africa, often as hedges separating properties in towns and villages. In Mali, thousands of kilometres of jatropha hedges can be found; they protect gardens from livestock and can also help reduce damage and erosion from wind and water. The seed is already used for soap-making and medicinal purposes, and jatropha oil is now also being promoted by a non-governmental organization to power multifunctional platforms, a slow-speed diesel engine containing an oil expeller, a generator, a small battery charger and a grinding mill (UNDP, 2004). Pilot projects promoting jatropha oil as an energy source for small-scale rural electrification projects are under way in the United Republic of Tanzania and other African countries.

Despite considerable investment and projects being undertaken in many countries, reliable scientific data on the agronomy of jatropha are not available. Information on the relationship between yields and variables such as soil, climate, crop management and crop genetic material on which to base investment decisions is poorly documented. What evidence there is shows a wide range of yields that cannot be linked to relevant parameters such as soil fertility and water availability (Jongschaap et al., 2007). Experience with jatropha plantations in the 1990s, such as the "Proyecto Tempate" in Nicaragua, which ran from 1991 to 1999, ended in failure (Euler and Gorriz, 2004).

Indeed, it appears that the many positive claims for the plant are not based on mature project experiences. Jongschaap et al. (2007) argue that, on a modest scale, jatropha cultivation can help with soil-water conservation, soil reclamation and erosion control, and be used for living fences, firewood, green manure, lighting fuel, local soap production, insecticides and medicinal applications. However, they conclude that claims of high oil yields in combination with low nutrient requirements (soil fertility), lower water use, low labor inputs, the non-existence of competition with food production and tolerance to pests and diseases are unsupported by scientific evidence. The most critical gaps are the lack of improved varieties and available seed. Jatropha has not yet been domesticated as a crop with reliable performance.

The fear that the rush into jatropha on the basis of unrealistic expectations will not only lead to financial losses but also undermine confidence among local communities – a recurrent theme in many African countries – appears to be well founded. Sustainable jatropha plantations will mean taking the uncertainty out of production and marketing. Further research is needed on suitable germplasm and on yields under different conditions, and markets need to be established to promote sustainable development of the crop.

5.12 The National Biofuels Project in Zimbabwe.

5.12.1 Introduction

The National Biodiesel Project was launched amidst erratic supply of imported fuel to the market and hence the need to build in self sufficiency and availability to the energy market. The author was part of the steering team that had to work on this reality. As a result, the author in collaboration with a few other specialists listed below took charge of the task. Invariably the author's opportunity of analyzing the cost of production for the biofuels industry arose. At the time of compiling this script, two commercial plants and one pilot plant for biofuels are in operation in Zimbabwe. The biodiesel plant has a plant capacity of producing 100 million liters per annum. Whilst the biodiesel pilot plant processes 60 000liters of biodiesel per month. The commercial plant is located about 17Km outside the central business district of Harare and the pilot plant is 143Km away in a location setup in rural Mashonaland East Province. The ethanol commercial plant is located 500Km from Harare and thus due to distance travelling challenges the author concentrated on the biodiesel plants.

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5.12.2 Brief background

Given the more than decade long harsh economic sanctions that Zimbabwe as a country was internationally subjected to, and the sudden fuel shortages as a result of unavailable foreign denominated currencies it then became apparent that engineering scientists had to proffer sustainable solutions to the erratic energy supply systems that were prevailing. Communities could no longer move or transport with ease goods and services neither could they carry out other economic activities. Lack of energy meant dwindling economic activities and decrease in the standard of living. Hence, in order to meet these obligations as scientists to society, Research and Development activities in the remotest places, i.e. in rural communities, commenced. In this regard the following were to be developed;

- Industrial and agricultural economic activities;
- Build a biodiesel producing plant in Mutoko Rural District;

- Using the meager financial resources at our disposal, lobby government to fully adopt the project at national level.
- However, on acceptance by government to consider the project at national level, the funding was slow in coming and inadequate.
- We also opted to:

1. Generate a policy framework for renewable energy;
2. Motivate:
    i. Peasant farmers through seed purchasing from their live fences;
    ii. School clusters for jatropha propagation through competitions;
    iii. Village heads for jatropha mobilization;
3. Creation of an energy farming zone through estate farming of jatropha. Purpose: to safeguard baseline feedstock supply levels to meet demand and use peasant farmer harvests as surplus;
4. Carrying out intercropping in jatropha plantations to generate revenue for funding other related activities.
5. Value addition to:
    i. Seed through crushing and obtaining crude oil and cake;
    ii. Conversion of:
        - oil through transesterification to biodiesel;
        - cake to organic fertilizer, stockfeed for pigs, electricity generation;
        - glycerine to laundry soap and other pharmaceutical uses;
        - use of biodiesel in power generation;
6. Meanwhile, initial capital investment was to be recouped through sales of biodiesel, soap, glycerine, and cake.

5.12.3 Milestones:

1. During production of biodiesel the trans-esterification process in the reactor was reduced from 2Hrs (according to literature) to 20 minutes;
2. We also designed and manufactured oil expellers suitable for crushing jatropha seed with a >95% proficiency and efficiency level;
3. We designed and constructed a pilot 60 000liter per month biodiesel producing plant using 70% local materials. The plant is placed on a 102Ha plot which we are also using as an experimental field for varieties of jatropha and their oil yields. A 500tonne feedstock storage facility and two quality assurance laboratories are also to be found

built on this land; The National Oil Company of Zimbabwe is the current consumer of the biodiesel;

4. A jatropha seed sheller of 1tonne per hour was also designed and installed;
5. Meanwhile, the whole pilot plant and ancillary buildings run on 100% pure biodiesel powered generator;
6. 400 x 1Kg bars of laundry soap are being produced per week using crude glycerin and corresponding oil ratios. The demand for the soap has been overwhelming.
7. A 3tonne truck that we use for purchase and collection of jatropha from peasant farmers also runs on 100% biodiesel;
8. We put in place jatropha out-grower schemes through satellite seed banks in rural areas;
9. We marketed through print and electronic media the growth of jatropha;
10. School children, village heads and members of parliament were mobilized to encourage jatropha propagation;
11. A 15 000Ha farm in one district is currently being developed for estate farming of jatropha;
12. Government on realizing our zeal and unwavering thrust on green energy has now decided that the project be commercialized as seen by its commitment to move the project from the Ministry of Higher and Tertiary Education, Science and Technology Development to the Ministry of Energy and Power Development. Two policies on Renewable Energy and Biofuels are currently underway to capacitate this project.
13. Targeted blending ratios are set at 2% (B2) by 2020; at 5% (B5) by 2025; at 10% (B10) by 2030.
14. This project has registered with UNFCCC since 2016 anticipating to access carbon credits for purposes of injecting reasonable quantum of funds to accelerate its implementation.
15. Currently we are in the process of registering for the ABU-DHABI Funds For Developing Countries which opened on the 16th of November 2017. We are almost through with the Executive Summary.

5.12.4 Economic background and justification

Zimbabwe imports all its diesel requirements (approx.1 billion liters/per year) and this requires foreign currency in excess of USD 500 million according to April 2005 statistics. The past five years have seen the country going through a trying period due to shortage of the requisite foreign currency. Meanwhile, the ever-fluctuating petroleum prices on the international scene have also played havoc on the national fiscus planning. These challenges have resulted in a number of local initiatives being undertaken by various corporate bodies including government institutions to explore alternative resources for energy and power development. One such area, found through extensive research work, is the substitution of mineral diesel with bio-diesel. Bio-diesel is produced by reacting vegetable oil and methanol in the presence of an alkali catalyst such as caustic soda. This process is called **transesterification**. Since Zimbabwe is an agro-based economy, it will be easy to mobilize raw materials for production of the bio-diesel. The money that has been used to import the fuel can easily be used to finance the production of raw materials as well as the construction of processing plants.

A number of plant oils that can be used for bio-diesel production are grown in Zimbabwe and these include sunflower, groundnuts, soya bean, maize and *Jatropha curcas*. The most economically viable of these is the jatropha oil. This oil is extracted from seeds of *Jatropha curcas* plant which have an average oil content of 40%. The plant can be grown in the semi-arid to arid regions of Zimbabwe, namely Region III and IV. Depending on climatic conditions and age, seed yield ranges from 0.4 ton/ha to 12 ton/ha. One liter of jatropha oil produces one liters of bio-diesel. Taking an average seed yield of 8 tons per hectare, the jatropha oil yield per hectare is 3 810 liters which translates to 3 810 liters of bio- diesel per hectare. With Zimbabwe's annual requirement of 1 billion liters of diesel per year, about 265 thousand hectares of jatropha would be required to satisfy this demand.

In the event that the program takes off methanol will, in the short to medium term, be imported since it is not readily available. In the interim, a project on methanol production should be implemented. There are established technologies for methanol production hence it is hoped that the local initiative on methanol and biomass energy resources will address this requirement in the long term. The amount of methanol required is one tenth of the amount of vegetable oil required which means that for the proposed plant capacity of 99 million liters per annum (to meet one tenth of national demand) about 10 million liters of methanol need to be imported. In addition to this about 3 % of sodium hydroxide (caustic soda) catalyst is required. The catalyst can easily be sourced from local suppliers. The bio-diesel is environmentally friendly as it does not release Sulphur dioxide (SO_2) and nitrous oxide (NO_x) hence does not contribute to global warming.

Local Tertiary Colleges had made commendable progress on bio-diesel technologies development and had already commenced benchmarking production based on small scale models (50 – 100 liters per day). It was therefore considered prudent to verify the research and development activities conducted through these local initiatives on the back of the availability of similar technologies on the international market and the possibility of technology transfer from interested partners. Accordingly, a Technical Steering Committee was set up to consolidate the research activities conducted so far with a view to recommend the way forward pertaining to the National Bio-diesel Project. The Committee was composed of members from Chinhoyi University of Technology, Masvingo Polytechnic College, Harare Polytechnic College, Verify Engineering (Pvt) Ltd. and the Ministry of Science and Technology Development. The given terms of reference were:

a. To assess the availability of feedstock and research into generation methods thereof.
b. To recommend bio-diesel production plants for a national capacity and farm size designs.
c. To carry out the program financial and economic analysis.

Subsequently, three sub-committees were formed and given specific terms of reference as indicated herein. Committee's research was based on the available information from the various institutions, internet services, magazines and visits to the rural areas and relevant industrial companies. In its findings, the Committee established that the availability of local industrial expertise and capacity to fabricate, construct and install the national bio-diesel production plant is an added advantage as this will reduce foreign component requirements.

On the availability of feed stock; according to estimates, Zimbabwe currently has about 2000 hectares under jatropha that is in Mutoko, Mudzi, Binga and some other rural areas. Assuming a seed yield of 6 tons/ha this can produce about 5.7 million liters of bio-diesel per annum. A sustained supply of agricultural raw materials is only possible if there was an organized form of agriculture. Furthermore, to ensure a viable supply of raw materials particularly in terms of the oil source, a model for raw material procurement must be put in place. During the implementation of the program, four agricultural models will be developed. The first national pilot plant with an annual capacity of 99 million liters of bio-diesel will be set up in Mutoko. Other bio-diesel production facilities may be set up at growth points or urban centers closer to Bikita, Binga, Nyanga, Chivi and Beitbridge. These districts have been chosen because there are limited cash crops grown in these areas. There would be no threat from introduction of jatropha. Gokwe is also suitable for jatropha growing, but because this is a cotton growing area, it is therefore not recommended for such a massive program.

In summary, the financial projections indicate inevitable huge savings on foreign currency and, in the long term, potential to improve inflows through export of excess bio-diesel.

- The required fixed capital for the national biodiesel plant was about USD23 000
- The working capital required was about USD7 million.
- The total capital injection required to set up the biodiesel plant was USD30 million.
- The unit cost of producing 1 liter of bio-diesel was USD0.41 (when feedstock seed was purchased at USD51.43 per ton).
- The projected sales per annum was approximately USD75 million (with a producer price of USD0.57 per liter)
- Pay back period was 2 years.

N.B.: Whilst we have referred the aforementioned statistics in past tense, but the whole context of the information in this chapter will be addressed in the present in-order to accurately capture the events at the time of executing this project. Meanwhile, any values given in local currency were convertible and transferrable at the rate of ZWD17,500:USD1.

FINANCIAL AND ECONOMIC ANALYSIS SUB-COMMITTEE COMPOSITION

NAME	INSTITUTION	REMARKS
Mrs R Karimanzira	Ministry of Science and Technology Development	Chairperson
Eng. C S Shonhiwa	Chinhoyi University of Technology	Member
Mr V Mukosera	Harare Polytechnic	Member

TERMS OF REFERENCE

The sub-committee is responsible to the Committee Chairman with regards to:

a. Appraisal of the Operating Environment i.e. international oil/fuel market pressures, fuel demand in Zimbabwe, monetary policy framework etc.
b. Investment impact and benefits to Zimbabwe.
c. Cost-benefit analysis of technology transfer (import) versus local innovation (capacity building).
d. Financial Projections.
e. Any other relevant investor considerations.

FEED STOCK GENERATION SUB-COMMITTEE COMPOSITION

NAME	INSTITUTION	REMARKS
Dr M Mupa	Verify Engineering	Chairperson
Mr L Mondo	Masvingo Polytechnic	Member
Mr G Jim	Chinhoyi University of Technology	Member

TERMS OF REFERENCE

The sub-committee is responsible to the Committee Chairman with regards to:

a. Assessment of potential agricultural input material and recommending the best two feed stock for the crude oil.
b. Assessment and recommendation of reactants and catalytic material with a view to produce high quality end product.
c. Appraisal of existing resource base of the recommended input materials.
d. Recommending the way forward on feed stock generation methods and distribution thereof.
e. Implementation plan.

PLANT DESIGN SUB-COMMITTEE COMPOSITION

NAME	INSTITUTION	REMRKS
Eng. L Mondo	Verify Engineering	Chairperson
Pr. Eng. C Kanyunga	Chinhoyi University of Technology	Member
Eng. P. Mpala	Harare Polytechnic	Member
Eng. Z. A Charangwa	Masvingo Polytechnic	Member
Dr. Z. Chiguvare	University of Zimbabwe	Member

TERMS OF REFERENCE

The sub-committee is responsible to the Committee Chairman with regards to:

a. Process flow review and plant automation.

b. Design and distribution model for small scale/farm size oil expressing machines.

c. National plant design (inclusive of feed stock handling, process and storage facilities).

d. Infrastructural and utility requirements.

e. Environmental Impact and Mitigation considerations.

f. Implementation plan.

5.12.5 PROCESS DESCRIPTION AND PLANT DESIGN

5.12.5a) Process flow overview.

The bio-diesel fuel can be produced from vegetable oils, animal fats and used cooking oil (yellow grease), using a fairly simple chemical reaction known as **transesterification**. In this process oil reacts with a simple alcohol, (methanol/ethanol) in the presence of a catalyst (caustic soda / potash), and under specified conditions such as a temperature of sixty-five degrees and normal atmospheric pressure, to yield a mixture of methyl or ethyl esters which is the bio-diesel:

Catalyst

Oil (vegetable/ animal fats) + alcohol (methanol) ⟶ bio-diesel + glycerol.

(100 kg) (10 kg) (1kg) (100 kg) (10kg)

Mass balance for the recommended national plant:

(300 tons) (30 tons) (3 tons) (300 tons) (30 tons)

Reaction temperature: 65^{o}C; Pressure: 1 bar; Reaction time: 2 hours per batch.

The flow charts below **(Fig. 5.6 and 5.7)** reflect the process of making bio-diesel.

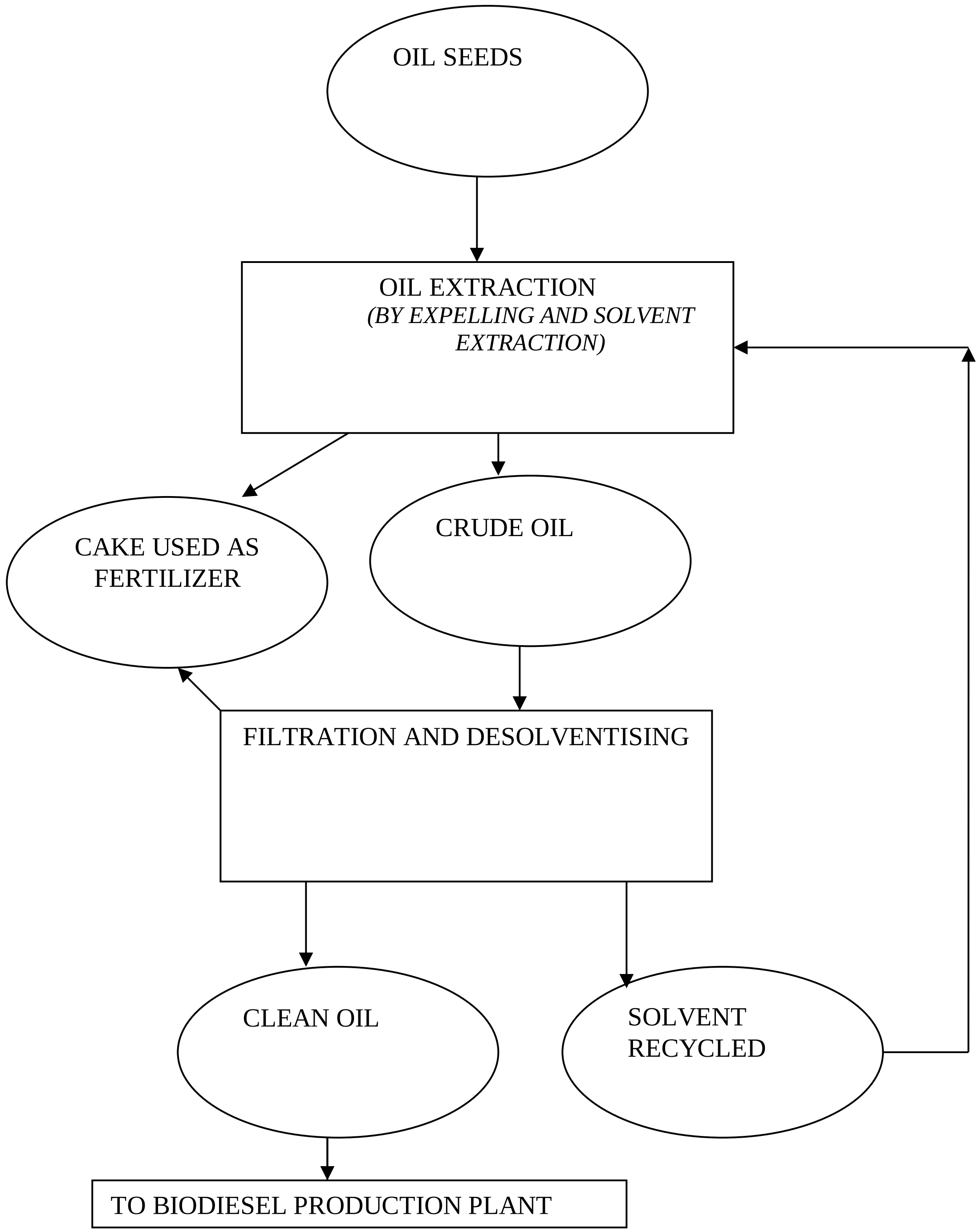


Fig. 5.1: Flow chart for the production of jatropha oil

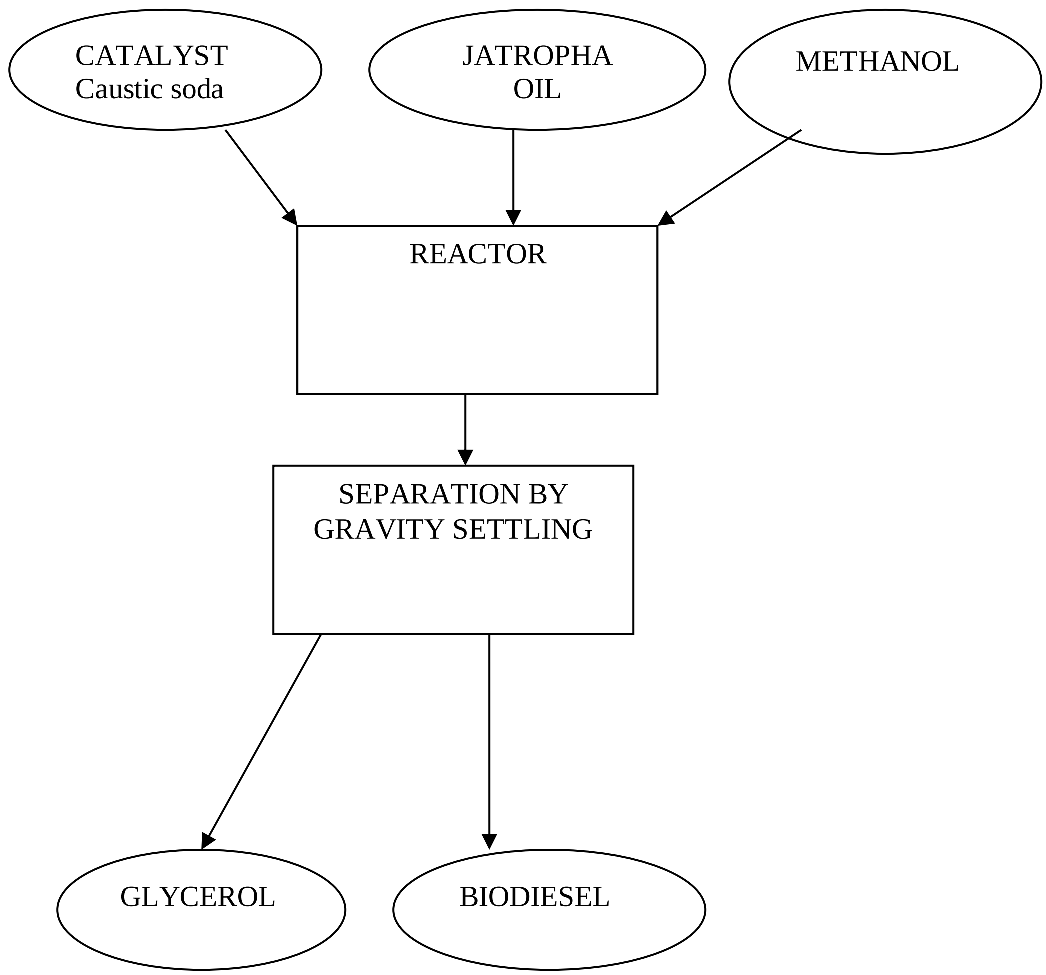


Fig. 5.2: Biodiesel production flow chart

5.12.5(b) Design and Distribution of Small Scale / Farm Size oil-expressing machines

The small scale or farm-size oil expressing machines are intended for use by individual farmers or groups of farmers (cooperatives) who produce oilseeds such as jatropha, castor beans, sunflower, soya beans, etc. The idea is to extract oil at the farms and then transport it to a bio-diesel processing plant located at some center in a district or province where it is then processed into bio-diesel. The farm set-up will comprise an oil expressing machine and filter press to clean the oil. The capacity of such machines can range from 1 to 5 tons of oil seed a day which translates to 250 liters to 1250 liters of oil per day respectively. Machines in this range are already available on the market and there is no need to design and build one at the moment. A typical oil expressing machine which can be used at Growth Points is a Chinese made screw type machine with the following details:

- Type: - Model 6YL- 100
- Capacity: - 1800 to 2400 kg oilseed per day.
- Price: -USD8 000.
- Local supplier in Harare: Appropriate Technology Africa
- The filter press from the same supplier costs USD2 000.

Oil expressing machines may be distributed among individual farmers or groups of farmers throughout a district. The farmers choose the size of machines according to their affordability and needs. The oil from the farms is collected by the bio-diesel processors using a model probably similar to the one used by the dairy industry when collecting milk from dairy farmers. This model may have the following advantages and disadvantages which need to be weighed against each other when deciding the best course of action.

- Oilseed cake remains at the farm and can be used as stock feed (applicable to raw materials other than jatropha and castor bean) or as a fertilizer.
- Processed oil is less bulky when transported to the bio-diesel plant than the unprocessed oilseeds.
- Extraction of the oil may be regarded as value addition of the product and hence should mean more income for the farmer.
- Some residual oil remains in the cake because the expeller cannot exhaust all the oil, hence less oil yield per given mass of oilseed and solvent extraction is neither economic nor safe at this level.

- Relatively high capital cost for acquiring an oil-expressing machine, filter press and solvent extraction technology.
- Handling of liquids is more problematic than is the case with solids.
- The process of oil extraction is time consuming for the farmers.
- Maintenance costs for the machines and filter press is prohibitive.
- The processed oil could encourage middlemen and side markets.

The process flow chart for the farm set-up is illustrated in Fig.5.3.

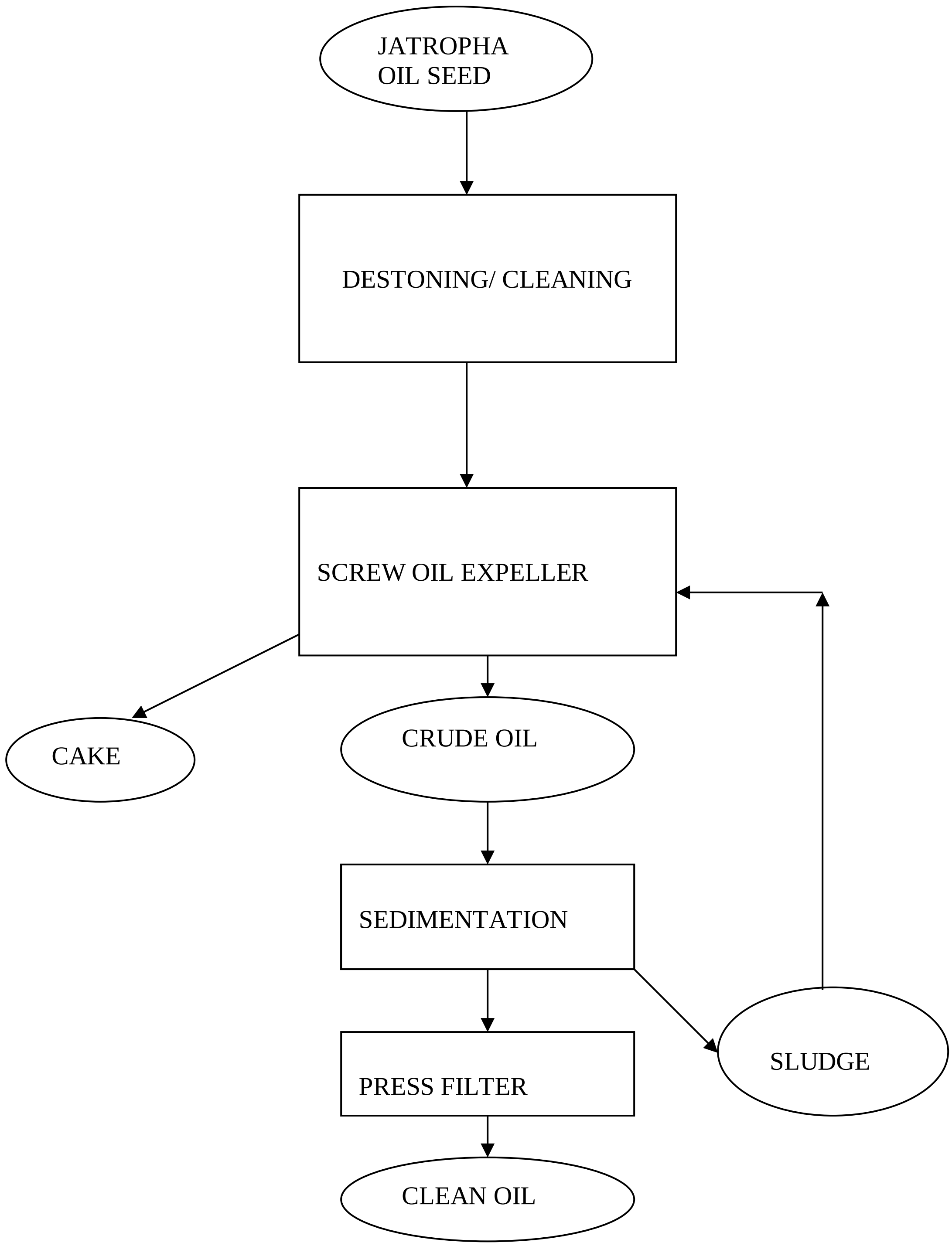


Fig. 5.3 Flow chart for the farm set-up.

