LIFE CYCLE ASSESSMENT OF ZBNF AND NON-ZBNF

A PRELIMINARY STUDY IN ANDHRA PRADESH

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CENTER FOR STUDY OF
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February 2020

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Executive Summary

Zero Budget Natural Farming (ZBNF) practice uses locally available resources to manage soil nutrition, fertility, pests, and weeds. The technology completely avoids the use of inorganic fertilisers, pesticides, and herbicides. It emphasises the effective utilisation of water through specified methods and recommends less tilling, to produce higher yields. This farming practice, indigenously developed by Shri. Subhash Palekar, maintains that ZBNF is resilient to climate change, reduces the cost of cultivation, and increases farmers' income. Rythu Sadhikara Samstha (RySS) is implementing ZBNF in Andhra Pradesh, with an objective to enhance farmers' welfare and conserve the environment. Over 1.63 lakh farmers in the state practise ZBNF, as of 2017-18, and the aim is to reach over 6 million farmers by 2024.

Center for Study of Science, Technology and Policy (CSTEP) conducted a study with the objective to compare ZBNF and conventional farming (referred to as non-ZBNF) on the following parameters:

1. Water and energy consumption
2. Greenhouse gas emissions
3. Cost of cultivation, yield, and net revenue

The farm-level comparative assessment was performed for the aforementioned parameters. The crops selected for the study were **paddy**, **groundnut**, **chilli**, **cotton**, and **maize**.

A survey was conducted in four districts of Andhra Pradesh, for a limited sample size (~120). Our initial findings indicate that ZBNF processes require 50%–60% less water and electricity compared to conventional farming practices for all the selected crops. For the irrigated crops, ZBNF requires 45%–70% less (compared to conventional) input energy (12–50 GJ per acre) and results in 55%–85% less emissions (1.4–6.6 Mt CO_{2e}). For the rain-fed crops, ZBNF requires 42%–90% less input energy (1.1–16 GJ per acre) and results in 85%–99% less emissions (0.5–11 Mt CO_{2e}).

The cost of cultivation is observed to be lower in ZBNF for all crops by INR 3,000–INR 22,000 per acre, except in cotton (higher by INR 9,000, due to larger labour engagement). The difference in yield between ZBNF and non-ZBNF for chilli and paddy is negligible. For the remaining crops, non-ZBNF appears to exhibit higher yields, with an increase in the range of 0.3 Mt/acre–0.7 Mt/acre. The net revenue is seen to be higher in ZBNF by INR 9,000–INR 37,000 for all the crops (except rainfed-based cotton and chilli), because of the lower cost of cultivation. Furthermore, non-ZBNF-based chilli, maize, and groundnut seem to show higher variance in cost compared to ZBNF crops.

Limitations of the study are:

1. Limited survey sample size ~120 (four districts of AP)
2. Water consumption and yield are based on survey findings, not through measurements
3. Soil carbon sequestration was not considered

Most responses from farmers indicate a positive outlook towards ZBNF, in terms of ease of production and health impact due to avoidance of inorganic pesticides.

Preliminary results suggest the need for a more detailed study coupled with more diverse and statistically larger sample size. The impact of ZBNF practices could have the potential to transform the agricultural sector in a significant and positive way in the coming years.

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List of Abbreviations

AP	*Andhra Pradesh*
CEA	*Central Electricity Authority*
CH_4	*Methane*
DAC & FW	*Department of Agriculture Cooperation & Farmers' Welfare*
FAO	*Food and Agriculture Organization*
GHG	*Greenhouse Gases*
GJ	*Giga Joule*
K_2O	*Potassium Oxide*
kg	*Kilogram*
km	*Kilometre*
km/l	*Kilometre/Litre*
kW	*Kilo Watt*
LCA	*Life Cycle Analysis*
MoCF	*Ministry of Chemicals & Fertilizers*
Mt	*Metric Tonne*
MW	*Mega Watt*
N_2O	*Nitrous Oxide*
Non-ZBNF	*Conventional Farming*
NPWM	*Nutrient, Pest, and Weed Management*
P_2O_5	*Phosphorus Pentoxide*
PJ	*Peta Joule*
RySS	*Rythu Sadhikara Samstha*
ZBNF	*Zero Budget Natural Farming*