5.12.6 National Plant Design *(300 000Litres/day of biodiesel)*

The national processing plant consists of two main sections namely the oil extraction plant and the Bio-Diesel processing plant.

5.12.6 (a) Oil Extraction Section

The extraction section will be composed of 3 modular oil extractions plants, each with a capacity of processing 300 tons of jatropha seed per day. This translates to 100 000 liters of Jatropha oil making a combined total of 300 000 liters of Jatropha oil per day. The oil is extracted in two major steps i.e. expelling and solvent extraction. The whole process may be divided as follows:

i) Raw material preparation

The main objective of the preparation stage is to ensure the seeds are in a state that gives optimization during the later conditioning and oil extraction stages. At the cleaning stage foreign materials like stones, leaves, trash and metallic objects are removed through use of shaking table – screens, suction fans, cyclones and magnets.

Dehulling is done to remove the coating (that is hulls) on seeds and the dehulled seeds are called meats. Separation of the hulls from the meats is done to bring their levels to 20% by mass. Temporary storage bins hold the seeds or meats prior to being conveyed to the conditioning stage. At the conditioning stage there is addition of steam and mixing of meats or seeds to expose their oil-bearing cells prior to the solvent extraction stage. The conditioned seeds are flaked and others are turned into collets or pellets.

ii) Extraction

Meats pass through the expelling stage where a screw press squeezes out the oil. The oil is screened and filtered from dirty material. The squeezed meat together with flakes and collets are conveyed to the solvent extraction stage. Here hexane is sprayed on the cake, flakes, and collets to absorb the oil during the extraction process. The oil and hexane now a mixture called the miscella is heated to remove the solvent, hexane by evaporation. The crude oil is pumped to the storage tanks. Hexane is cooled after the evaporation stage and then pumped back for reuse in the extraction stage.

iii) Meal handling

The meal, now composed of collets and flakes is dried, ground and then conveyed to the storage bins ready for use as an organic fertilizer.

5.12.6(b) Bio-Diesel Production Section

Jatropha oil collected from farmers or the oil extraction plant is stored in two large tanks ($4500m^3$ each) with a capacity of one month's supply of oil. Pumps, P1 and P2 transfer the oil into two $30m^3$ capacity batch reactors each with an internal steam heating coil. Each of the reactors has an explosion proof simple paddle mixer, which has fixed speed of 1750 rpm. A load cell is mounted on one leg of each of the reaction tanks. Methanol is added to the catalyst preparation tank using air operated pumps P3 and P4. The prepared alcohol catalyst solution is added to the reaction tank using pumps P5 and P6. Filling each of the reactors takes 30 minutes and the filling is done simultaneously. The reactants are agitated for two hours while steam for heating is passed through the heating coils. The steam is generated by two boilers. The reactants from the two reactors are transferred to a $60m^3$ cone bottomed tank using pumps P7 and P8 for bio-diesel and glycerin separation. Emptying of each reactor takes 30 minutes and for the two reactors this occurs simultaneously. Each 8hour shift uses 2 settling tanks so in total six of these tanks are required for the plant. The amount of biodiesel and glycerin is measured using a load cell. A Micro Motion coriolis-type density meter which is installed at the exit of the separation tank identifies the glycerin and biodiesel phases during the separation processes. A pump transfers the glycerin to the glycerin storage tank. After the glycerin has been pumped out the same pump then pumps the bio-diesel into the storage tanks with a capacity of holding up to one month's production.

5.12.6(c) Regional Bio-Diesel Processing Plant

(Capacity: 100 000Litres a day of Bio-diesel)

This plant is made up of a single 300 tons Jatropha seed oil extraction unit and a 100 000 liter per day bio-diesel production plant. The process is the same as in the National Plant but the difference is only in capacity. These will be located at district or provincial centers.

The infrastructural and utilities needs for the industrial plant:

- Area of land required is about 50 hectares measuring 500m by 1000m.

- Total road length to be constructed within the plant area is going to be about 2.5 km at an estimated cost USD70,000
- Ancillary buildings to be constructed (office blocks, ablution blocks, workshops, etc.) will cost an estimate of USD350,000
- Warehouse – USD300,000.
- Utilities (boilers, transformers, process air, etc.) – USD1.2 million.

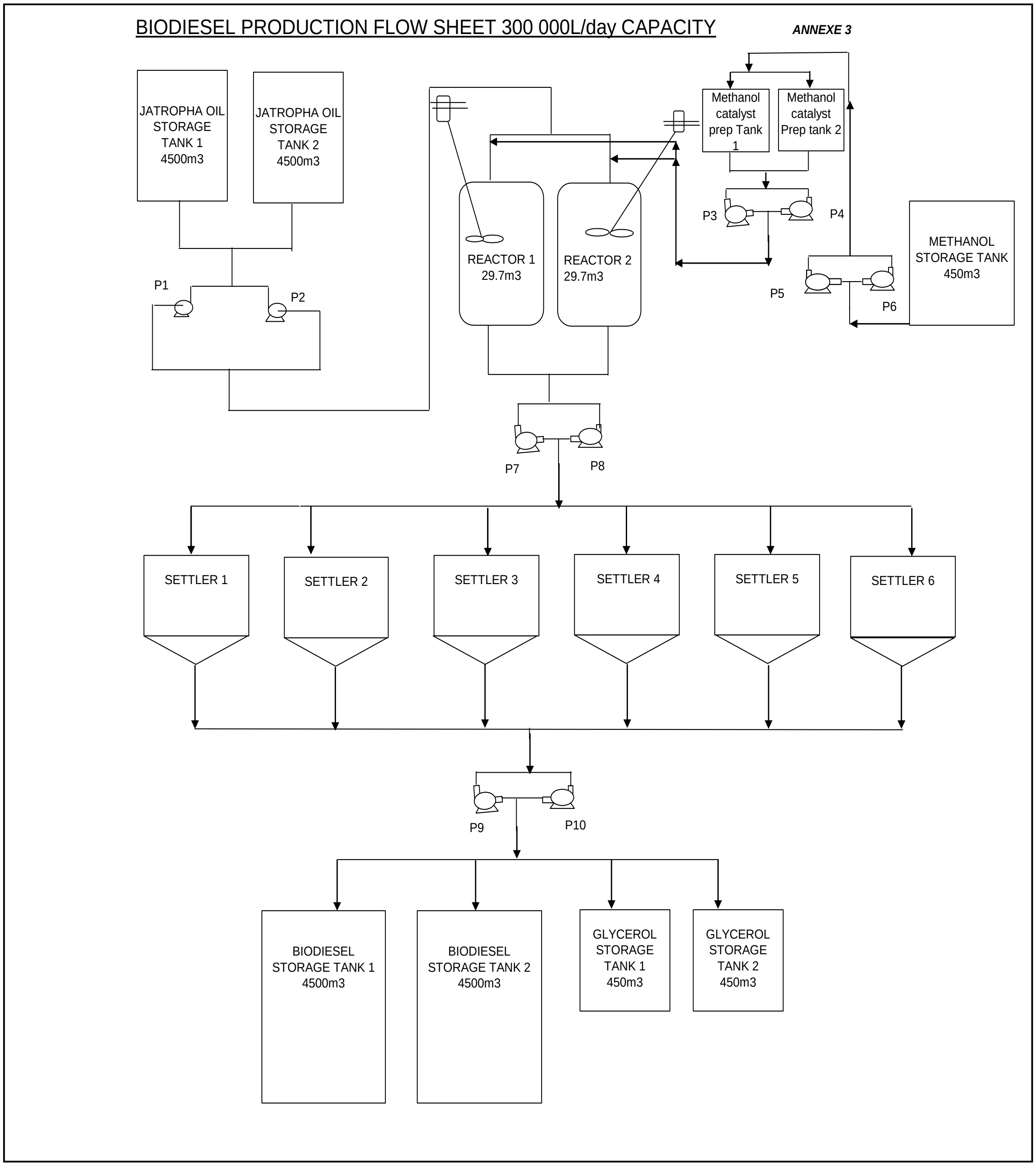
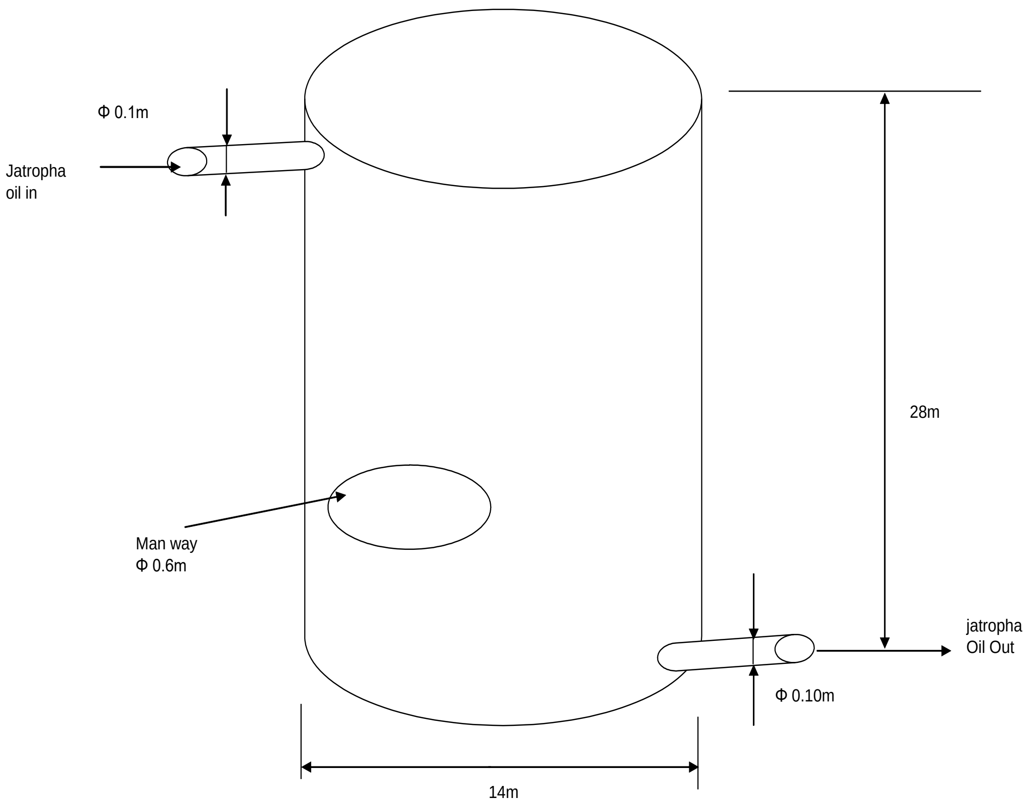


Fig. 5.4 Tank yard layout

Fig 5.5 Jatropha oil storage tank

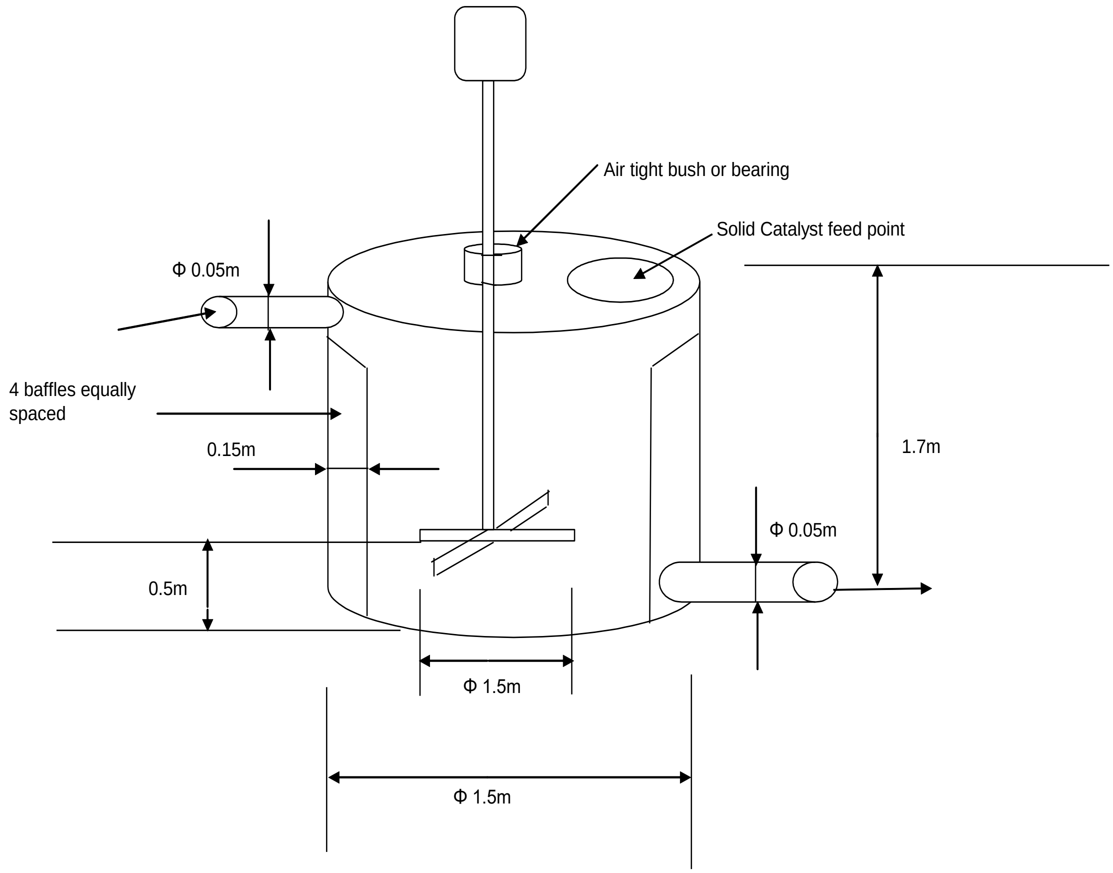
JATROPHA OIL STORAGE TANK DIAGRAM ***ANNEXE 4***



One month's supply of oil for the plant (combanied capacity)
Material of construction = Mild steel
Capacity = 4500m3

CATALYST PREPARATION TANK

ANNEXE 6

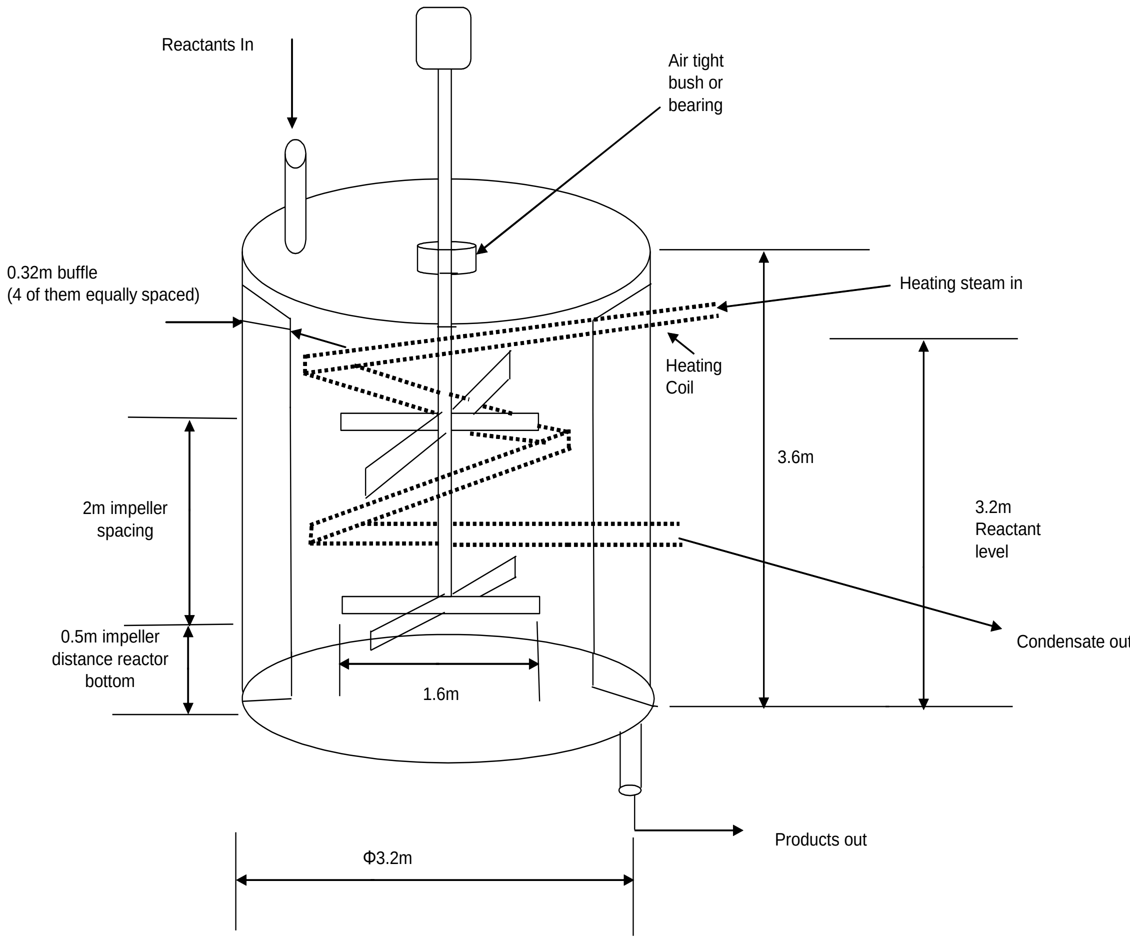


Tank capacity = 2.5m3
Filling up time = 10mins
Reaction time = 20 mins
Emptying time = 10 mins

Fig. 5.6 Catalyst preparation tank

REACTOR DIAGRAM

ANNEXE 7

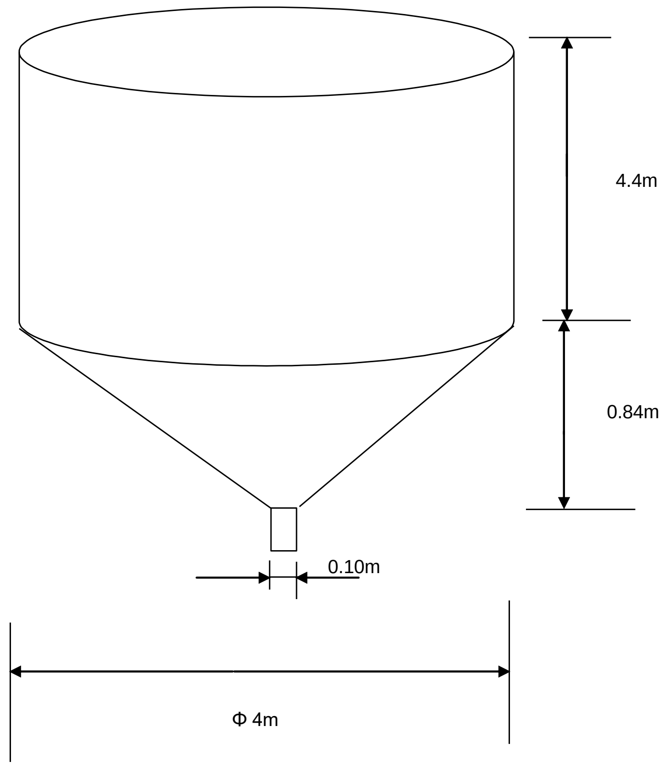


Reactor Volume = 29.7m3
Material of construction = mild steel
Filling up time = 40 mins, Heating up time = 30mins, Reaction time = 2Hrs, Emptying time = 40 mins

Fig. 5.7 Reactor Vessels.

SETTLER DIAGRAM

ANNEXE 8

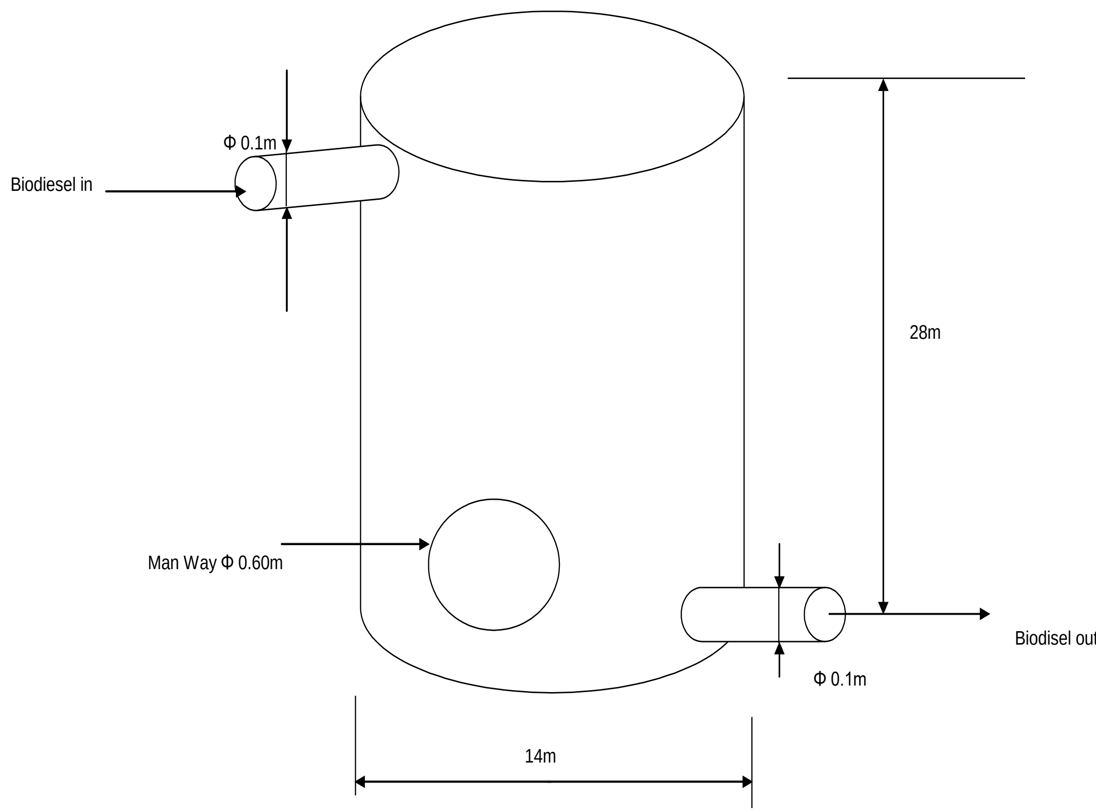


Volume = 58.7m3
Material of construction = mild Steel

Fig. 5.8 Settler tank.

BIODIESEL STORAGE TANK

ANNEXE 9



One month's production of biodiesel (Combined capacity)
Material of construction = Mild steel
Capacity = $4500m3$

Fig. 5.9 Biodiesel storage tank.

GLYCEROL STORAGE TANK

ANNEXE 10

Tank capacity = 450m3
Material of construction = mild steel

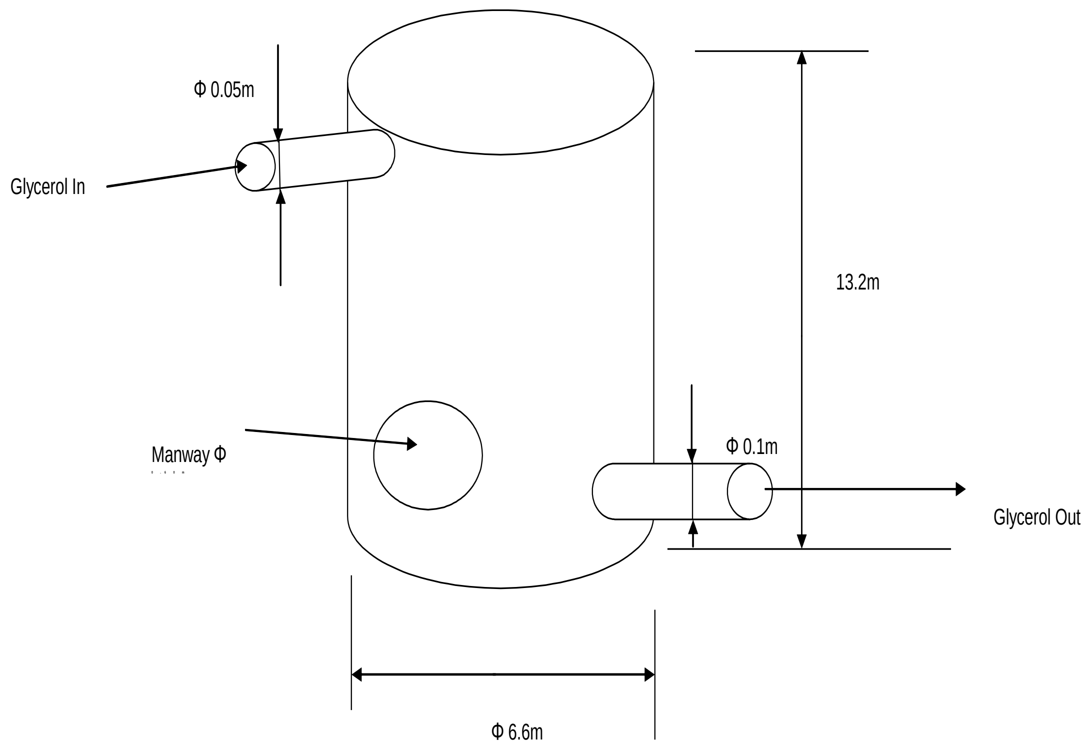


Fig. 5.10 Glycerol storage tank.

BIODIESEL PRODUCTION FLOW SHEET 100 000L/day CAPACITY

ANNEXE 11

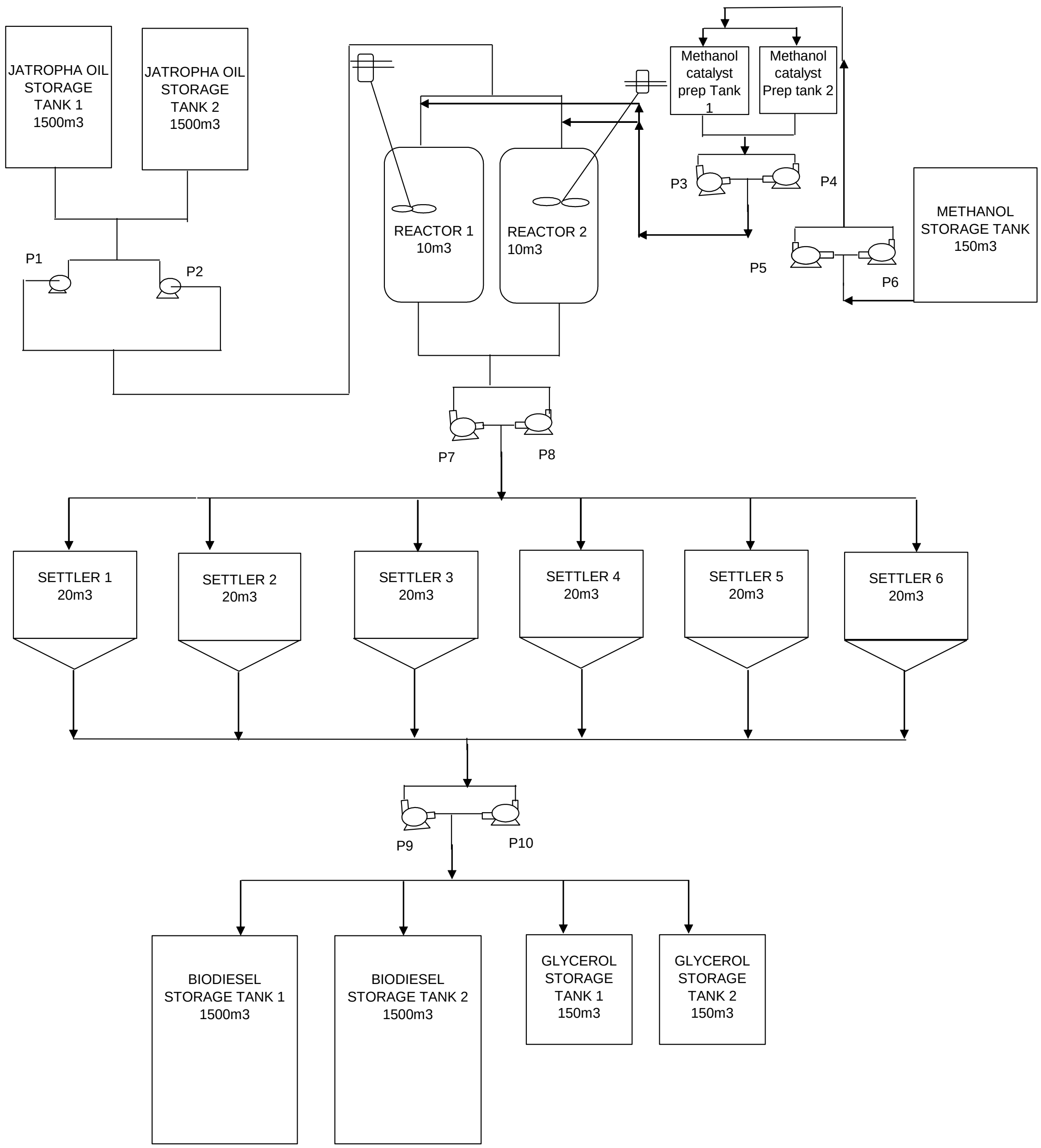


Fig. 5.11 Biodiesel production flow sheet.

SITE PLAN FOR BIODIESEL PLANT ***ANNEXE 12***

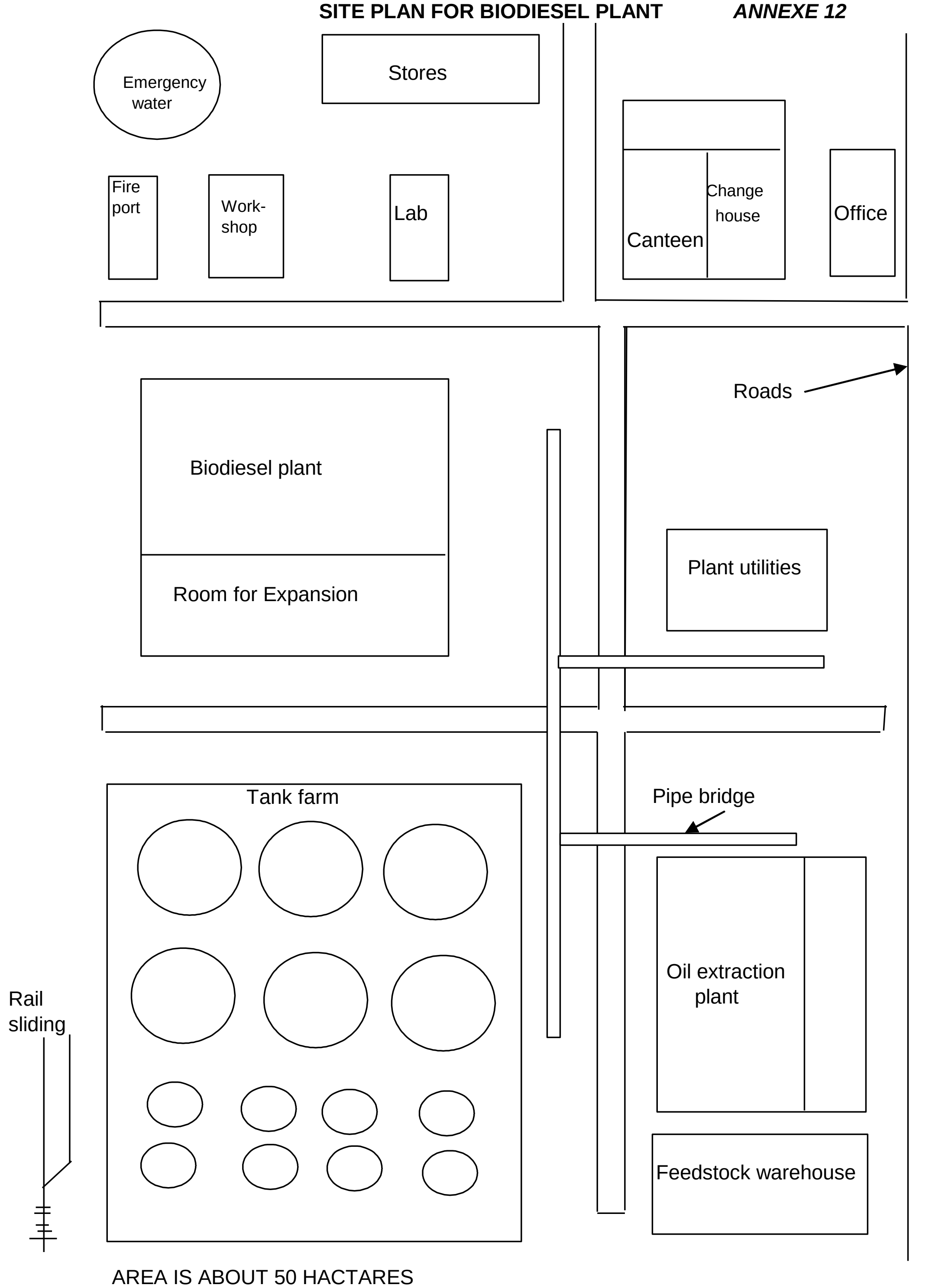
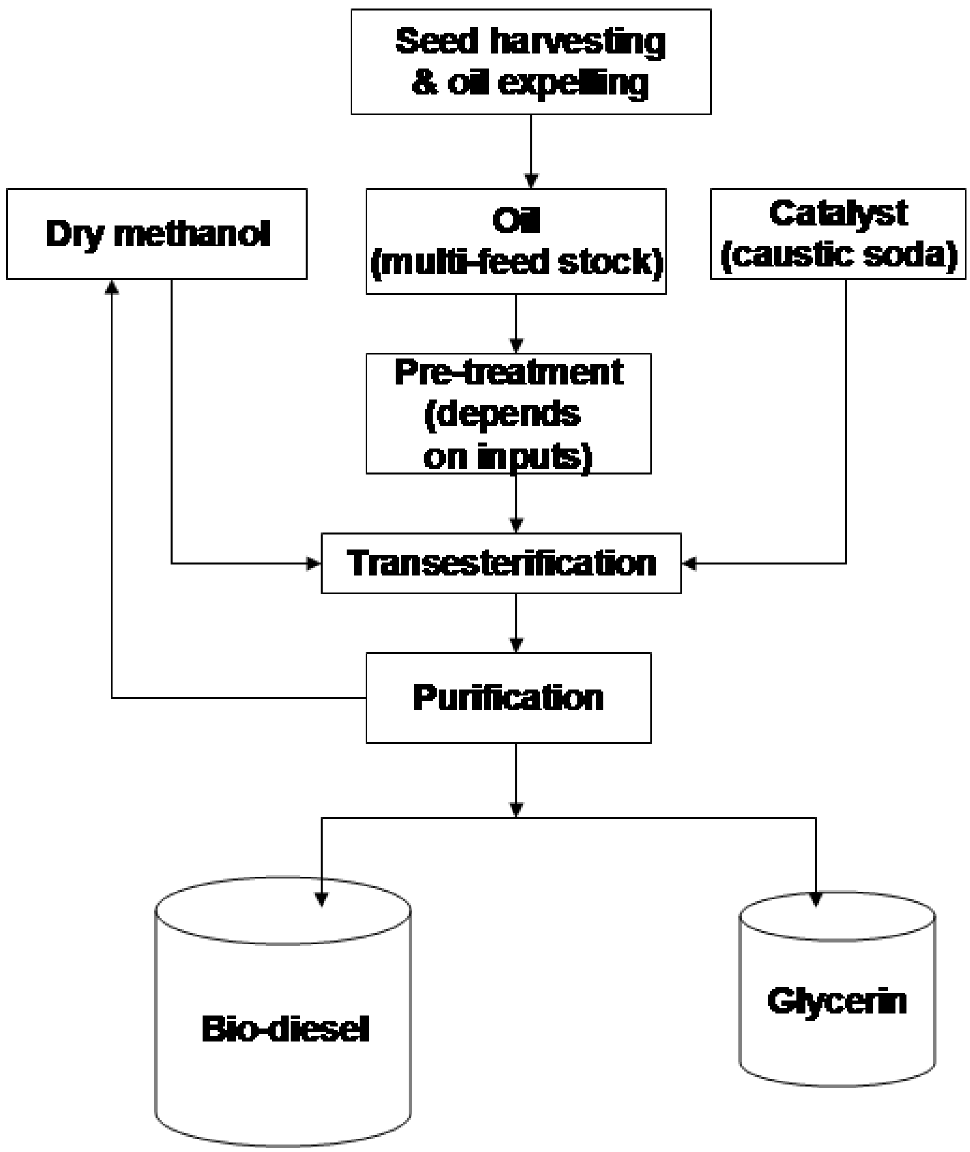


Fig. 5.12 Biodiesel plant plan layout.

15.12.7 Feed-stock generation

Production of bio-diesel requires two broad classes of raw material inputs; namely agricultural and chemical raw material inputs. The use of these raw materials is indicated in the process flow diagram for bio-diesel production in **Figure 5.13**. The process is normally referred to as transesterification**.**

Fig. 5.13 Bio-diesel Production Process



In the transesterification process for bio-diesel production, vegetable oil is reacted with dry methanol in the presence of a basic catalyst such as sodium hydroxide or potassium hydroxide at temperatures around 65^0 C. The main products of such a chemical reaction are bio-diesel (fatty acid methyl esters) and glycerin. Dry ethanol can also be used in place of methanol; however, the reaction takes place in the presence of potassium hydroxide. The feedstocks for the proposed bio-diesel production are vegetable oil and methanol. This project focused more on vegetable oil derived from *Jatropha curcas* seed. Growing of oil crops (like maize, soya bean, cotton, groundnuts, sunflower, castor, jatropha) in Zimbabwe is done at commercial as well as at subsistence level. Zimbabwe has three categories of farmers and these are the traditional commercial (large and small), the communal, and the resettled farmers (A1 and A2). Of all the oil seeds that can be grown for biodiesel production, the jatropha and castor bean have more advantages, in that:

a) **Castor Bean (*Pfuta*)**

This is a crop which is native to Ethiopia in East Africa. It can be found as both a domestic and wild plant. The crop has a potential yield of 2t/ha but the average yield in the country ranges from 0.5 to 1 t/ha. The actual yield has generally been low because small holder farmers do not apply any inputs in the form of fertilizers. The oil content is around 30-35%. Smallholder farmers generally grow the crop on contract basis. The varieties that are available for production are *Zimbabwe viz Aruna* and JCW94. Aruna is an annual variety that was imported from India and is the most widely grown crop. Production of JCW94 has since stopped because it is prone to diseases. Production in the country is generally low due to lack of a ready market as the contractors are no longer funding the production of the crop. The only buyer of the crop is Trinidad Industries which is facing a lot of problems to meet its annual demand of 100t against a national supply of 15t. Uses of castor include:

- Manufacture of paints and dyes;
- As a component of industrial lubricants;
- As input in the manufacture of synthetic material such as nylon;
- As base herbal medicine;
- As a component of waxes and polishes.

However, castor oil tends to have certain advantages such as;

- being produced at low cost in form of inputs;
- does well in low rainfall areas;
- some of the varieties are perennial;

- cannot be browsed by animals.

Meanwhile castor production has its own challenges, namely;

- Low yield (0.5-1 t/ha).
- Some are annual crops therefore the seeds need to be procured every year.
- It competes with crops like maize for inputs and labor during the planting time.
- The production costs are very high but the selling price is currently not competitive.
- There is generally a very small market for the crop as Zimbabwe has only two buyers in form of Castor oil Zimbabwe and Trinidad Industries and these buyers tend to dictate the prices as they have the monopoly in the industry.
- Very low numbers of producers as there are only 40 to 60 smallholder farmers who are growing the crop.

However, it is recommended that;

- Castor production should be promoted through the efforts of the government by setting up credit input schemes.
- Market for the crop should be expanded by incorporating it as alternative feedstock for biodiesel production.
- Government should participate in setting up prices of the crop.

b) *Jatropha curcas* (*Jirimono*)

The planting of the *Jatropha curcas* (physic nut) in Zimbabwe has been promoted by a number of local organizations. These organizations include Agricultural Research Trust (ART), the Biomass Users' Network (BUN), the Forestry Commissions (FC), the Plant Oil Producers Association (POPA), Environment Africa and Tree Africa. The growing and beneficiation of the *Jatropha curcas* is concentrated in communal areas where the focus is the upliftment or empowerment of resource persons. Large-scale commercial exploitation is yet to start. Meanwhile there are benefits of Using Jatropha for Biodiesel Production in that;

- Oil yield per hectare is among the highest of tree borne oil seeds. A ton of jatropha seeds produces 300 liters of oil as compared to 200-250 liters of soya beans and sunflower.

- It can be grown in areas of low rainfall (200mm per year) and in problematic soils (sandy soils). In high rainfall and irrigated lands yields are higher. Therefore, it can be grown in most parts of the country.
- Jatropha is easy to establish, grows relatively quickly and is hardy.
- Jatropha lends itself to plantations with the advantage on lands developed on watershed basis and on low fertility marginal, degraded, fallow, waste and other lands such as along the canals, on borders of farmers' fields as a boundary fence and live hedge in the arid and semi-arid areas. As such it can be used to reclaim wastelands in the forests and outlands.
- Jatropha seeds are easy to collect because the plants are not tall and mature before the onset of the rainy season.
- Jatropha is not browsed by animals hence needs no fencing.
- Being rich in nitrogen, the seed cake is an excellent source of plant nutrients.
- The plant starts giving seed in a maximum period of two years after planting.
- Seed production ranges from about 0.4 tons per hectare per year to over 12 t/ha/yr; depending on climatic conditions and age.
- Various parts of the plant are of medicinal value, its bark contains tannin, the flowers attract bees and thus the plant has honey production potential.
- Like all trees, jatropha removes carbon from the atmosphere, stores it in the woody tissues and assist in the build-up of soil carbon. It is thus environmentally friendly.
- Jatropha can be established from seed, seedlings and vegetatively from cuttings. Use of branch cuttings for propagation is easy and results in rapid growth.
- The plant is undemanding in soil type and does not require tillage.
- The oil can be used for the manufacture of soaps and cosmetics.
- It can meet a number of domestic energy needs such as cooking and lighting.
- Cars can be run from biodiesel derived from Jatropha oil without change in design of the engine.
- Tree plantations will have a lot of positive influence on the weather patterns of the country as what happened in Kenya when a massive tree planting program resulted in increased annual average rainfall in the belt in which the trees were planted.

- An economic analysis on the production costs of biodiesel produced from jatropha indicates that the price per liter is competitive compared to current market rate.

5.12.8 Agricultural Raw Materials

For the project to have a great impact on the diesel supply situation in the country, setting up of a bio-diesel production plant with an initial capacity of 300 000 liters per day is being recommended. Since jatropha oil is non-edible, focus of the project will be boosting jatropha oil-based bio-diesel production. However, since supply of jatropha oil might not sustain a bio-diesel plant with a capacity of 300 000 liters per day, alternative vegetable oil such as castor, sunflower and soya bean oil will be used until the bio-diesel plants can be sustained from jatropha oil only. Land and chemical raw material requirements for a national demand of one billion liters per annum are summarized in Tables 5.6, 5.7 and 5.8 respectively.

Table 5.6: Jatropha yield and hectarage required.

Jatropha Yield [t/ha]	**Oil Content %**	**Oil Yield [tons/ha]**	**Oil Yield [Liters/ha]**	**Zimbabwe's Diesel Requirements [Liters/yr]**	**Hectares of Land required [ha/yr]**
0.4	40	0.16	190	1 billion	5 263 158
1	40	0.40	480	1 billion	2 083 333
2	40	0.80	950	1 billion	1 052 632
4	40	1.6	1900	1 billion	523 316
6	40	2.4	2860	1 billion	349 650
8	40	3.2	3810	1 billion	262 467
10	40	4.0	4760	1 billion	210 084
12	40	4.8	5710	1 billion	175 131

Table 5.7 Chemical raw materials required for national demand of one billion liters per annum for a jatropha based bio-diesel.

Oil content (%)	40 – 45
Oil yield L/ha	3,810
Land requirements (ha)	265,000
Methanol (L/a)	100,000,000
Caustic soda (2 %)	2,000,000

Assumption: Yield of jatropha is 8 tons per hectare.

Table 5.8 Land and input requirements for a bio-diesel production plant with a capacity of 300,000 liters per day (99 million liters per annum).

Parameter	Plant/Crop			
	Jatropha	**Sunflower**	**Soya bean**	**Castor**
Oil content (%)	40 - 45	43 – 49	9 -10	
Yield (kg/ha)	3,202	800	375	1 188
Yield (L/ha)	3,810	852	446	1 413
Total land (ha)	26,000	117 000	222 000	70 100
Total methanol (L)	9,900,000	9,900,000	9,900,000	9,900,000
Total caustic soda (kg)	2,970,000	2,970,000	2,970,000	2,970,000

Assumption: Yield of jatropha seed is 8 tons per hectare.

5.12.9 Agricultural Models for the Jatropha Plant Growing and Extension Services

The agricultural production for jatropha is best done through the following models which will ensure a sustained supply of the raw materials and stable price for the final product. The recommended models were based on statistical data provided by AREX, the technical visit to Mutoko, Ministry of Energy & Power Development and the Interministerial taskforce.

These models should be implemented simultaneously to reduce overdependence on one particular model. It should be noted that it will take about seven years to achieve maximum yield of ten tons per hectare. In order to verify the situation on the ground, members of the committee visited the Mutoko area which is the area with the largest number of jatropha trees. This was done to determine the level of administration in the production of jatropha, the potential output of the crop in the area and the possible ways to boost production at national level. The team also visited the Victoria Falls area for the same purpose. A survey was carried out to determine this and the following findings for the Mutoko area were established.

A) Mutoko Findings

Administrative Structures: Mutoko has twenty-nine wards with each ward having an average of one thousand farmers. Each ward has six village development committees (VIDCOs) which can be used as developmental units for future jatropha production. Each ward has two AREX extension workers with five wards having one supervisor. Each VIDCO has a farmers' hall which is a center for agricultural activities like jatropha production as done by the Biomass Users' Network (BUN). The administrative structures can be used for future development in the jatropha production. Mutoko is generally a low rainfall area with poor sandy soils. This makes production of commercial cash crops like maize difficult. There is a lot of small horticultural crop production going on in the area, especially tomatoes which are transported to Harare for marketing. Due to concentration of farmers on horticultural activities, a lot of land is left fallow as there is low production of agronomic crops like maize. Farm sizes range from 2.5 ha to 5 ha and most of it is fallow. This fallow land can be utilized for production of jatropha which requires less labor and its production can be carried out side by side with horticulture as it demands less labor in its production. The production of jatropha is carried out in an uncoordinated fashion. Most of it is grown as hedges through the spacing of the plants that suit live fencing poles (0.5 – 1.00m) instead of the standard 20cm spacing in between hedge plants. This tends to affect the potential yield. The plant population varies from homestead to homestead. Some homesteads only have one plant used as shade while others have a whole perimeter of the field covered with jatropha hedge. The plant distribution tends to occur in clumps rather than in an even distribution fashion. Propagation is mainly through cuttings rather than seeds and there are no plantations.

The seeds are harvested by picking them from the ground after the pod has dehisced. They are sold to processors at USD0.57 per bucket of shelled seed. The seeds are then pressed into oil by either hand operated or electric powered machine. It is estimated that 30 kg of seed yield 10 liters of oil. The oil is used to make soap by local villagers. The electric powered oil expelling machine found at Makosa Village has a daily capacity of 100 L produced from 500 kg of seed. Marketing is either done directly to processors or through middlemen. From the sampled wards, the average perimeter of the hedge was 250 m (100 m x 25 m). In Chimoyo Ward A 30% of the homesteads have the hedges, while in Chimoyo B it is 50 %. The potential yield from these hedges is 2 kg per tree.

Table 5.9 A random sample of farmers surveyed.

Name of farmer	Number of plants
Homestead A	880
Homestead B	2,171
Homestead C	0
Homestead D	8
Homestead E	5
Homestead F	0
Homestead G	4,881
Homestead H	19
Total tree count	**4,573**
Average	**457**
Potential yield	**2 kg/plant**

The potential output per homestead in Mutoko currently stands at 1000 kg. Since they are 30,000 homesteads in Mutoko, the potential output for the whole district is 30 million kg (30,000 tons). This has a potential of being processed into 10million liters of biodiesel per annum. However, this feedstock is not enough to make a modular biodiesel plant designed by the national team with an annual capacity to process 99,000t seed into biodiesel. This may take up to five years for Mutoko to be self sufficient in producing the jatropha for this plant.

Table 8 below shows the potential yield of newly established jatropha plantation per hectare from the time of planting and the potential output of the crop from a potential plantations with a total area of 30,000 ha that can be established in the Mutoko area.

Table 5.10 Projected seed yield for five years.

Year	**Seed yield kg/ha**	**District seed output (t)**
1	91.5	2,700
2	450	13,500
3	2 800	84,000
4	4 000	120,000
5	5 000	150,000

However, with augmentation of production from the other surrounding districts such as Murewa, Nyanga and Mudzi, the requirements to run a modular plant could be attained. These districts are known to have quite significant quantities of jatropha plants. This may also be attributed to a cultural belief that the jatropha plant is associated with the spiritual sense of protection hence it is grown as hedges.

B) Victoria Falls Findings

Victoria Falls trip resulted in the researchers finding out that there is a great potential in the area for jatropha production as:

- There is some co-ordination in the production system as the local authorities like the town council and other interested organizations are actively participating in the jatropha production. This will give the implementation team good foundation on which to build their coordinating activities.
- There are under-utilized large tracts of land.
- There is enough plant material to act as nucleus for distributing propagation material.
- The system of using nurseries is well established, thereby providing an alternative way of distributing planting material.

- Growing of jatropha from seed is preferred as the yields are significantly higher than those from cuttings.
- Model C for jatropha production is already being practiced in the area.
- The locals view the plant with suspicion as it is associated with deaths in the families that have planted it around their homesteads. Hence, in the absence of massive promotion campaigns, the growing of jatropha in the area may face serious problems.

C) Recommended Agricultural Feedstock Generation Capacities.

In order to mobilise enough raw material for biodiesel production, the following measures should be put into place:

- Propagation of jatropha in Mutoko should be intensified and should concentrate on the use of cuttings only as early as September each year in order to take the advantage of the rainy season for the plants to establish themselves well.
- In order to expand the area under production to 1 million hectares, an annual target of putting 100,000ha under jatropha nationwide should be set. This can be achieved through identifying five districts and distributing 100 tonnes of seeds to farmers. This should be realised within a ten-year period. If local seeds output fail to meet this requirement then the seeds have to be imported.
- Each farmer should be supplied with 1kg of jatropha seeds in order to put at least a hectare under plantation.
- Formation of an institutional arrangement within the framework of the Parastatals Act is also recommended. This will be responsible for promoting the production and marketing of jatropha seeds for biodiesel production.
- District coordinators should be recruited to conduct activities at district level in areas selected for jatropha growing. This will involve working with such stakeholders as the Forestry Commission, AREX officials and local authorities such as chiefs and headmen.
- An agricultural input scheme should put in place at the earliest opportunity. This will involve mobilising resources to purchase seeds, cuttings and other logistics. Since this will be a mass production scheme, there will also be need to import seeds from countries like India where the seeds are found in abundance.

Importation of the seed in the early stages of the project will reduce competition for the seed between oil processors and farmers.

- Regular training workshops, radio and television programmes will be conducted as a way to build public awareness.
- Since the programme is also meant to empower rural farmers, Members of Parliament and Governors will be requested to use their political influence to encourage jatropha cultivation in their respective areas.
- Local Authorities and Traditional Leaders (chiefs and headmen) will be encouraged to participate actively so as to ensure the success of the programme. This may involve setting production targets. Lessons could be drawn from activities by chiefs and headmen involved in natural conservation programmes in which they act as regulatory authorities with powers to punish those who breach conservation rules. Jatropha plants can be used to limit soil erosion.
- Jatropha seed collection centres will be set up at WADCO/VIDCO level.

5.13 Supply of chemical raw materials.

The major chemical raw materials for the production of bio-diesels are methanol and caustic soda. Methanol is a petrochemical. It can be produced from coal, natural gas and coal bed methane gas. A block flow diagram for the production of methanol is illustrated in Fig. 5.14

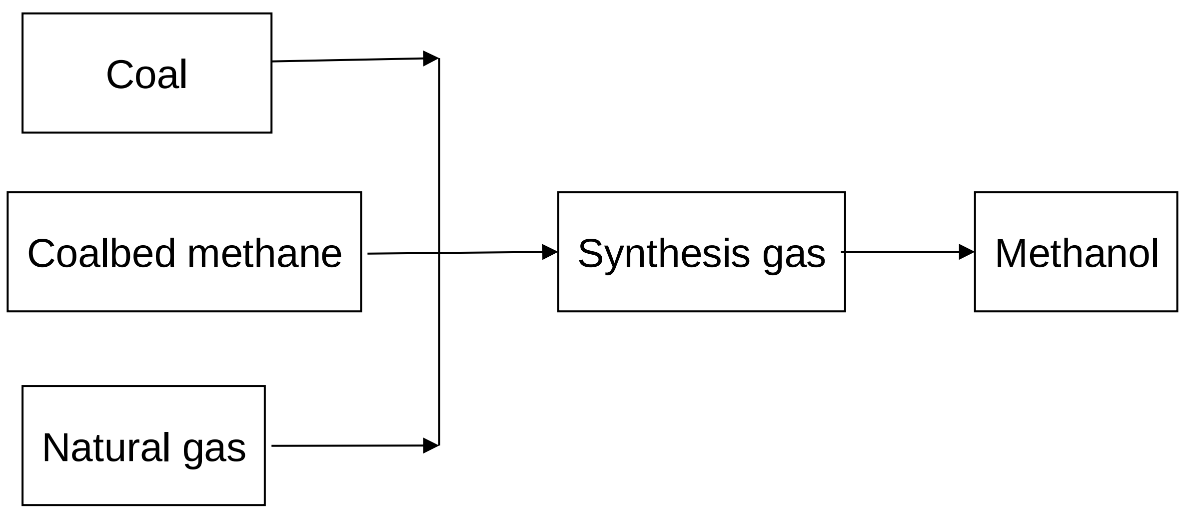


Fig. 5.14 Block flow diagram for production routes for methanol.

The main raw materials, coal, natural gas or coal bed methane gas are converted to synthesis gas (a mixture of carbon monoxide and hydrogen) through various technologies. Synthesis gas is converted to methanol in the presence selected metal catalysts. Despite the abundance of raw materials suitable for the production of methanol, Zimbabwe is currently importing all its requirements. Since the setting up of a methanol production plant requires huge capital investment, methanol will, in the short-to-medium term, have to be imported. In the long-term, Zimbabwe should set up its own methanol production plant to ensure price stability. For the proposed bio-diesel plant with an annual capacity of 99 million liters, 10 million liters of dry methanol is required. Since Zimbabwe's annual requirements on diesel exceed one billion liters, more than 100 million liters will have to be imported. Caustic soda is a common raw material in the local chemical industry and can easily be purchased from the local market although it is being imported. Since caustic soda is required in small quantities, there is no need to set up a plant specifically for the supply to the bio-diesel production plant.

5.13.1 Laboratory Testing Facilities for Feedstock and Final Products.

For the purpose of quality assurance, fully fledged laboratory testing facilities should be established at bio-diesel production facilities. However, this involves initial huge capital investment, it is proposed to utilize NOIC laboratory facilities in Mutare and Harare to conduct some of the laboratory tests during the early stages of the implementation of the project. A fully fledged laboratory will cost approximately USD2.3 million. The bio-diesel will be tested according to set international standards; some of which are highlighted in Table 5.11.