Chapter 1

Introduction

1. Introduction

India's food security—a result of the **Green Revolution** of the 1960s—has been accompanied by concerns regarding its sustainability. The Revolution-driven practice is dependent on the extensive use of external inputs and resources. The policies that promoted the Revolution were often unsupported by proper studies and encouraged the imprudent use of inputs. This led to unintended consequences, such as soil degradation, chemical run-off, and extensive water consumption (Pingali, 2012). Foodgrain production in 2017-18 exceeded the 2012-13 records by 24.66 million tonnes (DAC & FW, 2018). However, increasing input costs, decreasing produce prices, and diminishing land holdings have left the practising farmers largely dissatisfied. Moreover, the excessive use of fertilisers negatively affects the soil productivity, quality, and climate variations (Planning Department, 2015). The cost of such externalities from the agriculture sector has grown to be a global concern, calling for sustainable alternatives.

The **Sustainable Development Goals** (SDGs) set by the United Nations emphasise responsible production and consumption, eliminating hunger and poverty, providing good health and wellbeing, ensuring clean water and sanitation to all, and taking climate action and preserving life on land. It is, hence, imperative that the agriculture sector also promotes and contributes towards these goals. There is a need to adopt systems that produce better yields and minimise the impact on the environment. In response to this need, the UN Food and Agriculture Organization (FAO) is encouraging all countries to practise agro-ecology. This practice considers adopting efficient irrigation systems, manure recycling, composting techniques, basal organic manuring[1], crop succession, crop association, mulching, integrated pest management, natural phytosanitary treatments, and intensive rice farming (Agrisud International, 2010). Various countries have adopted such practices on a large scale to reach the SDGs and address issues of food security and climate change (FAO, 2016; UNDP, 2015).

Zero Budget Natural Farming (ZBNF) has the potential to be one such indigenous alternative to the current high-cost inorganic chemical-based practices in India. It is not an *avant-garde* innovation but an adaptation of ancient practices. This farming technique encourages farmers to use low-cost locally sourced natural inputs (like cow dung, cow urine, dried plant matter, etc.) and avoid the use of inorganic inputs. Preliminary experiments[2] have shown that the practice improves productivity and quality of soil, and has lower production costs. However, there are very few empirical studies to support such observations. While governments in Andhra Pradesh (AP) and Himachal Pradesh (HP) are formulating schemes for large-scale adoption of ZBNF, it is necessary to first determine the probable consequences of extensively scaling up these initiatives. This report attempts to provide a life cycle analyses based on preliminary data comparing ZBNF and non-ZBNF at the farm level in AP.

1.1. ZBNF in Andhra Pradesh

AP aspires to become the first 100% natural-farming state in the country. As part of a larger mission of alleviating rural poverty from agriculture and improving the quality of the ecosystem, the Government has decided to adopt ZBNF across the state. In 2016-17, the ZBNF programme was initiated in the state, with an aim to cover over six million farmers by 2024. This programme

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[1] Application of manure during land preparation

[2] Food and Agriculture Organization

has reached 1.63 lakh farmers (5.04 lakh acres of area coverage) by 2017-18. The large-scale adoption of this practice could help the state and the nation achieve the SDGs, improve the nutritional value of products, maintain biodiversity, and reduce farmer suicides (Planning Department, 2015). Rythu Sadhikara Samastha (RySS)—a not-for-profit organisation owned by the Government of AP—has been set up to ensure the implementation of the ZBNF programme.

Initial observations (2016-17) reveal that ZBNF farmers have seen a reduction in investment cost and increase in yield in certain instances. ZBNF farmers cultivating groundnuts and paddy had 23% and 6% more yields respectively than those practising non-ZBNF[3] (Planning Department, 2015).