Table 5.11 Bio-diesel Standards

Bio-Diesel	Unit	Austrian Standards C1190 Feb. 91	DIN 51606 Sept 1997	US Quality Specification NBB/ASTM	Euro Standards
Density at 15°C	g/cm3	0.86 – 0.90	0.875 – 0.90	-	In preparation
Viscosity at 40°C	mm2/s (cST)	06.5 – 9.0	3.5 – 5.0	1.9 – 6.0	
Flash point	°C(°F)	min. 55 (131)	min. 110 (230)	min. 100 (212)	
CFPP	°C(°F) summer winter	max. 0(32) max. –8(17.6)	max. 0(32) max.–20(-4)	-	
Total sulphur	% mass	max. 0.02	0.01	max. 0.05	
mg/kg	free of deposited water	max. 300	-	max 0.05	
vol. %	-	-	max. 0.05	min. 40	
mg/kg	-	max. 20	-	max. 0.02	
Degree of corrosion	-	1	No. 3b max		
Water &sediment					
Total contamination					
Copper corrosion (3hs, 50°C)					
Neutralization value	Mg	max. 1	max. 0.5	max. 0.8	
Methanol content	% mass	max 0.30	max. 0.x	max. 0.2	
Monoglycerides	% mass	-	max. 0.8	-	
Diglycerides	%mass	-	max. 0.4	-	
Triglycerides	%mass	-	max. 0.4	-	
Free glycerin	%mass	max. 0.03	max. 0.02	max. 0.02	
Total glycerin	%mass	Max. 0.25	max. 0.25	max. 0.24	
Iodine number		-	max. 115	-	
Phosphorus	mg/kg	-	max. 10	-	
Alkali content (Na+K)	mg/kg	-	max. 5	-	

5.14 Financial projections

The financial projections have been developed using the following assumptions;

a. The program implementation plan will be phased. The first phase involves setting up of the national plant with a capacity of 300,000litres per day of biodiesel. This will be followed by the second phase of introducing regional/provincial plants with a capacity of 100,000 liters per day of bio-diesel.
b. The farm gate plant with a capacity of 5,000 liters per day of crude oil is not budgeted for as this is available on the market and will distort the producer price of bio-diesel under this program.
c. All operational costs will be calculated according to the ratios contained in the standards - Perry's Chemical Engineers' Handbook, R Perry and D Green 1989; Chemical Engineering Volume VI, R Coulson and Richardson, 2000.

The outcome of the costing exercise is given in detail in Tables 5.12 to 5.13 below and summarized as follows:

- The required fixed capital for the national biodiesel plant is about US$22,648,264.00.
- The working capital required is about USD7 million.
- The total capital injection required to set up the biodiesel plant is USD30 million.
- The unit cost of producing 1 liter of biodiesel is USD0.41.
- The projected sales per annum is about USD74.3million.
- The pay back period is 2 years

5.14.1 Cost Benefit Analysis

The Committee understands that South Korea has made a technology transfer proposal for a Bio-diesel production plant of more or less the same capacity as recommended above (100 000 t/yr). The cost of the project is also pegged at about US$22 000 000.00 but does not include operational costs and overheads. This critical factor makes the local effort more cost effective. It is also felt that localization of the project has more benefits. Furthermore, this will build confidence in the local manufacturing industries and hence encourage innovation, research and development.

Biodiesel Plant	
Local currency: ZW$17,500:USD1	
Cost of Major Equipment	$18.257.448.000.00
Equipment Erection	$ 7.302.979.200.00
Piping	$ 9.128.724.00.00
Instrumentation	$ 3.651.489.600.00
Electrical	$ 1.825.744.800.00
Buildings (process)	$2.738.617.200.00
Utilities	$9.128.724.000.00
Storages	$2.738.617.200.00
Site development	$912.827.400.00
Ancillary Buildings	$2.738.617.200.00
Storage tanks	$30.000.000.000.00
Total Physical Plant Cost	**$88.423.833.600.00**
Total Physical Inc. VAT	$101.687.408.640.00
Design and Engineering	$26.527.150.080.00
Contractor's fee	$4.421.191.680.00
Contingency	$8.842.383.360.00
Subtotal	**$39.790.725.120.00**
Fixed Capital	**$141.478.133.760.00**

Oil Extraction Plant	
Crusher Mill	*$1.000.000.000.00*
Conditioner	*$1.200.000.000.00*
Mill	*$1.000.000.000.00*
Meal grinder	*$1.000.000.000.00*
Extractor	*$1.000.000.000.00*
Stationery Basket	*$1.200.000.000.00*
Desolventizer	*$1.200.000.000.00*
Vapour Scriber	*$2.000.000.000.00*
Evaporator	*$8.000.000.000.00*
Oil Screw	*$1.000.000.000.00*
Total Major equipment	***$18.600.000.000.00***
Equipment erection	*$8.370.000.000.00*
Piping	*$13.020.000.000.00*
Instrumentation	*$3.720.000.000.00*
Electricals	*$1.860.000.000.00*
Buildings Process	*$2.790.000.000.00*
Utilities	*$9.300.000.000.00*
Site development	*$930.000.000.00*
Subtotal	***$39.990.000.000.00***
Total Physical Plant cost	***$58.590.000.000.00***
Design and Engineering	*$17.577.000.000.00*
Contractor's fee	*$2.929.500.000.00*
Contingency	*$5.859.000.000.00*
Subtotal	***$26.365.500.000.00***
Fixed Capital	***$84.955.500.000.00***
3x Oil Plants	***$254.866.500.000.00***

NOTE: Total for the whole plant: $396.344.633.760.00 = US$22 648 264.79.
(at an exchange rate of Z$17 500)

Table 5.12: 300 000 L/day bio-diesel plant costs.

Operational Costs	**Quantity**	**Unit Cost (ZW$)**	***Total Cost***
Maintenance	6% of Capital Cost		*$ 23.780.678.025.60*
Supervision	10% labour costs		*$ 15.000.000.000.00*
Plant overheads	15% of labour costs		*$ 22.500.000.000.00*
Laboratory costs			*$ 2.000.000.000.00*
Payroll overheads	20% of labour costs		*$ 15.000.000.000.00*
Seed and cuttings supply			*$ 50.000.000.000.00*
Transport costs			*$ 30.000.000.000.00*
Promotional Activities			*$ 700.000.000.00*
Training workshops			*$ 600.000.000.00*
Stationery			*$ 250.000.000.00*
Sub-total			***$ 159.830.678.025.60***
Raw materials			
Jatropha Seeds (tones/year)	297.000.00	$ 900.000.00	*$ 267.300.000.000.00*
Methanol (liters/year)	9.000.000.00	$ 5.000.00	*$ 45.000.000.000.00*
Catalyst	900.000.00	$ 5.000.00	*$ 4.500.000.000.00*
Sub-total			***$ 316.800.000.000.00***
Operating labour		$79.200.000.000.00	*$ 150.000.000.000.00*
Utilities	0.2 of Capital cost		*$ 79.268.926.752.00*
Total Operational Costs			***$ 705.899.604.777.60***
Sales	**Quantity**	**Unit Prize**	
Biodiesel (litres)	99.000.000.00	$ 10.000.00	*$ 990.000.000.000.00*
Crude Glycerine (1kgs)	19.800.000.00	$ 25.000.00	*$ 495.000.000.000.00*
Cake (tones)	178.200.00	$ 100.000.00	*$ 17.820.000.000.00*
Total Sales Value per annum			***$ 1.502.820.000.000.00***
Total Cost			***$ 983.456.244.753.60***
Annual Profit			***$658.610.579.654.80***
Unit Cost Production Cost		***$ 7.130.30***	

TABLE 5.13 Production costing

Year	**Total Cost**	**Sales**	**Gross Profit**	**Sales Factor**	**DF**	***PVrev***
1	$983.456.244.753.60	$-	$(983.456.244.753.60)		1.00	*$(983.456.244.753.60)*
2	$705.899.604.777.60	$1.502.820.000.000.00	$724.472.362.092.73	0.26	0.91	*$658.610.579.654.88*
3	$641.726.271.707.27	$1.938.126.841.200.00	$1.071.410.250657.27	0.29	0.83	*$885.467.001.655.70*
4	$583.390.728.368.45	$1.968.694.200.000.00	$1.040.792.351.271.50	0.31	0.75	*$781.957.701.433.79*
5	$530.349.432.065.46	$2.028.807.000.000.00	$1.023.461.503.474.97	0.35	0.68	*$699.034.441.488.44*
6	$482.136.489.059.15	$2.073.891.600.000.00	$988.352.583.485.39	0.38	0.62	*$613.687.886.137.75*
7	$438.307.182.598.51	$2.134.004.400.000.00	$957.170.208.306.62	0.42	0.56	*$540.293.867.482.84*
8	$398.459.149.908.81	$2.194.117.200.000.00	$921.459.884.984.79	0.46	0.51	*$472.856.354.578.80*
9	$362.239.441.187.67	$2.269.258.200.000.00	$889.643.321.173.54	0.51	0.47	*$415.027.505.760.67*
10	*$329.309.224.624.80*	*$2.344.399.200.000.00*	*$854.599.658.556.62*	*0.56*	*0.42*	*$362.435.715.193.86*

NOTE: PAY BACK PERIOD IS 2 YEARS

Table 5.14 Envisaged ten-year cash flow.

5.15 Conclusion

In conclusion it is noted that, Sec. 79 (2) of the Construction, Equipment and Use Regulations of the Statutory Instrument (S.I.) 129 of 2105 states "Unless the exhaust gases emitted, when tested comply with the requirements as prescribed in the appropriate Standards Association of Zimbabwe standards." According to experts in the transport sector, no standards set by the Standards Association of Zimbabwe are existing nor being enforced actively. Also there does not seem to be a ban on the imports or sales of fossil powered cars for a specific year in the future as some countries have introduced, nor any specific roadmap of phasing out or reducing emissions from transport vehicles. As a result, no incentives are applied for zero emission (hydrogen fuel cell) electric vehicles. ZIMRA, the Zimbabwe Revenue Authority states that a carbon tax is applicable at the rate of US$0.03 (3 cents) per liter of petroleum and diesel products or 5% of cost, insurance and freight value (as defined in the Customs and Excise Act [Chapter 23:02]), whichever is greater. Hence, fisical authorities have to lay the foundation for promoting the production and use of biofuels, thereby influencing the production costs associated with direct and indirect costs. It also has to incentivize the creation of green jobs.

In real terms, the mobilization of raw materials in the biofuels sector tends to be problematic in that; catalysts and methanol are imported; whilst non-edible seeds like castor bean or jatropha curcas are either mobilized from peasant farmers and thus increasing logistical costs, estate farming is less costly but cannot be enough to meet demand. Hence, the wholesale price or retail price of the pure biodiesel becomes a blended cost. This in turn influences the buying prices of blended fuels for the consumer.

References

Biodiesel Web Sites

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- Bioenergy Atlas Two interactive maps, BioPower and BioFuels, which allow you to compare and analyze biomass feedstocks, biopower and biofuels data from the U.S. Department of Energy (DOE), U.S. Environmental Protection Agency (EPA), and the U.S. Department of Agriculture.
- Energy Information Adminstration's Renewable & Alternative Fuels Homepage Statistics on renewable fuels production and consumption.
- National Biodiesel Board National trade association representing the biodiesel industry in the United States.
- Biodiesel Education Program, University of Idaho Provides unbiased, science-based information for biodiesel producers and distributors, vehicle fleet operators, and the general public.
- National Bioenergy Center Part of the National Renewable Energy Laboratory
- Biodiesel Safety and Best Management Practices for Small-Scale Noncommercial Use and Production. Penn State College of Agricultural Sciences. 2008.
- Piedmont Biofuels Biofuels curriculum and general information on biodiesel from a commercial biofuels company.

- Collaborative Biodiesel Tutorial This site is written by people from around the world who make biodiesel, with the goal of helping others.
- State Level Biodiesel Incentives & Laws State by state listing of incentives and laws provided by the U.S. Department of Energy Alternative Fuels and Advanced Vehicles Data Center.
- Federal Biodiesel Incentives & Laws List of federal biodiesel incentives and laws provided by the U.S. Department of Energy Alternative Fuels and Advanced Vehicles Data Center.
- National Agricultural Law Center Renewable Energy Reading Room Virtual library of legal resources related to renewable energy that contains information specific to agriculture and energy, including an overview article, major statutes and regulations, case law, Center publications, materials from many government agencies and additional resources provided by the National Agricultural Law Center.
- Biomass-to-Biofuels Resources Vermont Sustainable Jobs Fund. Case Studies and Feasibility Analysis reports of small scale biodiesel production.
- Roundtable on Sustainable Biofuels -- an international initiative based in Switzerland,the RSB has developed a third-party certification system for biofuels sustainability standards.
- Sustainable Biodiesel Alliance -- this Texas-based organization promotes environmental, social, and economic sustainability of biodiesel. They aim to create certification for sustainability in biodiesel.
- Freeways to Fuel -- Utah State University and the Utah Department of Transportation are experimenting with growing oilseed crops on unused land near roadways, airports, railroads, and construction sites.

Biodiesel Fact Sheets and Publications

- Biofuels Incentives: A Summary of Federal Programs -- this 18-page publication is published by the Congressional Research Service.
- Biodiesel: An Alternative Fuel for Compression Ignition Engines This booklet is based on a lecture series presented in 2007 at the Agricultural Equipment Technology Conference. Includes information on biodiesel history, chemistry, processing, and use.
- Building a Successful Biodiesel Business This comprehensive book covers biodiesel production, developing a business, workplace safety issues, and environmental regulations. Authors are experts from Iowa State University, University of Idaho, USDA/NCAUR, and Renewable Products Development Laboratory.
- Biodiesel Handling and Use Guide (pdf 1.4MB) 4th Edition. This 50-page publication from the National Renewable Energy Laboratory is considered the definitive publication on biodiesel handling and use. It is intended for those who blend, distribute, and use biodiesel.
- Biodiesel - Do-it-yourself Production Basics ATTRA National Sustainable Agriculture Information Service, 2009.
- Small-scale Biodiesel Production and Use North Dakota State University Extension Service. Comprehensive overview, including oilseed preparation, turning oil into biodiesel, quality issues, economics of biodiesel production, use in engines, and storage.
- Biodiesel Analytical Methods NREL, Iowa State University, Renewable Products Development Laboratory, USDA
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- Worldwatch Institute (2007). *Biofuels for Transport: Global Potential and Implications for Sustainable Energy and Agriculture.* London: Earthscan. A global overview of the biofuels industry from a social and environmental perspective.

Biodiesel Powerpoints and Videos

- Biodiesel 101 powerpoint presentation By Steve Howell, Technical Director, National Biodiesel Board,Outreach and Education office, ppt 4MB
- Biodiesel Safety video A 10-minute video that helps home biodiesel producers to understand the safety precautions that must be taken when working with the chemicals used to produce biodiesel.
- Getting Started in Farm-Scale Biodiesel Production A one-hour video from the National Sustainable Agriculture Information Service.
- DIY Biodiesel: Keeping it Safe, Keeping it Legal The second installment of the biodiesel series from the National Sustainable Agriculture Information Service.

Commercial Publications

- Biodiesel Magazine-- this magazine aims to support the growth of the biodiesel industry.
- Biodiesel Smarter Magazine A quarterly magazine and web site for small biodiesel producers, focusing on best practices, safety, quality, and sustainability.
- Biofuels Magazine -- published by Future Science, this is a peer-reviewed journal providing commentary and analysis on biofuels research.

Biodiesel Case Studies

- Agricultural Marketing Resource Center: Oilseed Case Study and Decision Making Software The opportunities and challenges faced by a small scale oilseed processor located in Northwest Montana are examined this case study. Decision making software that allows users to enter their own capital and operating costs is also provided.
- Agricultural Marketing Resource Center: Biodiesel Case Study and Decision Making Software The opportunities and challenges faced by a small scale biodiesel producer located in western Montana are examined this case study. Decision making software that allows users to enter their own capital and operating costs is also provided.
- On-Farm Oilseed and Biodiesel Production at State Line Farm, Shaftsbury VT This case study by the Vermont Sustainable Jobs Funds provides details of the on-farm pilot project to develop a community-scale oil seed processing and biodiesel producing facility of appropriate scale to New England farms.
- Bio-Diesel Plant Location Decision This case study from the University of Idaho is a lesson plan suitable for undergraduate seniors.

CHAPTER 6:

SOLAR PV

6.0 Introduction

This chapter looks at the practical experience and knowledge gained by the author as he navigated the solar PV terrain just like in all other renewable energy projects dealt with in previous chapters. This particular project dealt with in this chapter, is a project set up in a small town called Chegutu about 90Km from the capital city Harare. The project was therefore itemized as the Chegutu 75MW Solar Plant. It is this project's detail that is then used in understanding the input costs into a solar PV project directed at deriving the ultimate production costs of energy in Zimbabwe. It is then these production costs that then influence the feed-in-tariff to the national grid before the national power utility ZESA transfers it to the consumer according to categories. However, at the time of going to print this manuscript, the author was also at the initial stages of implementing three other solar projects; one 105MW Solar PV plant in Norton about 40Km from Harare, one 40.8MW Solar PV plant in Ecosoft about 20Km outside Harare and another 20MW Solar PV plant in Chivu about 130Km from Harare. Having had the opportunity of participating in these projects will give a true picture of the challenges associated with production costs in the various geographical areas of Zimbabwe given that each particular area is governed by a different local authority but under the same country jurisdiction. Hence, it is assumed that the interpretation of the legislative instruments, rests with the local authorities and the strategic plans of that authority.

As a result, this report highlights the feasibility analysis for the design, and installation of a 75MW solar PV plant in the Chegutu area, Zimbabwe which will feed into the national grid. For optimized performance, the orientation of the PV array is at a tilt of 24^{o} and plane azimuth of 0^{o} (Southern hemisphere plant location). The Annual Energy Yield (AEY) for the 75MW plant using Canadian Solar, Polycrystalline, CS6A - 200P photovoltaic Modules, and SMA, Sunny Central 500CP XT inverters is estimated at 140573 MWh achieved using 375 000 PV modules and 116 inverters connected in string inverter topology. Installation area estimates are 488 556 m^2 for module area which includes inter-row spacing and Cell Area of 438 120 m^2.

Definition of Terms

Solar energy - is the radiant energy emitted by the sun. This energy can be directly converted to electricity using solar cells.

Direct Normal Irradiance (DNI) - Refers to the amount of solar radiation received per unit area by a surface which is held perpendicular to the incoming rays in a straight line from the direction of the sun at its current position in the sky.

Diffuse Horizontal Irradiance (DHI) – refers to radiation per unit area on a surface and the radiation does not strike from a direct path.

Global Horizontal Irradiance (GHI) – It is the total amount of shortwave radiation received from above by a surface which is horizontal to the ground. GHI incorporates both DNI and DHI and is given by;

$$GHI = DNI\, cos\, \theta + DHI$$

where θ is the angle used to determine the perpendicular component of DNI with respect to the surface.

Thin Film Cell Technology – These are PV cells fabricated by placing thin layers of semiconductor material onto various surfaces, usually on glass. The technology exhibits the lowest manufacturing costs and less efficient cells are produced compared to other technologies. Currently dominant thin film technologies include CdTe, CIGS, and amorphous (A-Si and TF-Si), with CdTe being the predominant accounting for 50% of thin film module manufacture. Modules currently under production exhibit efficiencies spanning between 9% and 13%. However, a lot of research is underway and technologies using organic materials, often organometallic compounds as well as inorganic are emerging with anticipated efficiencies reaching 12 – 20%.

Monocrystalline Cell Technology - These cells are also referred to as single crystal solar cells. Highly purified silicon is used to manufacture the cells giving them very high solar energy conversion efficiencies ranging between 15% and 21%. Due to the intensive purification process, the manufacturing process is quite expensive and complex which renders monocrystalline modules the most expensive of the three PV technologies.

Polycrystalline Cell Technology - Polycrystalline, often referred to as multi crystalline, cells are cut from multifaceted silicon crystals. The level of silicon purity is less than that of monocrystalline cells and this gives poly cells a less uniform appearance compared to mono cells. Polycrystalline solar panels are the most common in the market and are less expensive than monocrystalline cells. Their efficiencies range between 13 and 16%.

Standalone System – This is a photovoltaic system meant to provide power to a local load without the channeling of excess energy into a utility grid. Such systems have found great appreciation in households especially in rural and remotely located areas. They boost of large storage systems to cater for night time as well as for the low sunshine days where energy output of PV array is low. Thus, off grid systems need a PV array large enough to charge the batteries to full capacity during the day while at the same time it supplies the daytime load with power.

Grid Tied System - The power generated from this type of system is directly fed into the utility grid. There is no storage backup facilities included in the system and flow of energy is from panels to grid through intermediate conditioning modules. Close to 70% of the system cost for grid tied systems goes towards the solar PV modules and inverters. Such systems are finding widespread adoption as several nations' progress towards sustainable energy and increased supply for the utility grids.

Classifications of grid connected systems according to the IEEE std. 929-2000

Classification	**Capacity (C)**	**Description**
1. Small Systems	≤ 10kW	Usually installed at the distribution level.
2. Intermediate Systems	10kW <C ≤ 500kW	Usually installed at the distribution level.
3. Large Systems	≥ 500kW	Usually installed at the transmission/ sub-transmission levels

6.1 Topological Survey.

6.1.1 Hydrological Study.

The Selous area is in the hydrological subzone CUF 3. The subzone has a Mean Annual Runoff (MAR) of 64mm and a Coefficient of Runoff (C. V) of 110%. The area is mainly drained by Saruwe River and its tributaries. Saruwe River drains in Mupfure River. The average rainfall for the area is 739 mm/year and a C.V of 33%. Altitude for the area is ranges between 1220-1240 metres. The mean annual evaporation for the area is 1920mm/year.

The lithology of the area consists of the Great Dyke norite, gabbro, serpentine and pyroxemite alkali ring complexes with low groundwater development potential. The smaller part of the area consists of the dolerite sills and dyke with moderate groundwater development potential. The formation has moderate to low transmitting properties and the average depth to the water table of these dolerite sills is less than 10 metres. Groundwater yield ranges between 25-100m^3/day.

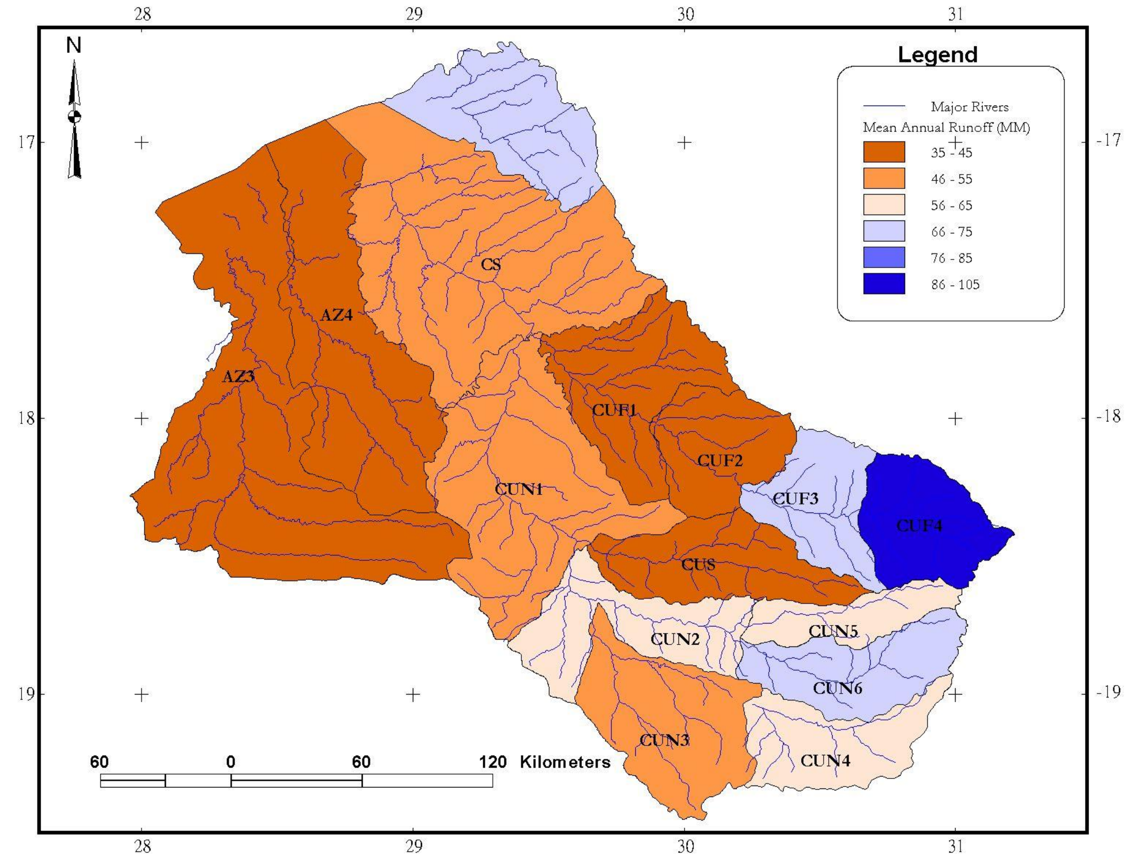


Fig 6.1 Mean annual runoff of sub-zones within the Sanyati Catchment

The nearest river to the project area is the Serui River that is about 10 kilometers away from the site. The project has no direct impact on water quality and attributing any changes to the Serui water quality to the project will be a distant idea. However, the potential erosive capacity that would probably result in the siltation will be mitigated through drainage works and grass cover. Water quality was therefore screened off as a minor environmental concern.

6.1.2 Geotechnical Study.

The project area is hosted within the Great Dyke of Zimbabwe, an ultramafic–mafic igneous body which hosts mineralization of platinum and chromium. It is approximately 400km long bisecting the country in half and has an average width of 3 – 5km. The Great Dyke is layered as follows from the ultramafic sequence to the mafic sequence: (a) serpentine and dunite, (b) transitional rocks, harzburgite, olivine pyroxenite and picrite, (c) gabbroic rocks; anorthositic-gabbro, norite, gabbro and quartz gabbro. The ultramafic sequence is cyclic and hosts the chrome seams while the mafic hosts platinum mineralization. It is divided into five sub-chambers namely the Musengezi, Darwendale, Sebakwe, Selukwe and Wedza sub-chambers.

The project area lies within the Hartley Sub-chamber which is the largest sub-chamber in the Great Dyke. The Hartley Complex contains sections of mafic and ultramafic sequences and it is this mafic sequence that hosts the area in the vicinity of Selous. The mafic sequence is composed of gabbroic rocks (*N*) which constitute the norites, gabbros and anorthositic gabbro. The gabbroic rocks are flanked to the east and west by pyroxenites band number 1 (*P1*) and serpentinites (S^E), of the ultramafic sequence which are in contact with granites (G^P) of the Zimbabwe Craton. Chromite seams No. 1 and No. 2 outcrop within the thin bands of serpentinites. In places the gabbroic rocks are intruded by dolerite sills (D^Q).

Table 6.1 Thicknesses of the gabbroic rocks in the Hartley sub-chamber

Rock type	**Average thickness**
Norite	274m
Gabbro	60m
Norite	518m
Anorthositic gabbro	30m

6.1.3 Ecological Study

6.1.3.1 Surrounding and Other Internal Land Use

The eastern part of the project area is bounded by Chengeta Game Park under the control of a private safari operator and the regulation of the Zimbabwe Parks and Wildlife Management Authority. The rest of the project area is surrounded by communal land with small scale farming areas within their settlement. Utilisation of the project area is mainly by livestock as a grazing field and also a source of fired wood for the community.

6.1.3.2 Vegetation description

The vegetation is defined by the underlying geology and these can be broadly separated into Miombo related groups around the project area and Acacia groups especially within the project area because of intense disturbance from fire and deforestation. Within the Miombo groups, *Jubernadia globifora* and Brachystegia species are the most dominant and within the project site *Acacia nigrescenes* is the most dominant species.

6.1.3.3 Wildlife

The Miombo environment is home to diverse wildlife species because it is a diverse community.

The area enclosed by the park is home to diverse species range of mammals, birds and reptiles. However, within the project area and the surrounding community, there are no resident wildlife species. Most of the sightings within the project area were of animals that would have escaped the park. This could be a result of high disturbance from fire and deforestation which increases the threat levels for wildlife, thus the animals migrate in a well-protected area. Species checklist in the park, indicate diverse ecosystem with more than 17 bird species, 100 hundred vascular plants and 60 animal species. Sightings within the project area where mainly of small antelopes that escape the park for the high nutrition green flash that shoots after burning. Livestock sightings can also be explained by the existence of the green flash. Apart from the livestock and a few sightings of antelopes, there are no other signs of wildlife utilisation in the project site. A significant feature of the project area is the absence trees that provide habitat and shade for different species and surface water.

6.1.3.4 Flora and Fauna baseline study

A site visit was conducted over one full day on the 2nd of October 2022 to identify the different biodiversity features and landscape units present at the site. Because of the scale of the project area, Walk-through-surveys were conducted across the site and all plant and animal species observed were recorded. Major and all listed trees within the project site observed were recorded their location with a GPS. The assessment involved identifying all species available and the presence of sensitive habitats of which none of sensitive habitats were noted in the project area. The project area was assessed for wildlife tracks, spoors and any indication of utilisation by wildlife in the area. GPS coordinated for spores was taken.

6.1.3.5 Sampling Limitations

The sampling approach weakness is the narrow temporal window of sampling. Ideally, a site should be visited several times during different seasons to ensure that the full complement of plant and animal species present are captured. It is however unlikely that a single site visit has had a significant impact on the results. The ecological patterns at the site were clear, and although additional plant species would be recorded at different times of the year, this is highly unlikely to alter the overall ecological patterns at the site which are related to physical soil properties, rather than season variation. It was difficult to identify grasses due to the grasses having no heads at the time of the sampling and also due to the fact that the area had recently been burnt, nevertheless some identification was made. However, as most grasses are widespread this would not significantly impact the results. The lists of avian species and mammals for the site are based on those observed at the site as well as those likely to occur in the area based on their distribution and habitat preferences.

6.1.3.6 Vegetation structure, composition and condition assessment

Vegetation study was carried out to describe the current state of vegetation on the project site with key focus on the impact footprint for the site so that there is a baseline description against which impacts can be identified. Two methods were used to gather data on vegetation structure, composition and condition. Mainly the assessment was done to determine whether the study area falls within the distribution range of species classified as vulnerable, endangered or critically endangered and protected according to the IUCN redlist.

The project area is small; therefore, a complete assessment of the whole project area was conducted. Data were collected for woody plants, herbaceous layer and general site characteristics, including presence of animal spoors. For the woody plants, the following were recorded: species name and height category (≥3 m = trees; 1 to <3 m = shrubs, <1 m = saplings). Visual assessment was used in each plot to determine the herbaceous species. The position of unusually large specimens of trees was recorded using a GPS.

From the assessment, *Acacia nigrescens* is the dominant tree species forming the woodland type of the project area. Other identified woody species are listed in Table 6.2.

Table 6.2 Species Checklist for the Proposed Site

Species	Common name
Acacia nigrescens	Knob thorn
Peltophorum africanum	Weeping wattle
Combretum imberbe	Leadwood
Pterocarpus angolensis	African teak
Bauhinia thoningii	Camel-foot
Terminalia elliptica	Crocodile bark
Acacia karoo	Sweet thorn
Terminalia sericea	Silver-cluster leaf
Dichrostachys cineria	Sicklebush

6.1.3.7 Project Site Vegetation Condition

Identified grass species included*: Aristida congesta, Heteropogon contotus, Cynodon dactylon, Sporobolus pyramidalis* (common in disturbed areas) and *Hyparrhenia filipendula*

Fig. 6.2 Acacia nigrescens; dominant species within the project area.

6.1.3.8 Wildlife presence, abundances and distribution

Data on existing wildlife species and their populations were collected using two methods namely: sightings and field based surveys using wildlife indices (spoors, dung and pellets, fur, feathers, burrows etc) that indicate wildlife utilisation. The assessment was conducted to establish the current state of the animals that are in the area so that there is a baseline description against which impacts can be identified and measured. Of importance the assessment established a description of the species composition and conservation status of the animals with the IUCN classification. The assessment also included animals that are likely to occur with reference to the Chengeta game park species checklist.

Although a lot of species exist within the park, only a few small antelopes are able to escape through small games on the game farm into the project area close to the boundary between the park and the project area. *Raphicerus campestris* (steenbok) and *Syvicapra grimmia* (Common duiker) were the only species that could be sighted within the project area and a track from the game fence was noted indicating that they only visit the area on a temporal basis. The species of conservation concern that occur is the *Raphicerus campestris* which however can be secured if the game fence is properly maintained and there is no interaction with the project site.

Species	Scientific name	Notes
Steenbok	*Raphicerus campestris*	1 sighted
Common duiker	*Syvicapra grimmia*	6 sighted
Bushbuck	*Tragelaphus scriptus*	1 Sighted

According to the Chengeta game park, more than 17 species of birds are listed. Birds do not follow any boundaries and they have large home ranges, we would expect to find some on the species within the project area. However, because of the extent of degradation and disturbance in the project area, there is no bird sightings recorded. Most of the sightings and bird calls where from the park. Bird calls for listed species that could be heard out of the project site include: black smith plover, red billed hornbill, Corry blustered, yellow billed francolin, Lialic breasted lola and white browed sparrow weaver. The loss of habitat for birds is not a threat because there is no sign of utilization by the birds of the project site.

6.2 Preliminary Design Layout and Technical Specifications

This section incorporates the technical aspects associated with the preliminary plant design and layout and associated technical specifications, preliminary solar resource and yield estimation and requirements for the establishment of ground measurements meteorological station for onsite measurements for the implementation of a prospective 75MW grid tied solar PV system in Chegutu, Mashonaland West Province in Zimbabwe. Parameters such as location, in terms of longitudinal and latitude position, average annual GHI, solar PV module orientations, shading and component selection are of paramount importance when designing and implementing solar PV projects for grid connectivity. Huge capital investments are required for such systems and as such the energy yield of the same systems should highlight a net profitability during the system's lifetime.

6.2.1 Site irradiance assessment

The availability of measured solar radiation data is critical for planning and implementing in solar energy projects. Ground measured data if not available can be substituted by satellite data, which is used for estimation of energy yield.

Data Source: NASA-SSE (1983 -2005, Resolution 1^o)

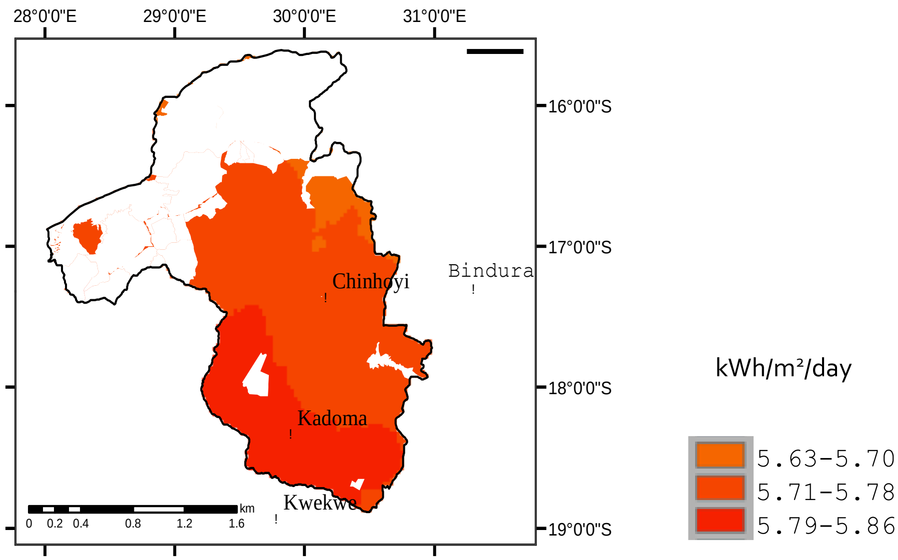


Fig. 6.3 Incident global irradiance distribution and gross PV output estimation- Mash West

Table 6.3 Site Assessment.

PARAMETER	SPECIFICATIONS
Site Name	
City	Chegutu
Site Area	150 hectares (1 500 000 m^2)
Site Perimeter	
Longitude	+30.41
Latitude	-18.14
Elevation	1 232m
Azimuth (from the north)	0

Site	Chegutu (Zimbabwe)			
Data source	NASA-SSE satellite data, 1983-2005			
	Global Irrad. kWh/m².day	Diffuse kWh/m².day	Temper. °C	Wind Vel. m/s
January	6.23	2.43	22.3	2.90
February	6.23	2.24	21.9	2.90
March	5.93	1.91	21.6	2.90
April	5.70	1.38	20.1	2.80
May	5.23	0.97	17.6	2.50
June	4.76	0.88	15.3	2.91
July	5.02	0.89	15.2	2.99
August	5.86	1.01	17.9	3.30
September	6.54	1.38	21.7	3.79
October	6.64	1.94	23.3	4.00
November	6.37	2.35	23.5	3.60
December	5.97	2.49	22.2	3.09
Year	**5.87**	**1.65**	**20.2**	**3.1**

Table 6.4 Plant monthly meteorological data.

6.2.2 General System Architecture

The main components of a grid connected solar PV system are the solar PV modules, inverters, mounting structure, cabling, metering, disconnects and generation transformer.

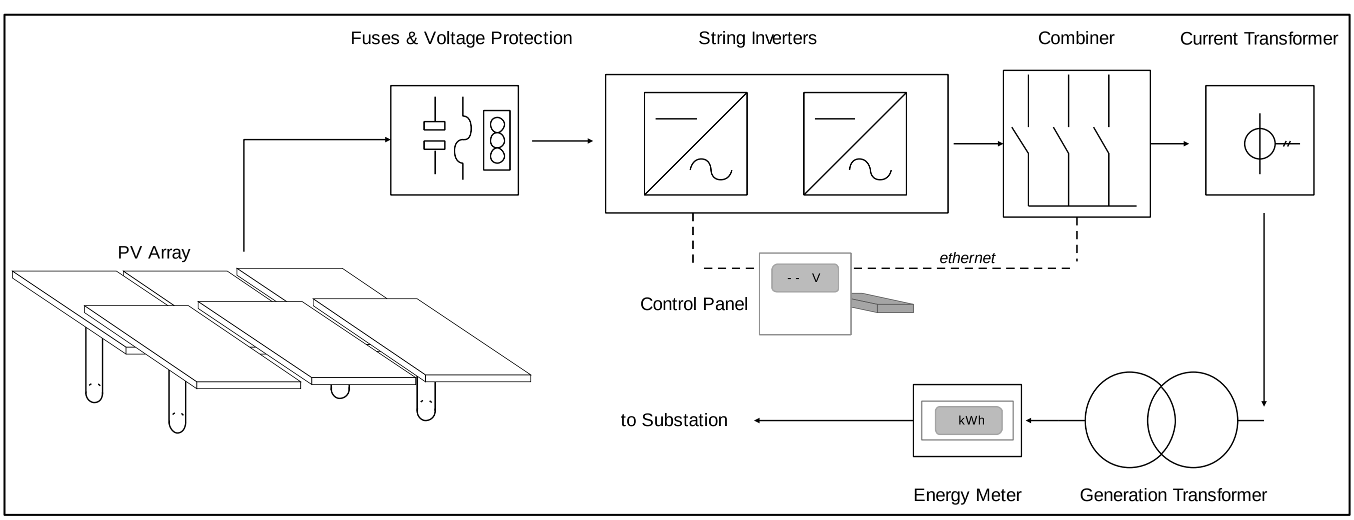


Fig. 6.4 Architecture of a grid connected solar PV system.

6.2.3 Array Orientation

Array orientation requires the definition of two aspects for installation, namely array tilt and azimuth. Tilt angle is the angular orientation of the array plane in relation to the horizontal axis. The plane azimuth relates to the compass direction where the panel plane is facing.

Azimuth Angle (γ^o); Since the installation is carried out in the southern hemisphere, the solar array should face north (0^o). Azimuth varies in the positive towards the west. Thus, for west facing array, $\gamma = +90^o$, while for east facing array $\gamma = -90^o$.

Plane Tilt (β^o); This design implements mono- orientated, fixed tilted plane without any form of daily or seasonal adjustment. The simulations in Figure 6.5 show the variations in Global irradiance on collector plane (*GonCP*) and Transposition Factor (*TF*) @ $\gamma = 0^o$ and $0^o \leq \beta \leq 32^o$. This γ and β optimization has been done w.r.t yearly irradiation yield.

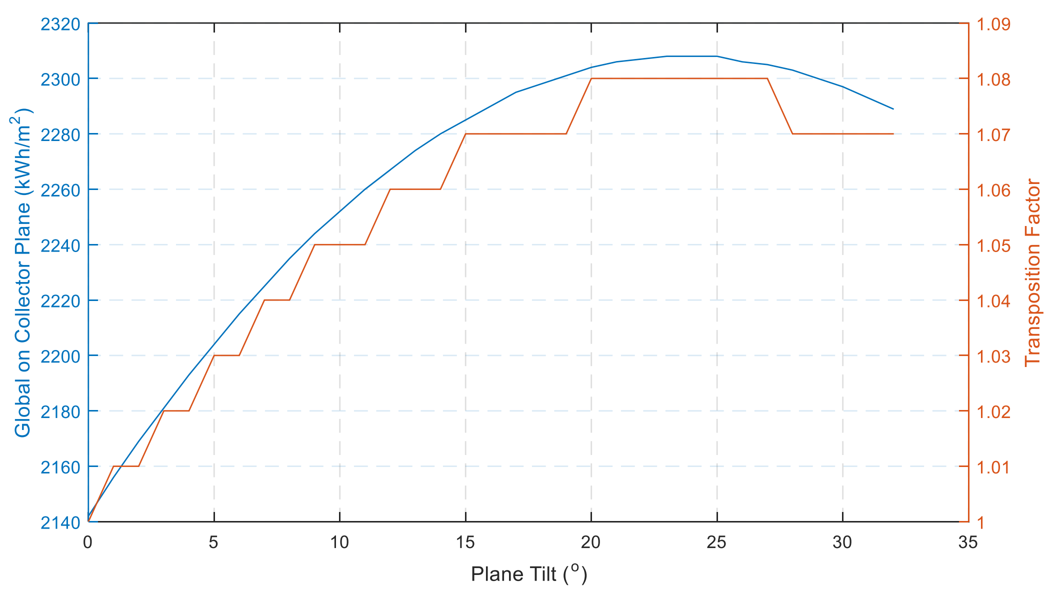
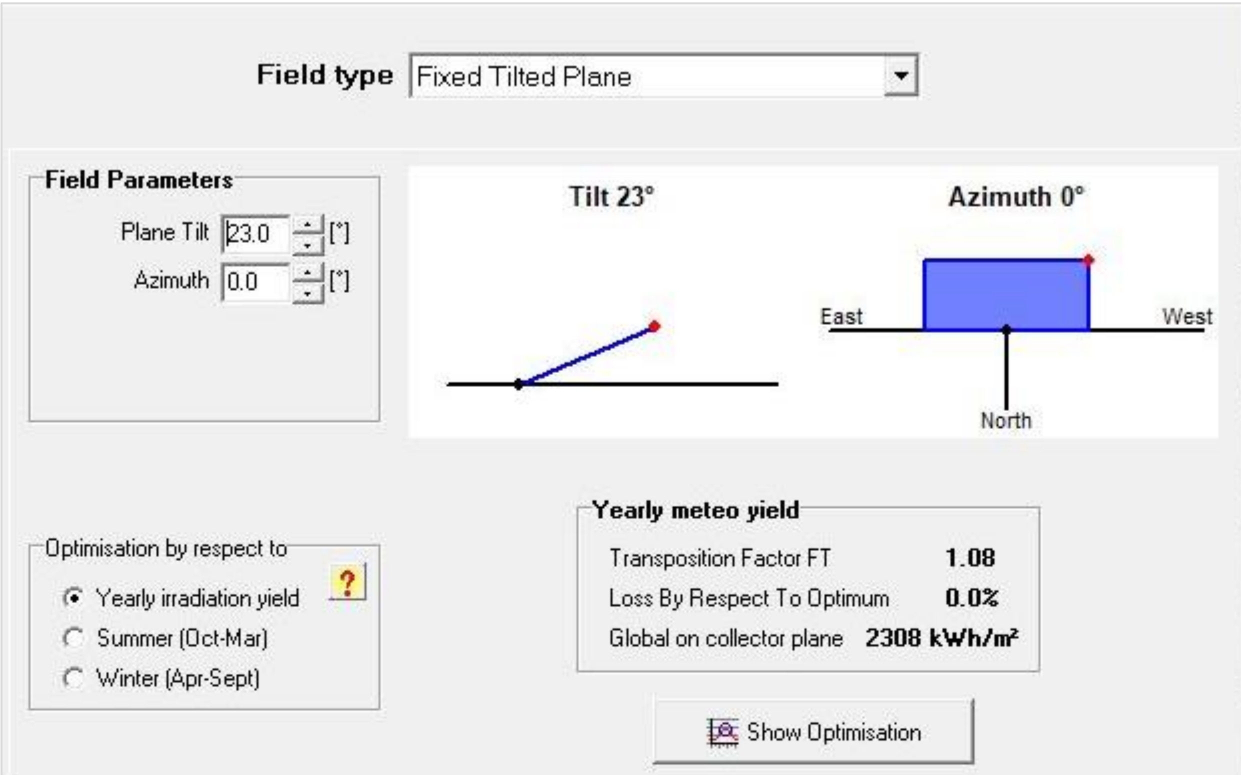


Fig.6.5 Tilt Variation and its effect on GonCP and TF.



$$Transposition\ Factor = \frac{Incident\ Radiation\ on\ Collector\ Plane}{Horizontal\ Irradiation}$$

The simulations in Figure 6.5 illustrate that for the chosen geographical location maximum energy yield can be obtained at an array azimuth of **0º** and a plane tilt of **23º**.

6.2.4 Shading and Inter-Row Spacing.

Shading occurs when a solar module/ array is partially or completely shadowed or screened from the sun by natural or artificial objects. Shading can be classified into near and far shading. Calculations to eliminate near shading are best done with reference to site sun path chart (Figure 6.6).

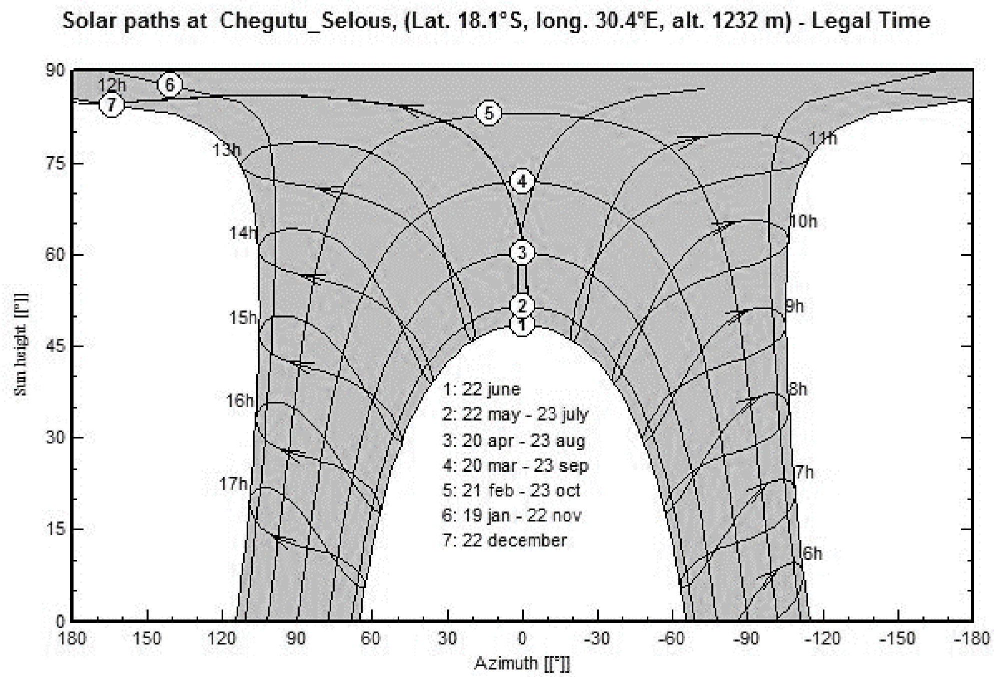


Fig. 6.6 Sun Path Chart for Location [18.14° S; 30.41° E]

6.2.5 Near Shading.

Near Shading occurs to PV modules when partly or totally obscured from the sun by nearby objects such as trees and buildings or by neighboring solar modules. Near shading due to other solar modules is best eliminated by undertaking best installation procedures for module inter-row spacing.

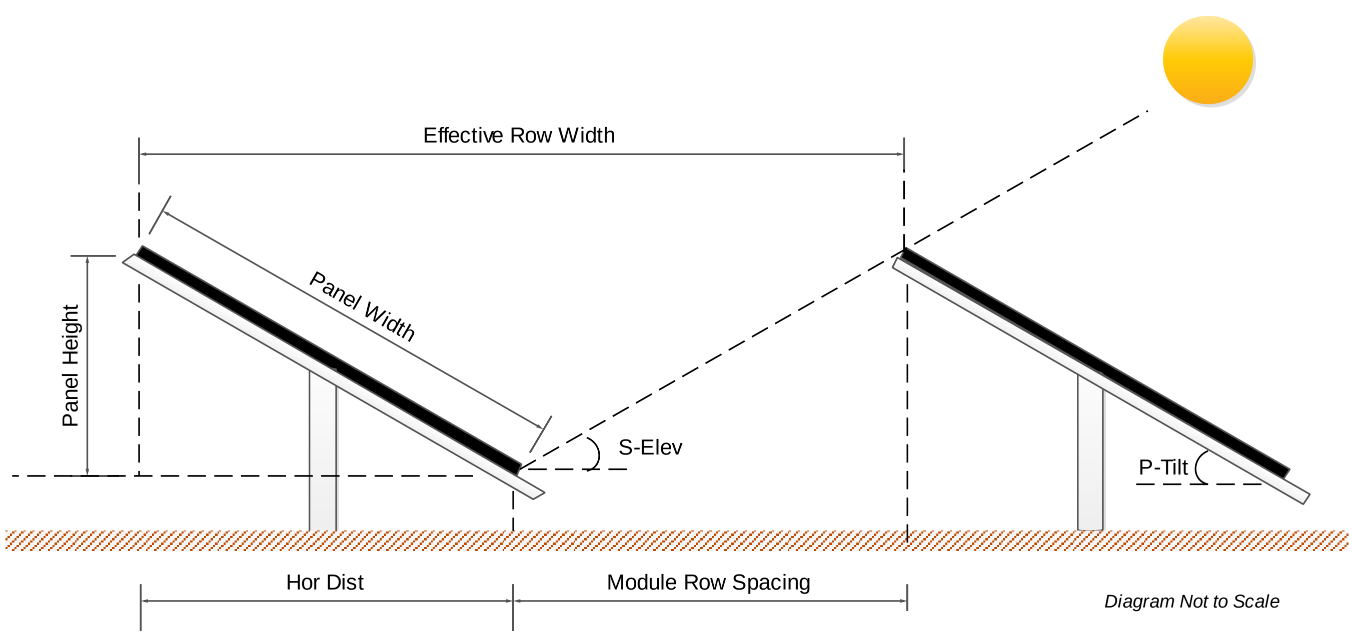


Fig. 6.7 Near shading

Variable Definitions:

Panel Height	$= Panel_h$
Effective Row Width	$= Eff_{width}$
Module Row Spacing	$= Row_{space}$
Panel Horizontal Distance	$= P_{Hor\_Dist}$
Panel Tilt Angle	$= P_{tilt}$
Solar Elevation Angle	$= Sun_{elev}$
Module Width	$= M_{width}$

Effective Row Width is the effective spacing of the solar module rows which includes shading compensatory space and row occupied space and is given by:

$$Effective\ Row\ Width = Module\ Row\ Spacing + Panel\ Horizontal\ Distance$$

$$Eff_{width} = Row_{Space} + P_{Hor\_Dist}$$

But, $P_{Hor\_Dist} = M_{width}\ x\ cosine\ (Ptilt)$

Thus, $Eff_{width} = Row_{Space} + M_{width\ x}\ cosine\ (Ptilt)$

Taking the sun Elevation into consideration to pre-calculate row spacing *(Row_{Space});*

$$tangent\ (Sun_{elev}) = \frac{Panel_h}{Row_{Space}}$$

$$Row_{Space} = \frac{Panel_h}{tan\ (Sun_{elev})}$$

To augment the pre-calculated value (Eff_{width}), sun's azimuth is factored in so as to determine the minimum raw spacing requirements. From the sun path chart (Figure 6.6), the commercial solar window is determined so that shading is eliminated during this period. The azimuth value for the chosen solar window is factored out. The shortest day-time is on 22 June, which is the winter solstice and that is when the sun will cast the longest shadow from objects. This is taken as the reference date for selection of this azimuth angle.

Thus,

$$\boldsymbol{Row_{Space} = R\_Spacing_{pre} + \cos(Azimuth_{Correction_{Angle}})}$$

6.2.6 Inverter Topologies

The inverter will convert DC power from solar PV modules to AC power before it is fed to the grid network. One of the critical features for inverters implemented in grid connected solar PV is the anti-islanding feature. A solar power plant or a distributed energy generator becomes an island if there is a blackout on the utility power grid. Islanding is unsafe for utility grid workers who may assume that there is no power when the utility power is shut down. Additionally due to the imbalance between load and generation, power quality and equipment lifetime are compromised. Anti-islanding is the feature which enables inverter units to detect shutdowns in the utility grid and subsequently shutdown the distributed generator. The following three centralized inverter topologies can be used in solar PV plant designs and implementations:

- String inverters
- Multi-string inverters
- Centralized inverter

A single inverter handles the whole plant, which can supply power even in the MW range. Solar modules are joined into m strings of n modules which are then joined in parallel. The configuration is simple, has limited economic investment and reduced maintenance cost.

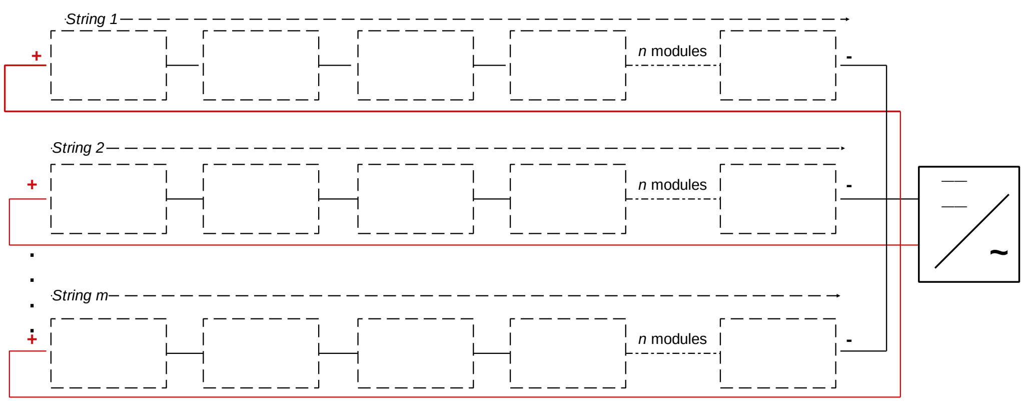


Fig. 6.8 Centralized inverter topology.

6.2.6.1 String inverter

Every string consisting of *n* series modules is equipped with an inverter. Such a string and associated inverter represents an independent mini plant, translating to *m* mini plants for the *m* strings. These can be combined at the combiner interface to yield the cumulative wattage for the *m* mini plants. The configuration for string inverters is shown in Figure 6.9.

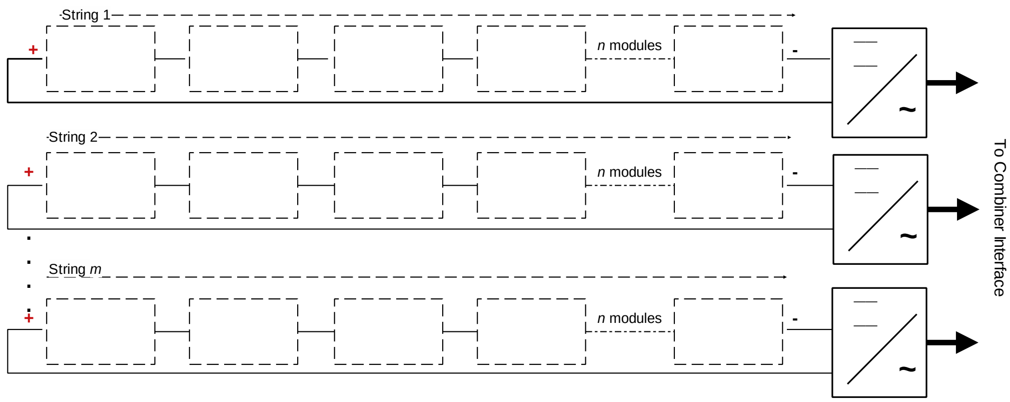


Fig. 6.9 String inverters configuration

6.2.7 PV Array and Inverter Co-Design

The solar photovoltaic array selection and configuration strongly depends on the electrical characteristics of the selected inverter. Likewise, the correct installation of the inverter is dependent on the solar array configuration. At this step, a holistic approach is taken to select solar PV modules and configure them to match the selected inverter. A string array approach will be used to design the system. The number of PV arrays per inverter will be dependent on the electrical characteristics of the inverters chosen.

Parameters	**Symbol**	**Parameter**	**Symbol**
Single PV Module Open Circuit	V_{oc}	System AC Active Power	P_{ACsys}
Single PV Module Short Circuit	I_{sc}	Single Module Max. Power	P_{MODmax}
Single PV Module Max. Open Circuit	MOD_{VdcMAX}	Inverter DC input power	P_{dcINV}
Single PV Module Min. Open Circuit	MOD_{VdcMIN}	PV Array Power	$P_{dcArray}$
Single PV Module Max. Current	MOD_{IdcMAX}	Inverter Efficiency	η_{INV}
Single PV Module MPP Voltage	MOD_{Vmpp}	Max. Inverter DC input	$V_{dcINVMAX}$
Max. Site Temperature	$Temp_{MAX}$	PV Modules per String	$n_{MODSTRmax}$
Min. Site Temperature	$Temp_{MIN}$	PV Modules per String	$n_{MODSTRmin}$
Module Temperature Coefficient of voltage. At Max SiteTemperature At Minimum site temperature	$T_{coeffV.}$ $T_{coeffVTmax}$ $T_{coeffVTmin}$	Inverter min. MPP voltage PV Modules per string String Voltage (max.)	$V_{dcMPPinv}$ n_{MODSTR} $V_{dcSTRMAX}$
Module Temperature coefficient of	T_{coeffI}	Max Inverter input Current	$I_{dcINVMAX}$
PV Array Nominal Power Ration	P_{nom}	String Voltage (min)	$V_{dcSTRMIN}$
Number of strings per inverter	$n_{strPERinv}$	Temperature at STC	T_{STC}

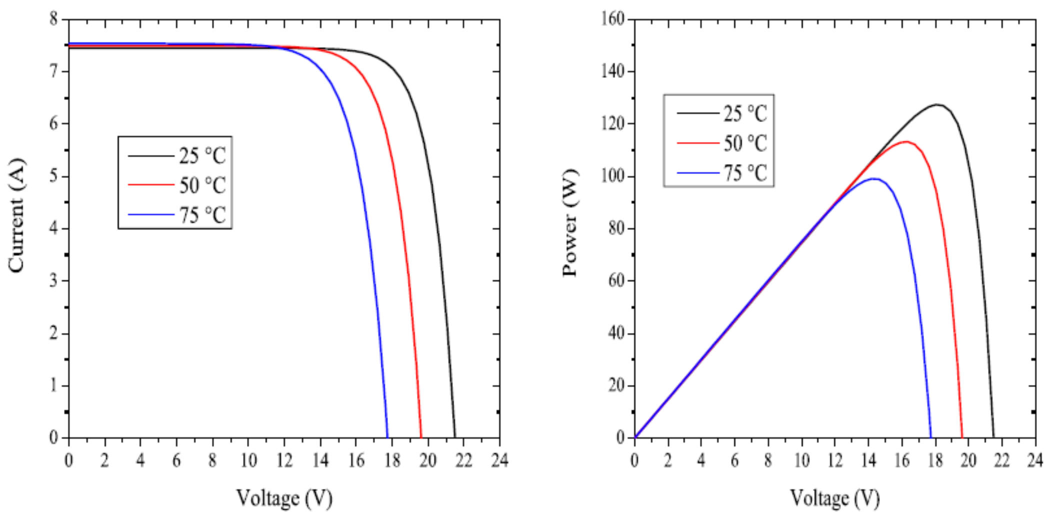
Power Calculations

$$Inverter\ DC\ input\ Power \qquad = P_{dcINV} = \frac{P_{ACsys}}{\eta_{INV}}$$

$$PV\ Array\ Power \qquad = P_{dcArray} = \frac{P_{dcINV}}{Pnom}$$

Voltages Calculations.

The current output of a solar PV module is highly determined by the incident solar irradiance (Figure 6.10) while huge fluctuations in voltage output of the module is due to temperature variations (Figure 11).



a) V-I characteristics and b) V-P characteristics with varying temperature

Fig. 6.10 Effect of Temperature changes on voltage of a PV module

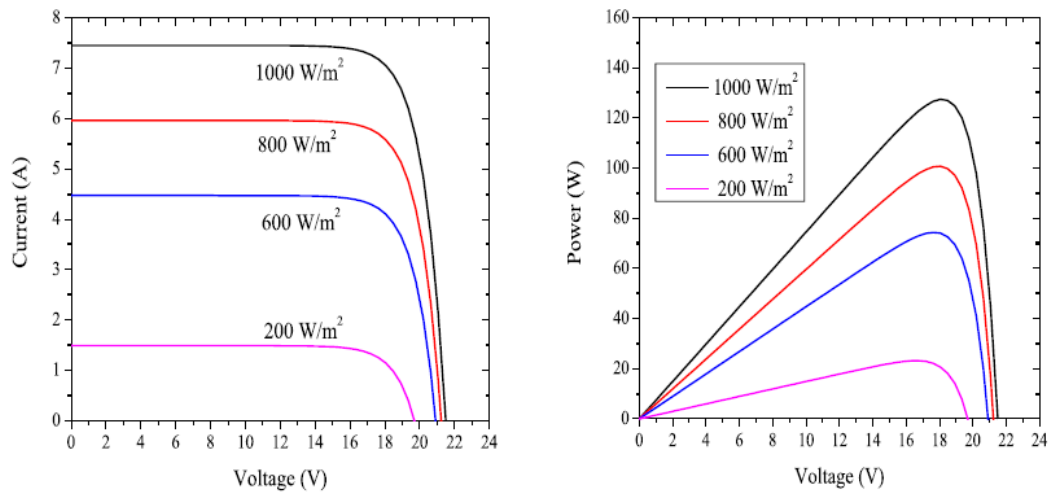
Figure 10 demonstrates a reduction in V_{oc} with increase in temperature which stipulates that at maximum plant location temperature, the PV array will output minimum V_{oc} while at minimum plant location temperature, then V_{oc} is maximum for static irradiance value. Thus;

$$Module\ Max.Open\ Circuit\ Voltage = MOD_{VdcMAX}$$

$$= V_{oc}\ x\left(1 + \frac{T_{coeffVTmin}(T_{min} - T_{STC})}{100\%}\right)$$

$$Module\ Min.Open\ Circuit\ Voltage = MOD_{VdcMIN}$$

$$= V_{mpp}\ x\left(1 + \frac{T_{coeffVTmax}(T_{max} - T_{STC})}{100\%}\right)$$



a) V-I characteristics and b) V-P characteristics with varying irradiance

Fig. 6.11 Effect of irradiance on current output of a PV module

Figure 10 shows wider changes in current when irradiation varies where higher current is obtainable at higher irradiances for the same temperature value. At a higher temperature module current is slightly higher for the same irradiance. Thus;

$$Max. PV\ Module\ Current = MOD_{IdcMAX} = I_{sc}\ x\ \left(1 + \frac{T_{coeffITmax}(T_{max} - T_{STC})}{100\%}\right)$$

For the string connected modules then, $\mathbf{MOD_{IdcMAX} = STR_{IdcMAX}}$

6.2.8 PV Modules String Configuration.

The PV modules are arranged in strings (series), where each string contains a specified number of modules dependent on voltage characteristics of inverter and a number of strings can be combined to a single inverter depending on current limits.

$$PV\ Modules\ per\ String\ (Max.) = n_{MODSTRmax} \leq \frac{V_{dcINVMAX}}{MOD_{VdcMAX}}$$

$$PV\ Modules\ per\ String\ (Min.) = n_{MODSTRmin} \geq \frac{V_{dcMPPinv}}{MOD_{VdcMIN}}$$

$$PV\ Modules\ per\ String \equiv n_{MODSTRmin} \leq n_{MODSTR} \leq n_{MODSTRmax}$$

$$String\ Voltage\ Max. = V_{dcSTRMAX} = n_{MODSTR}\ x\ MOD_{VdcMAX}$$

$$String\ Voltage\ Min. = V_{dcSTRMIN} = n_{MODSTR}\ x\ MOD_{VdcMIN}$$

$$Number\ of\ Strings = \frac{P_{dcArray}}{P_{MODmax}\ x\ n_{MODSTR}}$$

$$Strings\ per\ Inverter = n_{strPERinv} = \frac{I_{dcINVmax}}{STR_{IdcMAX}}$$

6.2.9 Preliminary Solar Resource Yield Estimate

The summary of results is as follows:

Parameter	**Specifications**
Annual Energy Yield	140573 MWh
PV Module Type	Canadian Solar, Polycrystalline, CS6A - 200P
Number of PV Modules	24 in series, 15, 625 strings, Total 375,000 equiv. 75MW
Module Installation Area	Module Area @ 488 556 m², Cell Area @ 438 120 m²
PV Array orientation	Tilt @ 24^{o}, Azimuth @ 0^{o}, Fixed tilted plane
Inverter Type	SMA, Sunny Central 500CP XT
Number of Inverters	116 inverters. PV Strings/ inverter @135

6.2.10 Design Components for Simulation

Fig. 6.12 Inverter Parameters

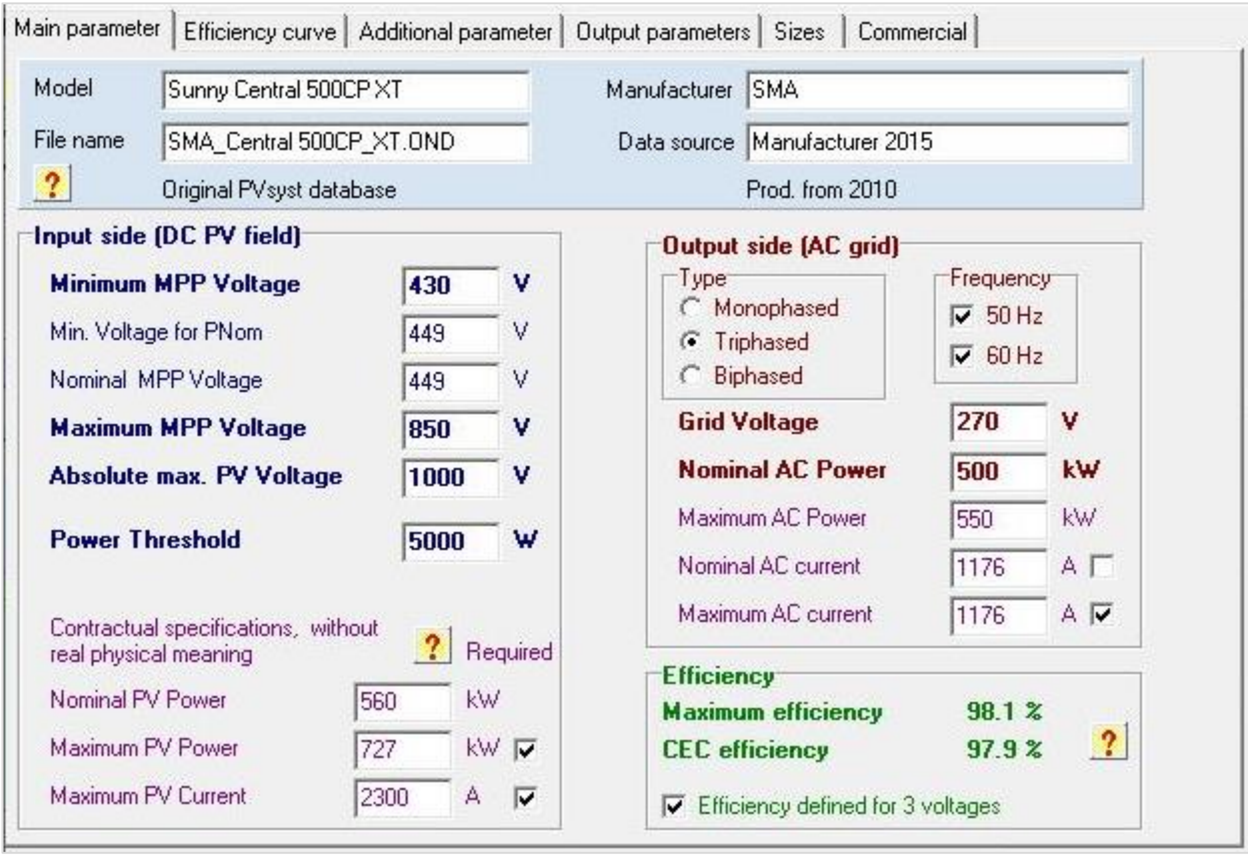


Fig. 6.13 Solar PV Modules Parameters

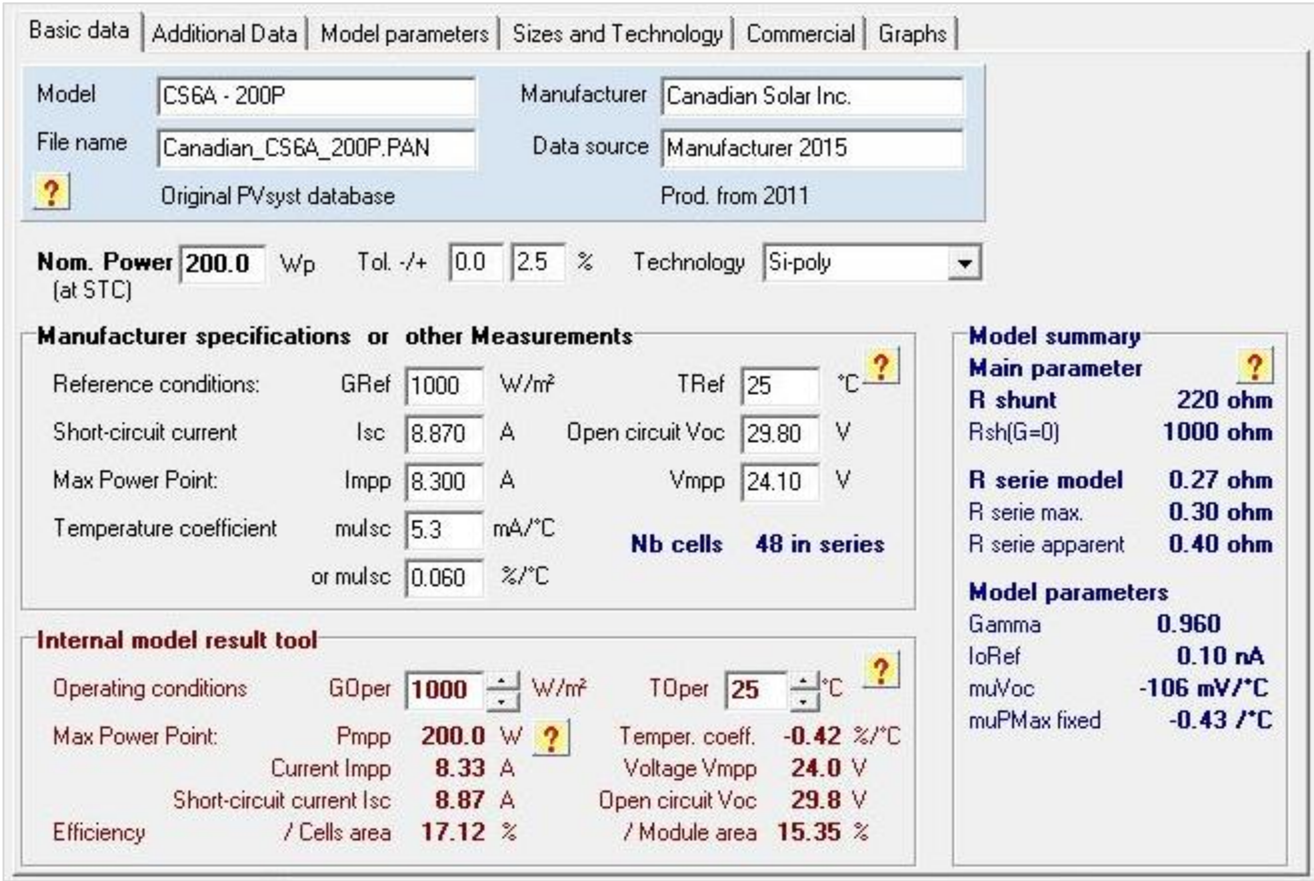
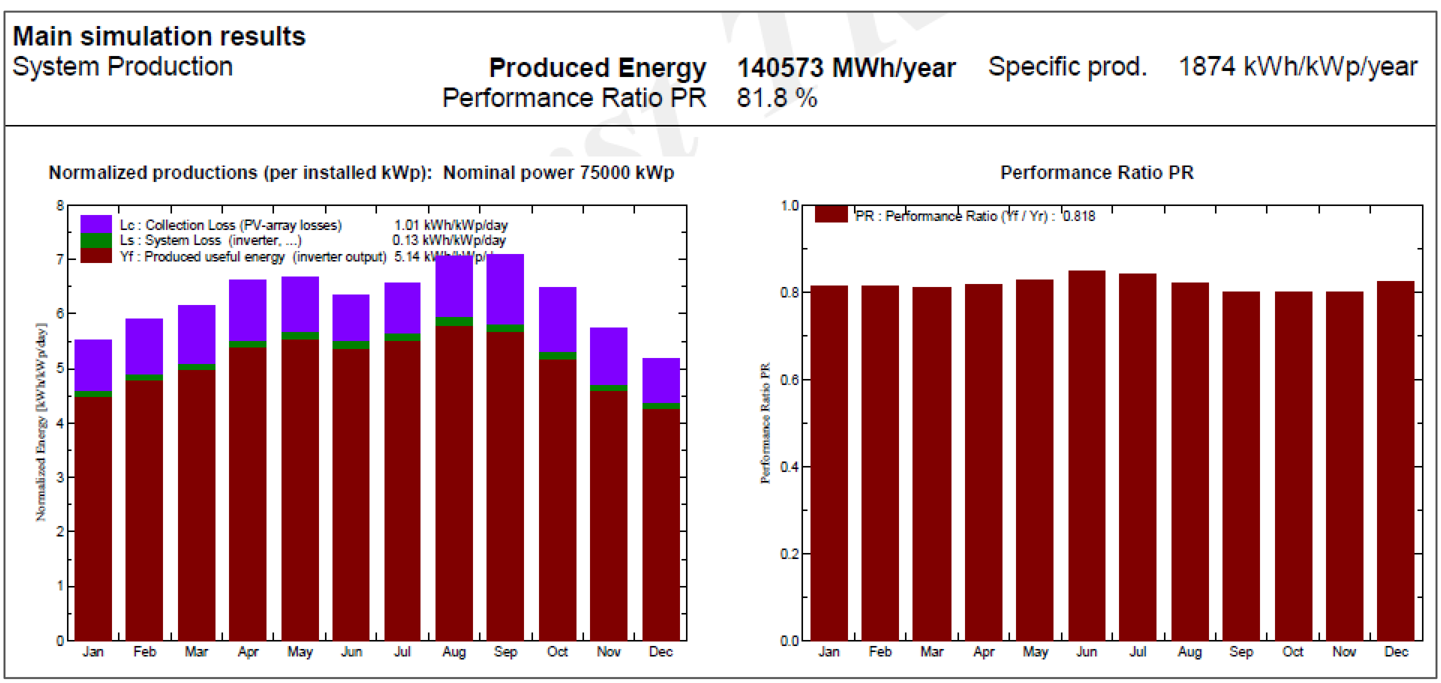


Fig. 6.14 Annual Energy Yield



	GlobHor kWh/m²	T Amb °C	GlobInc kWh/m²	GlobEff kWh/m²	EArray MWh	E_Grid MWh	EffArrR %	EffSysR %
January	193.1	22.30	170.8	163.4	10691	10426	12.81	12.50
February	174.4	21.90	164.9	158.4	10314	10060	12.81	12.49
March	183.8	21.60	190.8	184.5	11872	11582	12.74	12.43
April	171.0	20.10	198.3	193.4	12430	12127	12.83	12.52
May	162.1	17.60	207.2	202.6	13194	12876	13.03	12.72
June	142.8	15.30	190.4	186.0	12381	12092	13.31	13.00
July	155.6	15.20	203.3	198.8	13129	12817	13.22	12.90
August	181.7	17.90	219.0	214.5	13828	13494	12.92	12.61
September	196.2	21.70	212.3	206.8	13064	12754	12.60	12.30
October	205.8	23.30	201.1	194.2	12358	12069	12.58	12.28
November	191.1	23.50	172.4	165.5	10617	10345	12.60	12.28
December	185.1	22.19	160.8	153.3	10185	9930	12.97	12.64
Year	2142.8	20.20	2291.2	2221.4	144062	140573	12.87	12.56

Legends:
GlobHor Horizontal global irradiation
T Amb Ambient Temperature
GlobInc Global incident in coll. plane
GlobEff Effective Global, corr. for IAM and shadings
EArray Effective energy at the output of the array
E_Grid Energy injected into grid
EffArrR Effic. Eout array / rough area
EffSysR Effic. Eout system / rough area

Fig. 6.15 Monthly Variations

6.2.11 Meteorological Station and Onsite Measurements

Ground measured data gives an insight into the actual physically measured irradiance characteristics of a prospective power plant site. In addition to irradiance data, meteorological data is also essential in the estimation of solar PV power plant performance since the atmospheric at any given location has great influence on the amount of short-wave flux reaching the location. Hence, Annual Energy Yield (AEY) of solar power plants varies not only according to plant design and technology but also according to local weather and environmental conditions. The data measured and collected can be essential also for weather and irradiance forecasting and modelling, energy estimation validation and benchmarking and improving satellite derived data (if data is collected over a time frame).

For solar power plant development, high quality measured solar radiation data is essential. As such, at National level, there needs to be a station or institute responsible for solar radiation data measurement, processing, modelling, database development, storage, management and mapping so as to promote solar projects through the capability to zero in on the best possible sites for solar power plant installation.

6.2.11.1 Typical Measurement Station

The parameters to be measured can be classified into:

- Irradiance parameters: Direct, diffuse and global irradiance.
- Meteorological Parameters: ambient temperature, wind speed, atmospheric pressure, relative humidity, wind direction and rainfall.

Two towers are necessary, one for irradiance sensors and associated equipment and the other for weather parameters which should be long enough to avoid obstacles and measurement of ground induced parameters.

Fig. 6.16 Measurement Station Instrumentation

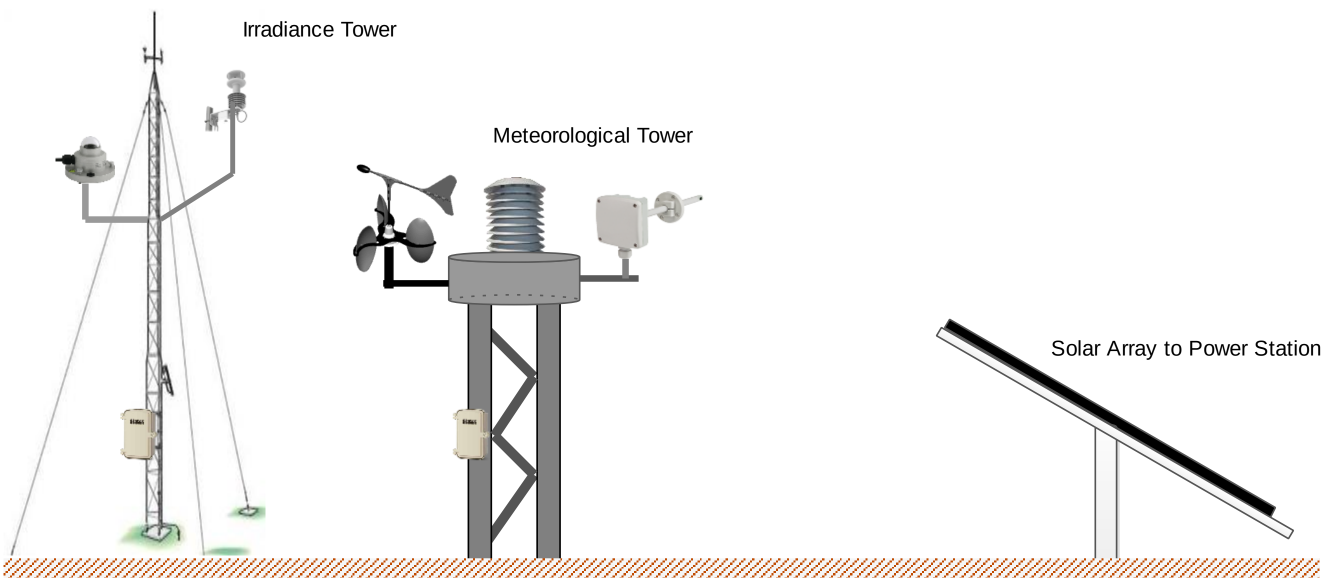
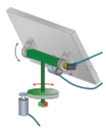


Table 6.5 Station Instrumentation

Class	Instrument		Parameter Measured
Irradiance Measurements		Pyranometer (shaded)	Diffuse Horizontal Irradiance (DHI)
		Pyranometer (Unshaded)	Global Horizontal Irradiance (GHI)

		Pyrheliometer	Direct Normal Irradiance (DNI)
		Solar Tracker	Align sensors with incidence irradiance
Meteorological Measurements		Wind Sensor	Wind Speed and Direction
		Rain Gauge	Measure amount of rainfall
		Temperature Sensor	Ambient Temperature
		Humidity Sensor	Relative Humidity
		Barometer	Atmospheric Pressure
Data Storage and Transmission		Data Logger and modem	Log sensor data and send to control station
		GPS	Synchronize sun tracker with sun motion
		GPRS antenna	Transmit field data through mobile SIM to control station
Station Power Source		Solar Panels and Charge Controller	Charging Battery for powering measurement station
		Battery	Energy storage for Measurement station

6.3 Areas for further ancillary community solar PV development startegies:

These strategies are meant to evaluate the off-grid energy generation facilities in and around the community in order to augment those activities through supply and demand energy management systems for net metering purposes.

- Roof Top Photovoltaic Systems operating in individual mode and Grid connected mode (net metered).
- Solar Photo Voltaic Water Pumping Applications.
- Remote Village Electrification using micro grids / nano-grids.
- Solar based Hybrid Systems for power generation.
- Evaluation of Solar PV cell technologies used in power generation.
- Solar Thermal Applications viz. Water heating Systems, Dryers.
- Solar based Applications for Rural Environment.
- Field studies on installed Solar Energy Systems.
- Standards and Policing.

6.4 Theoretical Considerations tied to understanding solar PV usage

6.4.1 Grid connected rooftop solar PV system and net energy metering.

Roof top PV (RTPV) systems can offer substantial benefits in terms of providing peaking supply of power, reducing Transmission and Distribution (T&D) losses, improving tail end voltages, and creating local jobs. Roof top PV system is ideally suited for Zimbabwe. It is sustainable (through the use of solar PV, a renewable resource in the grid-connected mode, thus avoiding the use of batteries). Renewable energy resources have attracted public, governmental, and academic attention due to the global energy crisis. An important technical challenge is the integration of renewable resources into the existing utility grid such that reliable power is injected without violating the grid codes and standards. There is an increasing focus on the development of solar energy in Zimbabwe for a variety of reasons, including our limited conventional energy reserves, their local environmental and social impacts, energy security, and climate change and energy access. Rooftop PV (RTPV) systems are PV systems installed on rooftops of residential, commercial or industrial premises. The electricity generated from such systems could either be entirely fed into the grid at regulated feed-in-tariffs, or used for self-consumption with the net-metering approach. A net-metering mechanism allows for a two-way flow of electricity wherein the consumer is billed only for the 'net' electricity (total consumption – own PV production). Such RTPV systems could be installed with or without battery storage, and with one integrated net meter or two separate meters (one for export to grid and one for consumption).

For commercial buildings, the use of PVs may significantly influence the geometry, positioning and orientation of the building to maximize their viability. For domestic properties there is normally a part of the building, usually the roof that lends itself to the location of PVs. However, if the opportunity exists it is worth thinking about the building design where it can be influenced to maximize the potential of PVs wherever possible. This is especially true where solar thermal panels are also being considered as there may be a limited amount of space suitable for mounting the panels. PVs need to be considered as an integral part of the energy strategy of the building and of its functioning. The integration of PVs with the other building elements is critical to success, as ever appearance and aesthetics are especially important. The use of PVs should be part of the overall energy strategy for the building. Reasons to use PV include Energy costs, Environment, Security of supply, Demonstration / Education purposes, Architectural design / feature.

Hence, solar PVs are worth installing if the following key factors are right:

- **Location:** The solar radiation at the site is important and the building on the site needs to have good access to it.
- **Demand:** The PV installation should be sized so as to optimize (in practical and economic terms) the amount of electricity which can be contributed to the overall electrical demand, e.g. Storage or stand-alone system, grid-tied system.
- **Design:** PVs will affect the form and aesthetics - the community, the client and the designers all need to be satisfied with the result.

However, solar PVs make a difference to buildings such that the following attributes have to be taken care of:

- Orientation
- Footprint
- Facade
- Section

A building orientated to the south for delighting, passive solar gain and free of over shading is eminently suitable for PVs. Similarly, a footprint with the long axis running east-west thus giving a large south-facing wall area and potentially a large south-facing roof is advantageous for PVs. The façade of a building is more complex. It is important to remember that PV can be wall mounted as well as roof mounted, but can still be very beneficial in terms of contribution to the overall energy requirement of a building. A similarity can be drawn to a window, which is a very simple "passive" element of a building, which provides free energy gains to a building (heat and light). Firstly, in construction terms, building-integrated PV systems need to play the same role as the traditional wall and roofing cladding elements they replace. Consequently, they must address all the normal issues, for example:

- Appearance;
- Weather tightness and protection from the elements;
- Wind loading;
- Lifetime of materials and risks and consequences of failure;
- Safety (construction, fire, electrical, etc.);
- Cost.

Invariably, there are a number of more particular aspects, often associated with being able to use the electricity produced, namely:

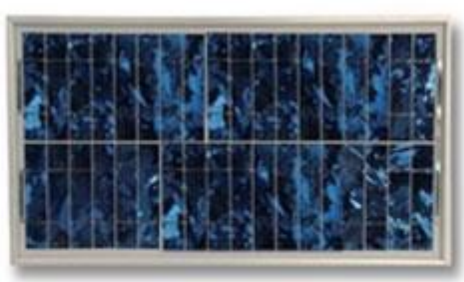
- Avoidance of self shading;
- Heat generation and ventilation;
- Provision of accessible routes for connectors and cables;
- Maintenance.

6.5 Choosing solar PV panels

There are three main types of photovoltaic solar panels for both commercial and residential use. They are: Monocrystalline, Polycrystalline and Amorphous Silicon also called "Thin Film".All three types of solar panels have both advantages and disadvantages depending on the end user's budget, the size and type of environment where they are used and the expected output of the system to name a few:

6.5.1 Monocrystalline Photovoltaic Solar Panel: Made from a large crystal of silicon. Monocrystalline solar panels are the most efficient and most expensive panels currently available. Because of their high efficiency, they are often used in applications where installation square footage is limited, giving the end user the maximum electrical output for the installation area available.

6.5.2 Polycrystalline Photovoltaic Solar Panel: Characterized by its shattered glass look because of the manufacturing process of using multiple silicon crystals, polycrystalline solar panels are the most commonly seen solar panels. It is little less efficient than monocrystalline panels also less expensive.



6.5.3 Amorphous Silicon "Thin Film" Photovoltaic Solar Panel: These panels can be thin and flexible which is why they are commonly referred to as "Thin Film" solar panels. Amorphous silicon solar panels are common for building integrated photovoltaic (BIPV) applications because of their many application options and aesthetics. They are cheaper and are not affected by shading. Drawbacks are low efficiency; loss of wattage per sq. ft. installed and heat retention. They are manufactured using silicon, copper indium di selenide (CIS) or cadmium telluride (CdTe)

6.5.4 Comparison of Different Types of solar PV Modules

Cell material	Module efficiency	Surface area needed for 1 kWp	Advantages	Disadvantages
Monocrystalline Silicon	15-18 %	7-9 m²	- Most efficient PV Modules - Easily available on the market - Highly standardized	- Most expensive - Waste of silicon in the production process
Polycrystalline Silicon	13-16 %	8-9 m²	- Less energy and time needed for production than for monocrystalline cells (= lower costs) - Easily available on the market - Highly standardized	- Slightly less efficient than monocrystalline silicon modules
Micromorph tandem (aμ-Si)	6-9 %	9-12 m²		- More space for the same output needed
Thin film: Copper indium diselenide (CIS)	10-12 %	9-11 m²	- Higher temperatures and shading have lower impact on performance - Lower production costs	- More space for the same output needed
Thin film: Cadmium telluride (CdTe)	9-11 %	11-13 m²	- Higher temperatures and shading have lower impact on performance - Highest cost-cutting potential	- More space for the same output needed
Thin film: Amorphus silicon (a-Si)	6-8 %	13-20 m²	- Higher temperatures and shading have lower impact on performance - Less silicon needed for production	- More space for the same output needed

6.5.5 Third Generation Solar Cells

Currently there are solar cells based in different new technologies in the way to market maturity, for example the high efficiency cells:

i) Thin film III-V solar cells:

- Union of the semiconductors from the third and the fifth group from the periodic table.
- Efficiency of 20-25%
- A variety of possible combination increasing price while increasing efficiency
- Most common connection: gallium arsenide (GaAs)
- Application: Power supply of satellites

ii) Multi-stack thin film:

- "Stacking" III-V solar cells or silicon cells
- Efficiency up to approximately 37% Each cell absorbs a certain wavelength, and then the stack can absorb more from the solar spectrum
- The top cell material has the highest band gap and covers the highest absorption area. Underlying cells absorbs the section of the solar spectrum with smaller wavelengths.
- Series connection of the overlying cells

Other names for multi-stack solar cells (depending on the number of layers) are: Tandem, triple, or multiple cascade cells.

6.6 Concentrator photovoltaics (CPV)

CPV are based on lenses or mirrors which focus direct sun light on solar cells. These cells consist of a small amount of highly efficient, but expensive, PV-material (silicon or III-V compounds, generally gallium arsenide or GaA). At present concentrating intensities vary from a factor of 2 to 100 suns (low concentration) to 1000 suns (high concentration). Commercial module efficiencies lay in the range of 20 to 25 percent, although efficiencies of 25 to 30 percent could have been achieved with gallium arsenide. An efficiency of 41. 1 percent has been achieved in the laboratory by the Fraunhofer Institut für solare Energie systeme, Germany (concentrating intensity: 450 suns).

In order to follow the course of the sun, the Concentrator modules are mounted on a 2-axis tracking system. In case of low-concentration-PV there exist 1-axis tracking systems and less complex lenses.

Fig. 6.17 Concentrator Photovoltaics Panel

6.7 Types of photovoltaic network systems

6.7.1 Off grid system: The term off-grid refers to not being connected to a grid, mainly used in terms of not being connected to the main or national electrical grid. In electricity, off-grid can be stand-alone systems (SHS) or mini-grids typically to provide a smaller community with electricity. Off-grid electrification is an approach to access electricity used in countries and areas with little access to electricity, due to scattered or distant population. It can be any kind of electricity generation. The term off-the-grid (OTG) can refer to living in a self-sufficient manner without reliance on one or more public utilities. Off-the-grid homes are autonomous; they do not rely on municipal water supply, sewer, natural gas, electrical power grid, or similar utility services. A true off-grid house is able to operate completely independently of all traditional public utility services.

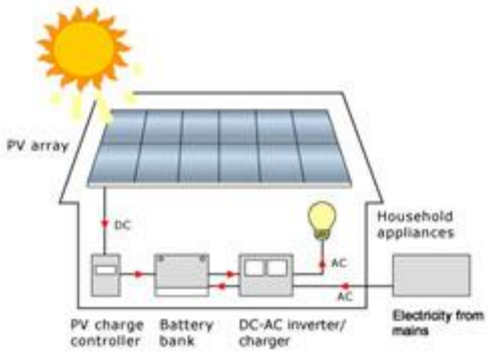


Fig. 6.18 Off-Grid system

6.7.2 Grid-tied system:

A grid-tie inverter is a power inverter that converts direct current (DC) electricity into alternating current (AC) with an ability to synchronize to interface with a utility line. Its applications are converting DC sources such as solar panels into AC for tying with the grid. Inverters take DC power and invert it to AC power so it can be fed into the electric utility company grid. The grid tie inverter must synchronize its frequency with that of the grid (e.g. 50 or 60 Hz) using a local oscillator and limit the voltage to no higher than the grid voltage. The inverter has an on-board computer which will sense the current AC grid waveform, and output a voltage to correspond with the grid. However, supplying reactive power to the grid might be necessary to keep the voltage in the local grid inside allowed limitations. Otherwise, in a grid segment with considerable power from renewable sources voltage levels might rise too much at times of high production. Grid-tie inverters are also designed to quickly disconnect from the grid if the utility grid goes down. The grid tie inverter will shut down to prevent the energy it transfers from harming any line workers who are sent to fix the power grid. Properly configured, a grid tie inverter enables a home owner to use an alternative power generation system like solar or wind power without extensive rewiring and without batteries. If the alternative power being produced is insufficient, the deficit will be sourced from the electricity grid.

6.7.3 Net metering system:

Net metering allows residential and commercial customers who generate their own electricity from solar power to feed electricity they do not use back into the grid. Net metering is a billing mechanism that credits solar energy system owners for the electricity they add to the grid. For example, if a residential customer has a PV system on the home's rooftop, it may generate more electricity than the home uses during daylight hours. If the home is net-metered, the electricity meter will run backwards to provide a credit against what electricity is consumed at night or other periods where the home's electricity use exceeds the system's output. Customers are only billed for their "net" energy use. On average, only 20-40% of a solar energy system's output ever goes into the grid. Exported solar electricity serves nearby customers' loads. Electricity delivered to the grid can be compensated in several ways. "Net metering" is where the entity that owns the renewable energy power source receives compensation from the utility for its net outflow of power. So for example, if during a given month a power system feeds 500 kilowatt-hours into the grid and uses 100 kilowatt-hours from the grid, it would receive compensation for 400 kilowatt-hours. Another policy is a feed-in tariff, where the producer is paid for every kilowatt hour delivered to the grid by a special tariff based on a contract with distribution company or other power authority.

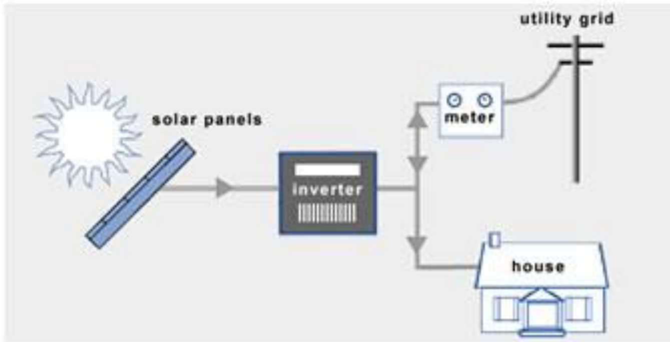


Fig. 6.19 Net-metering system

6.8 Grid connected roof top solar PV system

In recent years solar PV systems became viable and attractive. Available roof-top area on the buildings can also be used for setting up solar PV power plants, and thus dispensing with the requirement of free land area. The electricity generated from SPV systems can also be fed to the distribution or transmission grid after conditioning to suit grid integration.

6.8.1 The roof-top solar PV systems:

- Area easy to install and maintain
- Have long life of 25 years

Grid-connected solar photovoltaic (PV) systems are expected to proliferate over the coming decade and higher penetration levels will put a premium on achieving optimal performance and reliability. A PV solar plant is a plant that uses solar cells to convert solar irradiation into electrical energy. PV solar plants consist of solar modules, an inverter converting DC into AC and transformer conveying the generated power into the grid net. It has been shown in practice that the energy efficiency of PV solar plant decreases from 0.5-1% annually. The real lifetime of silicon-made PV modules is expected to be at least 25 years. Since there are no moving parts in the system and it requires only minimal attention. But depending upon the dust level, the system requires periodic cleaning. The grid connected roof top solar PV system would fulfill the partial / full power needs of large scale buildings. The following are some of the benefits of roof top SPV systems:

- Generation of environmentally clean energy.
- Consumer becomes generator for his own electricity requirements.
- Reduction in electricity consumption from the grid.
- Reduction in diesel consumption wherever DG backup is provided.
- Feeding excess power to the grid.

6.9 The basics of sizing a solar PV system

The most important thing that one needs to know before sizing a PV system is the energy requirements of a setup. (Along with all the electrical values mentioned in article mentioned above) A few things that can help are: Wattages and counts of all the appliances that need to be run on solar PV. If you do not have wattages then you can look at the current requirement (in amperes) of the appliances and calculate wattage with this simple formula:

Watts = Ampere x 240 (voltage)

Electricity bills of the setup. Used to check the monthly electricity units used in a setup. Daily units can be obtained by dividing month units by 28/29/30 or 31 (depending on the number of days in the month for which the bill is generated)
Daily usage of each appliance in hours. This is required if you do not have a sample electricity bill. This helps in calculating the number of units of electricity used in a day using the formula below:

Units = (Watts x Hours) /1000

Two things absolutely essential are: Total wattage of appliances (which denotes the instantaneous electricity requirement of a setup) and Total Units (which denotes the total electricity used in a day).

6.9.1 Sizing a PV panel

To size a PV panel, the most essential thing to know is the Total Units consumed in a day by the appliances in a setup (unless it is a direct connected system or a grid connected system for which details are mentioned here). The size of PV system should not be less than the one that can generate total units consume in a day. Every solar PV panel has a peak wattage (Wp) mentioned on them. A 1 kWp (or peak kilo watt) system would generate 5 to 7 units in a day. Therefore, the right size of PV system (in kWp) should be estimated by dividing maximum daily usage units divided by 5.

One can buy a bigger system if going for a grid connected system where extra electricity produced will be sold back to the electricity provider. In such cases one can optimize the size of PV system based on the space that one has for installing solar PV panels .

6.9.2 Sizing Battery bank for solar PV system:

If one is not going for a grid connected system or a direct connected system, one needs batteries to store the energy generated using solar PV panels. Along with sizing of the solar PV panel, it is important to size the batteries as well. Because if one purchases more batteries then they will not get fully charged, if one buys fewer batteries, one may not be able to get the maximum benefit out of the solar panel.

Most big PV systems use deep cycle (or deep discharge) batteries that are designed to discharge to low energy levels and also to recharge rapidly. These are typically lead acid batteries that may or may not require maintenance. In case of solar mobile phone chargers or other small chargers the batteries may be Lithium Ion, etc.

Batteries have energy storage ratings mentioned in Amp-hour (Ah) or milli-Amp-hour (mAh). They also have a nominal voltage that they generate (typically deep discharge batteries are 12 V batteries, cell phone batteries are 5 V batteries, etc). To calculate the total energy a battery can store one can use the following formula:

Units = (Volt x Ah) / 1000 or (Volt x mAh) / 1000000

We have already talked about how to calculate the total units required in a day and also the sizing of the PV system. Batteries should be sized in such a way that the units of energy generated by the

PV system should be equal to the number we have calculated above.

Therefore, assuming we have a 1 kWp system and we assume that on an average it generates 6 units a day and if we have to buy 12 V battery for it, the Ah (or storage) of battery required would be:

$$(6 \times 1000) / 12 = 500 \text{ Ah}$$

6.9.3 Sizing Inverter for a Solar PV system:

A power inverter or inverter is a system that converts Direct Current (or DC) to an alternating current (or AC). A solar panel produces DC current, batteries also generate DC current, but most systems we use in our daily lives use AC current. Inverters also have transformers to convert DC output voltage to any AC output voltage. Depending on the type of system (grid or off-grid) various types of inverters are available.

Sizing of inverter depends on the wattage of appliances connected to it. The input rating of inverter should never be lower than the total wattages of the appliances. Invariably, it should have the same nominal input voltage as that of the battery setup. It is always better to have inverter wattage about 20-25% more than that of the appliances connected. This is specifically essential if the appliances connected have compressors or motors (like AC, refrigerator, pumps, etc), which draw high starting current.

Most inverters available in market are rated on kVA/VA or Kilo Volt Ampere/Volt Ampere. In ideal situations (power factor of 1) 1 VA = 1 Watt. But in real power factor varies from 0.85 to 0.99. Hence, one can assume 1.18 VA = 1 Watt. Therefore, if one has a setup where the total wattage of the system is 1000 Watts, it means the inverter size required is more than 1180 VA or 1.18 kVA (add some extra to be on a safer side).

The higher the VA of an inverter, more is the number of appliances it can support, but more costly it would be. As a result, it is quite important to size it right while buying. Meanwhile, for a grid-tied system, as there are no batteries connected, the size or VA of the inverter should match the wattage of PV panel for efficient and safe operation.

6.9.4 Costs of solar PV systems and incentives

The government of Zimbabwe has initiated a subsidy scheme to help individuals and organizations to procure these solar energy systems at reduced capital costs.

6.10 Micro Solar Pumps

In some cases, farmers grow vegetables on a very small size plot largely using manual irrigation methods like swing bucket, hand pumps or treadle pumps. A small micro solar pump with less than 75 Wp to 500 Wp with 0.1 HP to 0.5 HP pump of power needed could do a similar function as a manually operated pump. Most of these farmers have no access to electricity. There are applications of micro solar pumps even in rural schools, health centers and drinking water.

Fig.6.20 Typical micro-solar pump

- A solar-powered pump is a pump running on electricity generated by photovoltaic panels or the thermal energy available from collected sunlight as opposed to grid electricity or diesel run water pumps.
- A system with 1800 watt PV array capacity and 2 HP pump can give a water discharge of 1.4 lakh liters per day from a depth of 6 to 7 meters. This quantity of water is considered adequate for irrigating about 2-3 acres of land holding for several crops.

SOLAR WATER HEATERS

Flat Plate Collectors (FPC)
The solar radiation is absorbed by Flat Plate Collectors which consist of an insulated outer metallic box covered on the top with glass sheet

Evacuated Tube Collectors (ETC)
Evacuated Tube Collector is made of double layer borosilicate glass tubes evacuated for providing insulation. The outer wall of the inner tube is coated with selective absorbing material.

Flat Plate Collectors (FPC) Evacuated Tube Collectors (ETC)

Fig. 6.21 Solar water heaters.

Salient Features of Solar Water Heating System

- Around 60 deg. – 80 deg. C temperature can be attained depending on solar radiation, weather conditions and solar collector system efficiency.
- Solar water heaters (SWHs) of 100-300 litres capacity are suited for domestic application.
- A 100 litres capacity SWH can replace an electric geyser for residential use and saves 1500 units of electricity annually.
- Life -15-20 years.
- Payback period: 3-4 years.

6.11 Solar PV operations and maintenance

Before one addresses the issues of solar photovoltaic (PV), one must understand the nature of solar PV O&M first. The common belief is that solar requires very little to almost no maintenance at all. This statement turns out to be true, but at the same time can be very misleading. In the past utilities have dominated the energy industry and more or less have supplied all the electricity to residential and commercial customers. One pays for the energy one consumes per month and that's it. Why would one consider solar, then? A typical answer might be because it is cleaner than coal or natural gas. This is true, but ultimately it comes down to money, and if solar is the cheaper option. This is where the central idea comes from in order to understand PV O&M. Solar is an investment that is likely to last for 20-25 years. How can one know if converting to solar will save them money, especially if initial capital costs are very high? In order to calculate an accurate return on investment, one must account for O&M issues, as well as understand them as to develop procedures for dealing with these issues in the most efficient and cost effective way. This is why the statement that solar requires little maintenance can be misleading. If one has very low margins to convert to solar, and does not accurately create a return on investment report, economically the results could be disastrous. In this section, O&M issues are addressed and references are given as to provide a better understanding of solar PV.

6.11.1 Natural Degradation

All solar cells naturally degrade over time, regardless of the environment they are in. This is called natural degradation, and is completely normal for all solar cells to experience once in operation. As seen in figure 1, for silicon (Si) panels, both mono crystalline and poly crystalline, degradation rates on average are around 0.7% a year, with a median value of 0.5% a year [12]. This difference is significant because it appears by the trend of the graph that outliers are skewing the data to the right. Manufacturing companies such as Jinko Solar, Solar World, and Q Cells offer warranties if degradation rates exceed certain amounts. One qualifies for panel replacement or compensation if degradation values exceed 0.8%, 0.7%, or 0.6% respectively for each company.

Over time, the system will be outputting less energy, which means one will be saving less money. Adjusting the return on investment with an accurate natural degradation rate is essential to getting an accurate reading of the true amount of energy the solar PV system will be generating. Amongst PV installers, it is standard practice to do this, but vital nonetheless.

6.11.2 Chemical Hazards

With the disposal of PV materials there is a potential chemical hazard as well. Traditional Silicon panels have no chemical hazards associated with them. CdTe (Cadmium Tellurium) panels, on the other hand, do. Cadmium can be toxic/carcinogen, but through experimentation it is shown that it can only be dangerous through ingestion. The most likely case in which one would consume cadmium from a solar panel would be if the panels were disposed in a landfill, and the chemicals from the cadmium panel leaked into the water bed; however, a certain bulk of Cadmium is needed to institute health risks. In Colorado, one of the largest states in regards to number of PV installations, 20% of its landfills are too small for this volume of Cd to even exist. To exceed the waste volume limit of $5000yd^3$ to be deadly, a single landfill would have to absorb 680 thousand Cd panels every year for the next 20 years.

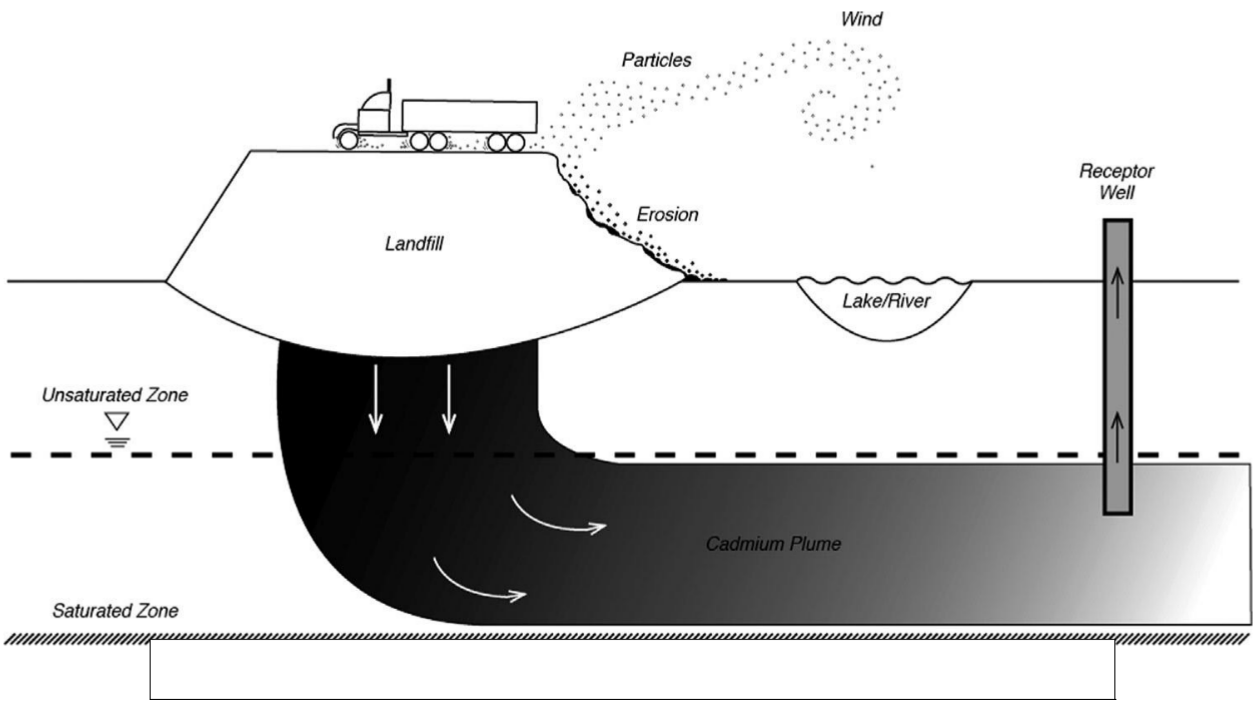


Fig. 6.22 – The process of how Cadmium could infiltrate a landfill

Based on the CdTe market in 2010, that would mean 8% of all panels being made going into 1 landfill. This is beyond improbable of occurring, even with the market continually growing. Also, nearly all landfills have protective lining. It was shown that with lining, CdTe proved to have no risk, regardless of the amount of cadmium. Only 3% of landfills did not have protective lining during the

Colorado study. Overall, cadmium panels should be disposed of with care, but ultimately if the panels are professionally decommissioned and handled properly, there should be no chemical hazards. Figure 6.22 shows a diagram on how Cadmium could infiltrate a landfill.

6.11.3 Grounding and Lightning Protection

As with any large, costly structure, a lightning protection system is of high importance. There are multiple aspects of a solar PV system that one must account for to create an effective lightning protection system. The first is to create some form of grounding system to redirect the energy from the lightning into the ground, and away from the panels. Table 6.6 is a chart that tells you what type of material should be used for the grounding system depending on what type of racking system the array uses.

Table 6.6: Grounding Materials

Type of Foundation		Material for Earthing System Driven into the Soil
1	Galvanized steel directly buried into the soil	Galvanized steel, Stainless steel
2	Steel profile embedded in concrete	Copper coated steel, Copper, Stainless steel
3	Reinforced concrete block placed above ground level	Galvanized steel, Copper coated steel, Copper, Stainless steel
4	Reinforced concrete foundation into the soil	Copper coated steel, Copper, Stainless steel
Note 1: Copper Conductor may be tinned; Note 2: Aluminum not allowed to be buried into the soil		

If the racking system is galvanized steel rod drilled deep into the soil, galvanized steel or stainless steel should be used for the grounding system. Even with a proper grounding system, a PV installation can still be at risk from lightning. Once the energy from lightning is discharged into the ground, it can still cause a power surge within the array. Because of this, surge protection equipment is needed to fully protect an array from lightning. In some cases if the grounding system is effective enough to reduce the energy dissipated from a lightning strike, it will reduce the need to use more surge protection equipment. Because metals must be used to create the grounding system, the same type of metal should be used to avoid corrosion between different types of metals.

6.12 Component Failure

6.12.1 Panels

As the main component of a solar PV system, maintaining panels is key to achieve an ideal power output. Throughout the life of a PV system, there are multiple issues that can lead to panel failure, or loss of optimal efficiency.

6.12.2 Panel Cracking

Panel cracking can be caused from a variety of sources. Physical impacts, oscillation from wind, or manufacturing issues can all lead to cracking. Panels should be inspected on purchase because there could be micro cracks created during the manufacturing or shipping process that will grow into larger cracks over time. Cracks will reduce module energy output and efficiency. This is because the cracking will alter the optical properties of the panel, and cause light to penetrate the surface of the panel differently. This leads to loss of efficiency because the maximum amount of light is not penetrating the panel. Depending on the amount of cracking, sometimes it is not warranted to buying an entire new panel. Usually, extra panels are ordered whenever a system is purchased, and in this case it could be worth utilizing these panels to replace cracked ones. Otherwise, it would not be worth buying an entirely new panel to replace ones with cracks. Figure 6.23 shows an example of panel cracking.

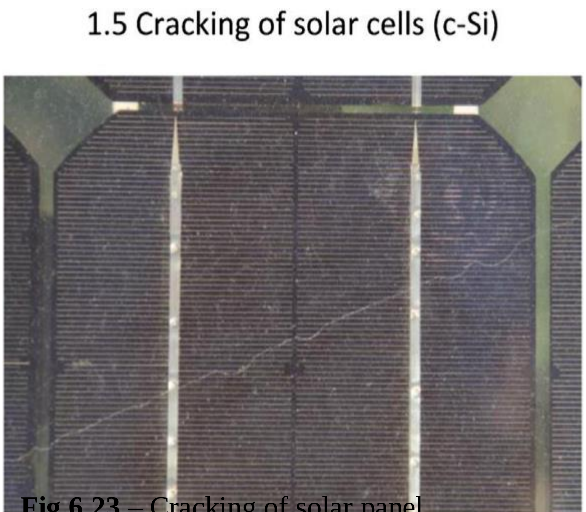


Fig.6.23 – Cracking of solar panel

6.12.3 Panel Discoloration

Visual discoloration is a common defect that reduces the amount of sunlight that penetrates into a solar cell. This means solar cells being less exposed to solar irradiation, and generating less energy. The reason it leads to loss of efficiency is because different color panels change the wavelength of light that can be absorbed. For instance, purple discoloration, such as in Figure 6.24, means that purple light is not absorbed by the panel. This causes loss of efficiency because not every wavelength of light is being absorbed. Different types of semi-conductor materials absorb different wavelengths. Some examples that cause discoloration are poor encapsulant quality, high temperatures, humidity, and if a PV system is located

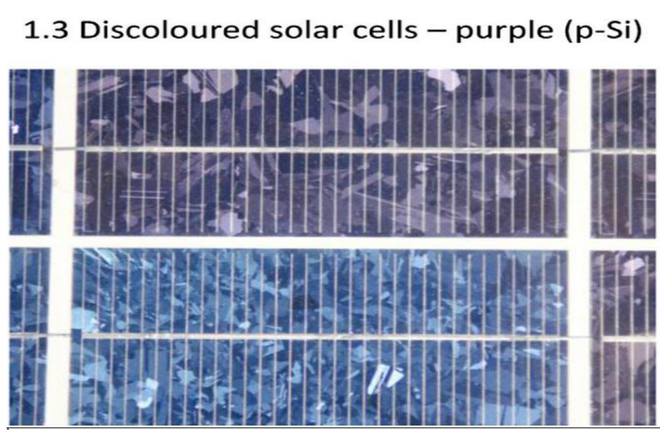


Fig. 6.24 – Solar cell with purple discoloration

near an ocean: ocean salt. Similar to panel cracking, there is not much you can do to reduce the effects of discoloration once it has occurred, other than replacing the panel entirely. Higher quality panels will become discolored less easily. There is not an exact method to see how much power is lost, other than comparing the energy output before and after discoloration has occurred.

It is a common misconception that solar panels are the most efficient in the highest temperatures. Solar cells do not gain efficiency based on temperature, but instead based on the amount of solar irradiance. On the other hand, high temperatures can actually damage solar panels, and can lead to hot spots. Hot spots occur when a panel is shaded, damaged, or electrically mismatched. Hot spots decrease power output, and because solar cells are attached in strings, just one hot spot can lead to multiple cells functioning poorly. To solve this problem, all shading should be negated, and electrical connections should be optimized. Depending on the severity of other issues that could lead to hot spots, a panel replacement might be justified. Hot spots can be easily seen with the use of an IR Gun. Figure 6.25 shows an example of multiple hotspots.

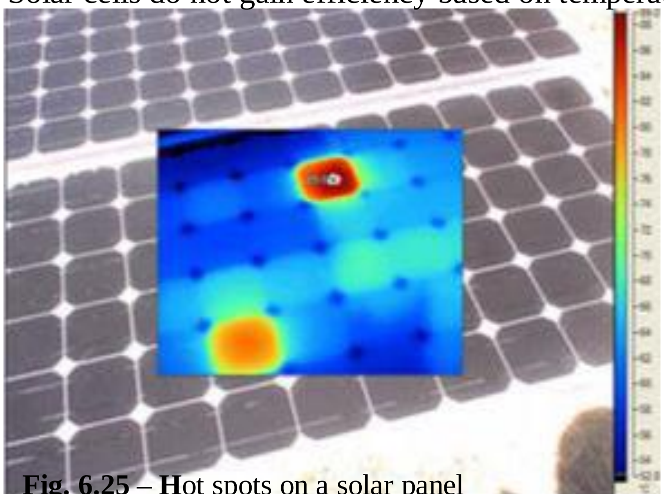


Fig. 6.25 – Hot spots on a solar panel

6.12.4 Inverters

One of the main electrical components to a solar installation, the inverter changes the electricity created by the solar panels from DC to AC. Currently there are 2 inverter schemes that one can use. The first is a single, central inverter. The other is a multi-scheme setup that utilizes 2 or more inverters in a single array. Micro inverters are gaining popularity as well. In this setup, each panel has its own separate inverter. The lifetime of a central inverter is 10 years with a standard deviation of 3 years. This is an older reference, and as such inverter lifespans have been a huge issue. A large amount of research has gone into improving inverters, though, and newer models are expected to last for the lifespan of the system.

6.13 Monitoring Failure

Modern inverters usually have monitoring instruments integrated into their build. Typically, both the voltage and the current of the electrical output can be measured. For newer models of inverters if the data link is broken, it could be useful to check the inverter itself to see if the data link is turned on and information is being monitored. For older models though, one must check each individual instrument to make sure the data stream is up.

6.14 Panel Orientation and Grid

Panel orientation is an issue that must be addressed before a system is installed. It requires due diligence on the consumers part to make sure the installer is taking the proper steps necessary to determine an ideal panel orientation. Now, if the installation is using panels with tracking systems, then the panel orientation is less important. For static panels, though, it is essential to have an ideal panel orientation. Depending on your location, there is a unique tilt angle and solar azimuth angle to optimize energy output.

6.15 Soiling

Soiling is one of the most prominent issues in dusty environments. It is also very costly, as the only way to deal with it is to clean panels. On a large commercial array, heavy soiling could

Fig. 6.26 – Soiling on panels

warrant multiple cleanings a year. At a cost of a couple thousand dollars a cleaning, having to do this every year for a PV systems lifespan can be very taxing, and in many instances can even discourage the switch to solar. One of the best ways one can deal with soiling is to combat it before it even happens. One can do this by performing due diligence and seeing if panel cleaning comes under warranty. Also, according to Mejia and Kleissl, out of 186 sites, each site was found to have losses greater than 0.01% per day, over double the average. This is because the tilt angles were less than 5 degrees. Tilt angles less than 5 degrees were shown on average to have 5x more soiling than ones that were tilted more than 5 degrees. If environment is very dusty it would be well worth it to consider a higher tilt angle even if maximum solar irradiance is gained from an angle of 5 degrees or lower. This is because over time there will be less soiling, and ultimately you will produce more energy in the long run, as well as not having to clean as often. There is only so much one can do to combat soiling before you have to clean panels. Because rain cleans panels very effectively, it should be noted that soiling effects depend primarily on time since previous rainfall. When rain does occur, it should be noted and panel cleanings should be postponed accordingly.

6.16 Wind

Similar to soiling, wind is a locational issue. Because of regulations, all solar panels must be tested to withstand certain wind loads. Usually the wind loads are significant (~50+ mph), but they do not accurately simulate wind patterns in real life. This is because in testing, a panel will be put in a wind tunnel and blasted with wind linearly from a single direction. In the field, wind patterns are not linear, and can cause damage to solar panels. This occurs when oscillation is induced, and a large enough frequency of vibration is reached that will cause the panels to outright break. As discussed by Banks, many wind patterns are circular (vortexes), and cause lift under solar panels. The most vulnerable part of an array is the corners, and often depending on the orientation of the environment, and the position on the panels, this can be a deciding factor whether or not if your array will survive through the wind over a 20-25year lifespan. Currently there is no easily accessible way of testing if solar panels can handle dynamic wind loads. It would require accurate fluid dynamics simulations to see if panels are sturdy enough or not. Usually, installers are very knowledgeable about wind loads, and through years of experience will be able to tell if it will be an issue. As all installers require an inspection before any building takes place, a professional PV installer will be able to foresee any large issues.

6.17 Maintenance

6.17.1 Panel Cleaning

It is important over the lifespan of an array to maintain optimal energy output. In order to accomplish this, panel cleaning will be necessary. Cleaning early in the morning when the mirrors are wet from dew is probably the best time to clean the panels because dust can easily be rinsed without coating removal or damage. The best technique today in the strategy of high-pressure sprays is a spray with commercial anionic detergents. Effective cleaning solutions employ chemicals which reduce surface tension, lower the cost, are capable of being handled and mixed by automated equipment, and are non-toxic, safe, and biodegradable. Detergent based solutions are normally able to restore the surface to 98% of its original reflectance. High-pressure sprays proved to be a very effective method for cleaning large-scale arrays. A Benchmark of 3-gallon per minute spray at 300 psi (with detergents) recovered up to 90% of reflectance.

Because it is variable how often one should clean, an algorithm should be used to determine when cleaning should be done to be as cost effective as possible. This means cleaning when the cost of energy lost exceeds that of cleaning. In order to calculate this, first one must adjust the actual energy production. This means taking the ratio of the actual solar irradiation the solar PV system receives to the expected solar irradiation. Once the actual energy production has been calculated, one must compare the result to the expected projection (adjusted for natural degradation). When the cost of energy lost exceeds the cost of cleaning the panels should be cleaned. This is a simple formula to follow, but requires an accurate monitoring system to utilize. This is because every day of the year has a different projection for energy production: The incidence angle changes and solar irradiation varies by day. For short sample records, the result is small enough that it is negligible, but comparing month to month produces better results. However, it is hard to do this comparison without accurate month to month data, which means drawing on data from an installation in operation for more than a year, or using a very accurate prediction tool. An example would be the NREL PV Watts software, which can be accessed at http://pvwatts.nrel.gov/. In order to determine when to clean, the cost of cleaning has to be acquired. This can be difficult because cleaning companies require a visual inspection to get an accurate prediction on the cleaning cost. Typically for commercial arrays, the price of cleaning was averaged around $2.50 a KW plus transportation and special equipment costs.

6.18 Warranties

It is important to take advantage of warranties to reduce costs. At the time of installation, the buyer receives information regarding everything from operation procedures, inverter information, module information, combiner information, racking information, monitoring system, electrical balance of systems, as-built/plans, and maintenance options. Amongst this information are the product warranties for each aspect of the solar PV system. It is important to utilize this information so that warranties can be enforced. Being able to prove that something has failed under warranty is key to reducing the lifetime costs of an installation. When trying to enforce a warranty, consult the installer of the array first, before the manufacturer. It is often in the best interest of the installer to help you to maintain their reputation. It is difficult to contact the manufacturer directly, and an attorney may need to be involved in order to make sure manufacturers uphold their warranties.

6.19 Component Optimization

The key to keeping panels working at optimal efficiency is to keep them clean, and make sure they were installed in the optimal orientation to maximize power output. Panel cleaning is discussed in the above section, and finding an optimal tilt angle is discussed in the Panel Orientation and Grid section.

In the configuration of a common DC bus, the number of inverters should not exceed 5, as it becomes inefficient. The configuration with a common DC bus is the lowest risk oriented for investors. In the case of a 1 MW case study, the configuration with two 500 kW inverters in parallel connected to a common DC bus had the lowest energy cost. Compared with a central inverter, this configuration is preferable not only because of its higher energy yield and lower cost, but lower investment risk. As seen from this study, a multi-inverter scheme is the most efficient, and because of this the industry is moving in this direction. Through the use of micro inverters, every panel will have its own inverter as to maximize efficiency and minimize issues that would affect entire strings of panels. Another crucial strategy is to use a single inverter for panels with similar orientation. For large commercial arrays, it is unlikely that all the panels will be facing the exact same direction, with the same tilt angle. For each part of an array with a different orientation, a separate inverter should be used. This is because each part of the array with different orientation will have different electrical properties, and electrical mismatch could cause inverter issues and loss of efficiency.

6.20 Procedures for decommissioning after ceasing operation

The Project consists of numerous recyclable materials, including glass, semiconductor material, steel, wood, aluminum, copper, and plastics. When the Project reaches the end of its operational life, the component parts can be dismantled and recycled. The Project components will be dismantled and removed using minimal impact conventional construction equipment and recycled or disposed off safely.

6.20.1 Temporary Erosion Control

Appropriate temporary (construction-related) erosion and sedimentation control best management practices (BMP) will be used during the decommissioning phase of the project. The BMPs will be inspected on a regular basis to ensure their function.

6.20.2 General Removal Process

Effectively, the decommissioning of the solar plant proceeds in reverse order of the installation.

1. The PV facility shall be disconnected from the utility power grid.
2. PV modules shall be disconnected, collected and returned per the Collection and Recycling Program.
3. Site above ground and underground electrical interconnection and distribution cables shall be removed and recycled off-site by an approved recycling facility.
4. Solar PV module support wooden beams and aluminum racking shall be removed and recycled off-site by an approved recycler.
5. Solar PV module support steel and support posts shall be removed and recycled off-site by an approved metals recycler.
6. Electrical and electronic devices, including transformers and inverters shall be removed and recycled off-site by an approved recycler.
7. Concrete foundations shall be removed and recycled off-site by a concrete recycler.
8. Fencing shall be removed and will be recycled off-site by an approved recycler.
9. The only roads constructed for the project site will be the interior perimeter fire break road to be constructed of a minimum 4” aggregate base. The interior roads can remain onsite should the landowner choose to retain them, or be removed and the gravel repurposed either on- or off-site.
10. The Project Site may be converted to other uses in accordance with applicable land use regulations in effect at that time of decommissioning. There are no permanent changes to the site and it can be restored to its original condition including re-vegetation. Any soil

removed for construction purposes will be relocated on the site or used for landscaping after construction is complete.

6.20.3 Solar PV Module Collection and Recycling

The project will use Certified Solar PV modules; these products are sold with an inherent unconditional, prefunded Collection and Recycling Program. To take advantage of this program, the modules will be electrically and mechanically disconnected from the solar array and packaged for shipment in accordance to best practices and arrangements for the transportation and recycling of the modules from the site. The module recycling program includes the glass and the encapsulated semiconductor material, with over 90% of the material recovered for future use.

6.20.4 Electrical Wiring Removal and Recycling

The electrical wiring is typically installed underground (limited amount) or is attached to the wooden beams (majority) on the module racking structure. To remove the underground wire, the original trenches in which the wire is buried will be dug up and the conduit and wire removed. The wire attached to the wooden rail is primarily attached via plastic clip and can be removed by hand. The wiring is either copper or aluminum (depending on the function/location) encapsulated in an insulating plastic material; most of these materials are desirable commodities that can be recycled.

6.20.5 Racking Structure Removal and Recycling

The racking structure consists of aluminum racking rails, wooden cross beams, and steel posts. All of these materials can be recycled and/or reused. Removal of the aluminum racking and wooden beams is straightforward, as the primary attachment is via screws, clips, nuts, and bolts. The steel posts are secured by small concrete foundations and will be removed using heavy equipment. An appropriate recycler can reuse these materials.

6.21 Procedures for decommissioning during construction (abandonment of project)

In case of abandonment of project during construction, the same decommissioning procedures as for Decommissioning after Ceasing Operation will be undertaken and the same decommissioning and restoration program will be honored, in as far as construction proceeded before abandonment. The facility will be dismantled, materials removed and recycled, the soil that was removed will be graded and the site returned to its preconstruction state.

6.22 Financial guarantees

The proposed solar power project is comprised of several levels of contracts that are to be put in place to ensure performance during the operational life; therefore, it is a very secure investment with significant residual value.

1. Secured revenue stream: The project will have a PPA with ZETDC that guarantees a fixed rate payment for the power generated during a 25year term. ZETDC's credit rating backs the PPA and assures that power payments will reliably be made to cover operating costs and the initial investment. In contrast to most businesses the solar facility is not selling into an open market, but rather has a fixed revenue stream for 25 years – an assurance that should give great comfort around the operations of the facility.
2. Operational Security: Solar modules are the primary component to the solar facility and represent approximately half of the overall project cost. The solar modules to be used for the proposed project will carry with them a 25-year performance warranty. In the event a module breaks down, the manufacturer provides a replacement module at no cost to the facility owner. Solar fuel is free and low operational costs provide few opportunities for mismanagement or project failure.
3. Performance Incentives: Because ZETDC is paying only for kilowatt hours produced, key facets of the development include selection of high-quality equipment, investment in system design, and management the facility to run it optimally for the duration of the term and life of the facility. Bank financing of initial project costs will ensure deep scrutiny of selected equipment and operational contracts to protect their investments. Following the financial complications of the last few years, banks are more conservative and require deeper diligence than ever before.
4. Security against company performance: Should the project owners fail to operate the facility successfully, the financiers, as long-term investors in the project, will step in to take over the facility and run the project for the life of the PPA.
5. High residual value: At the conclusion of the 25year PPA contract term, the facility will have an additional 10 – 15 years of operational life, free of encumbrances and can operate at an extremely low cost, thus creating a high residual value of the facility. The equipment will no

longer be cutting edge, but its production of kilowatt hours will always have value and the equipment's performance will be guaranteed by an industry standard solar module warranty to be approximately 80% of its original production. The owner will either establish another long-term PPA contract or sell high value peak production into the spot market. If the facility cannot remain on the same parcel of land, the expected value of the kilowatt hours the facility can produce between years 26 to 40 is worth roughly 30 times the cost to remove and relocate the facility to another market where there is a buyer for the power, making the removal of the system a sound economic decision for the owner.

6. Salvage value: At the end of the useful life of the solar modules, after 40 years, the facility value will be reduced to that of the commodity materials it's constructed of – steel, copper, aluminum, and wood.

With these facts in mind, and in line with the requirements from other counties, the following surety is proposed:

Decommissioning Trust: As part of the financing of the project, the project owner will establish a series of Trusts to be managed by a third-party financial institution determined by the project financiers. It has been confirmed that payments from the PPA can be routed directly to fund the Trusts. One of the Trusts that will be established at financing will be a Decommissioning Trust, which will be funded directly by payments from ZETDC two years prior to expiration of the PPA contract. Automatic routing of ZETDC payments into the Decommissioning Trust by a third-party financial institution alleviates the project of any burden associated with notifying the project owner that decommissioning payments are due. At the beginning of year eleven (11) of the PPA term, 10 percent (10%) of the estimated decommissioning cost shall be deposited into the Decommissioning Trust. For each of the fourteen (14) subsequent years, 6.43% per year will be deposited into the Decommissioning Trust, bringing the total to 100% of the estimated decommissioning costs.

a) If a PPA contract is renewed, extended, or a new PPA is contracted, then the Trust will return the funds to the project owner, so long as the new contract has a mechanism to route a percentage of the decommissioning costs to the Trust in the years prior to the termination of the new contract such that an equal yearly amount will be contributed to the Trust to fully fund the Trust during the last 10 years of the new contract.

b) Both parties and the land owners have an interest in decommissioning the facility, should it be abandoned. The proposed Decommissioning Trust would likely function as a construction fund, which pays for decommissioning costs incurred, upon completion. The land owner and the other parties could be given sequential terms in which to activate the construction fund. The terms and conditions under which the funds would be released are explicitly to be negotiated.

c) Given that the financial assurances being requested amount to a pre-funded repossession of private property, the conditions and terms under which the decommissioning security can be drawn on will need to be explicitly defined through negotiations.

The value of the Trust shall be based on the net cost of executing the Decommissioning Plan. Table 6.7 illustrates the estimated cost for removing the solar power plant offset by the value that will immediately be recovered from recycled scrap materials.

Component	**Disposal Costs**	**Labor Costs**	**Value of Recycled Materials**	**Net cost**	**Note**
Fence	175,000	375,000	75,000	475,000	
AC and DC electric wiring	125,000	1,250,000	750,000	625,000	Entirely reusable copper/aluminum wire; assumes market value of scrap Cu from LME
Transformer + Switchgear	250,000	200,000	625,000	-175,000	Lifetime of transformer and switchgear >> 25 years; significant reclamation value
PV-Module	0	1,000,000	0	1,000,000	Cost of solar module removal labor = similar to cost of installation
Aluminum Module Support	50,000	375,000	1,250,000	-825,000	Commodity price for scrap aluminum from LME
Wooden Beams	0	375,000	0	375,000	Wood can be scrapped or buried
Steel posts	0	625,000	425,000	200,000	Concrete removal offset by recovery of steel at scrap commodity price from LME
Concrete and residual waste	625,000	750,000	0	1,375,000	
	6,175,000		**Net sum**	**3,050,000.00**	

Table 6.7 Net cost of decommissioning

Notes on Table 6.7:

1) Disposal costs estimated based on transport plus disposal fee.
2) Labor costs based on discounted installation costs (disassembly requires more unskilled labor).
3) Value of recycled materials based on commodity scrap prices from London Metals Exchange.
4) Revised cost estimate will be prepared and submitted to Planning prior to funding of the Trust

6.23 Conclusion

This chapter has dwelt on the ingredients that influence the final product. Each stage of development for the solar PV plant was captured. Simultaneously, these stage costs then build up into the maintenance and operational costs leading to the decommissioning costs after 25years of functionality. As a result, the transmission and distribution costs are often calculated by the national utility ZESA. It is then ZESA in collaboration with the national regulator, ZERA, that a tariff structure is then given to the corresponding customers according to the category, say domestic, commercial, agriculture, mining, etc. Whereas, in Zimbabwe, capital costs are affected by several factors which however are managed within the context of the policy under the custody of the Department of Energy Conservation & Renewable Energy in the Ministry of Energy & Power Development of Zimbabwe.

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7.0 Overview Conclusion

Zimbabwe currently has a national electrification rate of 42%. While electricity has reached 83% of the urban households, rural electrification is still around 13% as per the National Energy Policy of 2012. The country has an installed capacity of about 2,300 MW, with Zimbabwe Power Company (ZPC), a generation subsidiary of ZESA, owning around 95% of this. More than 50% of electricity is generated from hydropower while the remainder is from thermal power. Bagasse, mini hydropower and small sized grid connected solar systems have an installed capacity of about 130MW.

Power Station	**Company**	**Installed Capacity (MW)**
Kariba Dam Hydroelectric Power Station	ZPC	750
Hwange Thermal Power Station	ZPC	920
Rusitu Hydro	Rusitu Power Corporation	0.75
Munyati (Coal)	ZPC	100
Bulawayo (Coal)	ZPC	90
Harare (Coal)	ZPC	80
Triangle (Bagasse)	Triangle Ltd	45
Hippo Valley Estates (Bagasse)	Hippo Valley Estates	33
Green Fuel (Bagasse)	Green Fuel	18
Border Timbers (Wood waste)	Border Timbers	0.5

Against this background, the actual power generation capacity in 2019 averaged below 1000MW against a peak demand of about 1700MW. The limited generation capacity is attributed to water availability issues, obsolete equipment and limited coal supplies. Hence, policies have been developed on improving the share of renewable energy in the overall energy mix as well as addressing issues of Climate Change, setting of overall targets for renewable energy based on the NDCs interventions submitted to UNFCCC. Hence, the intention is to attain a renewable energy capacity of 1,100 MW (excluding large hydro) or 16.5% of total electricity supply, whichever is higher, by year 2025 and 2,100 MW or 26.5% of total electricity supply, whichever is higher by year 2030. The installed capacity of renewable energy excluding large scale hydropower is expected to increase by 27% in 2030. Furthermore, the country is expected to promote the installation of more than 250 000 solar geysers in old (as retrofits) and new buildings by the year 2030. Other additional alternative energy programs include institutional and domestic biogas digesters, solar mini-grids, solar water pumping systems and the production of biofuels on a large scale.

As a result, the National Renewable Energy Policy (NREP) and the National Biofuels Policy (NBP) promote investment in the renewable energy sector by providing specific incentives, such as:

2.1 provision for National Project Status to all the renewable energy projects so as to enable projects to be exempted from the customs and general excise duty and regulations. This will allow the developers to import certain RE systems used in the generation plants at competitive rates. The incentives under national project status are guided by the Finance Act, Income Tax Act, Value Added Tax Act and Value Added Tax Regulations, Customs and Excise Duty Act and Customs and Excise General Regulations Tax Holidays as stipulated in the amended Finance Act of 2018 as well as duty free status for most of the renewable energy projects as stipulated in SI 147 of 2010 and SI 6 of 2016 (with subsequent amendments). In addition, accelerated and full tax deductible depreciation allowance is given for all solar equipment installed in a consuming or producing entity.

2.2 Prescribed Asset Status will encourage investors/developers to have access to sufficient capital to fund RE projects. It will attract capital from pension funds and insurance funds as under the investment guidelines, pension funds have to invest certain percentage of the capital in Prescribed Assets. It will also encourage projects to raise funds through issuance of bonds. Ministry responsible for Energy shall recommend RE projects on case-to-case basis to Ministry responsible for Finance for according Prescribed Asset Status.

2.3 Viability Gap Funding for Off-grid Community Project in Rural Areas To increase electricity access and develop off-grid community solutions, projects in rural areas will be eligible for Viability Gap Funding from REF for development of distribution network in the area. The quantum of Viability Gap Funding will be as determined by REF.

2.4 Incentives for Sale of Power to Third Party Grid Access: Certain incentives shall be provided for promoting third party grid access for sale of electricity from RE generators:

- Indiscriminative open access shall be granted to RE producers or beneficiaries.
- Priority dispatch shall be granted to RE producers.
- Energy banking facility shall be extended by the utility for solar and wind generators.
- Utility and the developers shall enter into a wheeling agreement. Utility to submit and get the model wheeling agreement approved by the Regulator within four months from the date of notification of the policy. The approved model wheeling agreement shall be used for execution.
- Net metering facility shall be extended to beneficiaries, namely the consumers availing net metering facility. Reduced Licensing Fees and Requirements for Developers of RE Projects

2.5 Being a clean source of energy, RE projects shall be provided concessions in licensing fee and enjoy relaxations in other licensing requirements. Based on the values of the capacity factor and the ratio between the capacity factors of RE technologies to that of conventional power plant, the licensing fees shall be reduced for developing RE projects.

2.6 Tax Exemption: For community funded or NGO sponsored off-grid projects, all import duties on import of equipment and all the taxes related to consumption of electricity shall be waived off as provided in the respective legislation and future amendments (Finance Act, Income Tax Act, Value Added Tax Act and Value Added Tax Regulations, Customs and Excise Duty Act and Customs and Excise General Regulations).

2.7 All the projects would need to obtain a license. However, licensing fees shall be waived off for installation and operation of micro-grids and mini-grids with an installed capacity of less than 1 MW and as applicable to biofuels producing plants.

GLOSSARY OF TERMS

ADFD	Abhu Dhabi Fund for Developing Countries
ASU	Air Separation Unit
AEY/P	Annual Energy Yield/ Production
BUSE	Bindura University of Science Education
CAAZ	Civil Aviation Authority of Zimbabwe
COE	Cost of Energy
CoH	City of Harare
CUF	Capacity Utilization Factor
DDF	District Development Fund
DHI	Diffuse Horizontal Irradiance
DNI	Direct Normal Irradiance
EDP	Free Democratic Party (Germany)
EEG	Renewable Energy Act (Germany)
EIA	Energy Information Administration (USA)
EMA	Environmental Management Agency
EMRECC	Environment Management, Renewable Energy & Climate Change
EPC	Engineering, Procurement & Construction
FCAS	Future Combat Air System
GF	GreenFuels (Pvt.) Ltd.
GHG	Greenhouse Gas
GHI	Global Horizontal Irradiance
GIS	Global Information System
HIT	Harare Institute of Technology
IPP	Independent Power Producer
IRENA	International Renewable Energy Agency
LACE	Levelized Avoided Cost of Energy
LCOE	Levelized Cost of Energy
LCOS	Levelized Cost of Storage

MCC	Motor Control Center
MoEPD	Ministry of Energy & Power Development
MoIC	Ministry of Industry & Commerce
NASA-SSE	National Aeronautics and Space Administration- Surface Metrology and Solar
NBP	National Biofuels Policy
NDC	Nationally Determined Contributions
NDS1	National Development Strategy
NEP	National Energy Policy
NOIC	National Oil Company (Zimbabwe)
NREP	National Renewable Energy Policy
NRZ	National Railways of Zimbabwe
PFAN	Private Financial Advisory Network
POTRAZ	Postal & Regulatory Authority of Zimbabwe
PPA	Power Purchase Agreement
PR	Performance Ratio
PV	Photovoltaic
RDC	Rural District Council
RE	Renewable Energy
REF	Rural Electrification Fund
SA	South Africa
SADC	Southern African Development Community
SAPP	Southern African Power Pool
SASSCAL	Southern African Science Service Center for Climate Change & Adaptive Land
SAZ	Standards Association of Zimbabwe
SET	School of Engineering & Technology
SI	Statutory Instrument
SME	Small to Medium Enterprises
SRRA	Solar Radiation Resource Assessment
tCO_2	Tonnes of Carbon Dioxide

UNFCCC	United Nations Framework Convention on Climate Change
VFSE	Victoria Falls Stock Exchange
ZERA	Zimbabwe Energy Regulatory Authority
ZESA	Zimbabwe Electricity Supply Authority
ZESCO	Zambia Electricity Company
ZETDC	Zimbabwe Electricity Transmission and Distribution Company
ZIDA	Zimbabwe Investment Development Agency
ZINARA	Zimbabwe National Road Authority
ZINWA	Zimbabwe National Water Authority
ZNCC	Zimbabwe National Chamber of Commerce
ZPC	Zimbabwe Power Company
ZSE	Zimbabwe Stock Exchange