1.2. Objectives of the Study

The aim of the study is to perform an exploratory study comparing life cycle assessment (LCA) of ZBNF and non-ZBNF at the farm level. The specific objectives are to perform comparative assessments at the farm level, in terms of:

a. Water and electricity consumption
b. Energy consumption
c. Greenhouse gas (GHG) emissions
d. Monetary and yield aspects
e. Social aspects

1.3. Scope of the Study

The study considers five major crops cultivated in the state—paddy, groundnut, cotton, chilli, and maize. The comparative analysis considers two sources of water—irrigation and rain.

The comparative assessment includes **LCA** and **farm application assessment**. Life cycle assessment usually considers the environmental impact of the product from **cradle** to **grave**. However, the life cycle assessment in this study is limited to **cradle** to **farm**:

- **Cradle**: Procurement of raw materials (e.g. mining)
- **Gate**: Industrial manufacture of inputs (e.g. manufacture of fertilisers, production of diesel)
- **Distribution**: Transportation of inputs (e.g. transport by rail/road)
- **Farm**: Utilisation/Application of inputs on soil (e.g., energy consumption and emission release during combustion of diesel, while tilling)

The LCA considers energy and emission-intensive parameters such as electricity, diesel, and agro-chemicals[4] (fertilisers, pesticides, herbicides, and other chemicals).

The farm application assessment considers the impact of the inputs as well as cultivation processes at the farm. It is conducted for water, seeds, farm machinery, farmyard manure (FYM), and human and animal labour. Further, the study compares the cost of cultivation, yield, and net revenue for ZBNF and non-ZBNF.

The following processes are beyond the scope of the current study:

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[3] Conventional (inorganic chemical-based) agriculture is being referred to as Non-ZBNF in the present report

[4] Inorganic and natural as applicable for ZBNF and non-ZBNF

- Life cycle assessment of seeds
- Life cycle assessment of machinery employed in the practices
- Use of human/animal labour beyond the farm

Chapter 2

Methodology

2. Methodology

The impact of ZBNF practices vis-à-vis non-ZBNF is analysed across seven parameters: **water**, **energy, emissions**, **cost of cultivation**, **yield, net revenue,** and **social impact**.

The assessment considers the inputs required at the farm level for each crop on a per-acre basis. The next step is the life cycle assessment for the relevant energy and emission parameters. Figure 2.1 and Figure 2.2 present the inputs (considering one complete life cycle) required at the farm level for non-ZBNF and ZBNF, respectively.

The details on assessing various inputs at the farm level and their associated life cycle energy and life cycle emissions (as applicable) are discussed below.

2.1. Water

For assessing the **water requirement** for the selected crops, two types of water sources have been considered—irrigation and rain. The sources of water for irrigation are usually canals, wells (tube and/or open), and tanks.

The water requirement for cultivation depends on the type of crop, soil, climatic condition, and farming practices. Further, the water requirement for the crop varies across the stages of cultivation. Conventionally, water requirement[5] for irrigated crops is assessed as,

$$Water\ requirement\ (m^3) = \frac{Land\ area\ (m^2) \times Depth\ of\ irrigation\ (m) \times Crop\ life\ (days)}{Frequency\ of\ Irrigation\ (days)} \tag{1}$$

In theoretical reporting, the water requirement is provided in terms of the total water level, including all the stages (nursery to harvesting) of the crop. In such cases, the water requirement is assessed as,

$$Water\ requirement\ (m^3) = \{Land\ area\ (m^2) \times total\ water\ level\ (m)\} \tag{2}$$

ZBNF mandates multiple aeration by increasing the frequency of irrigation while cultivating paddy. Also, it insists on providing water for the crop in alternate furrows, in ridge-based irrigation (FAO, 2019). These factors were considered for only the theoretical assessment. Our survey indicates that these practices are not followed by the farmers.

ZBNF uses techniques like **Mulching** and **Waaphasa** to decrease water requirements by improving soil health. These aspects (mulching and waaphasa) are not considered in the current study while estimating the water requirements.

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[5] 1 m^3 = 1 k*l*

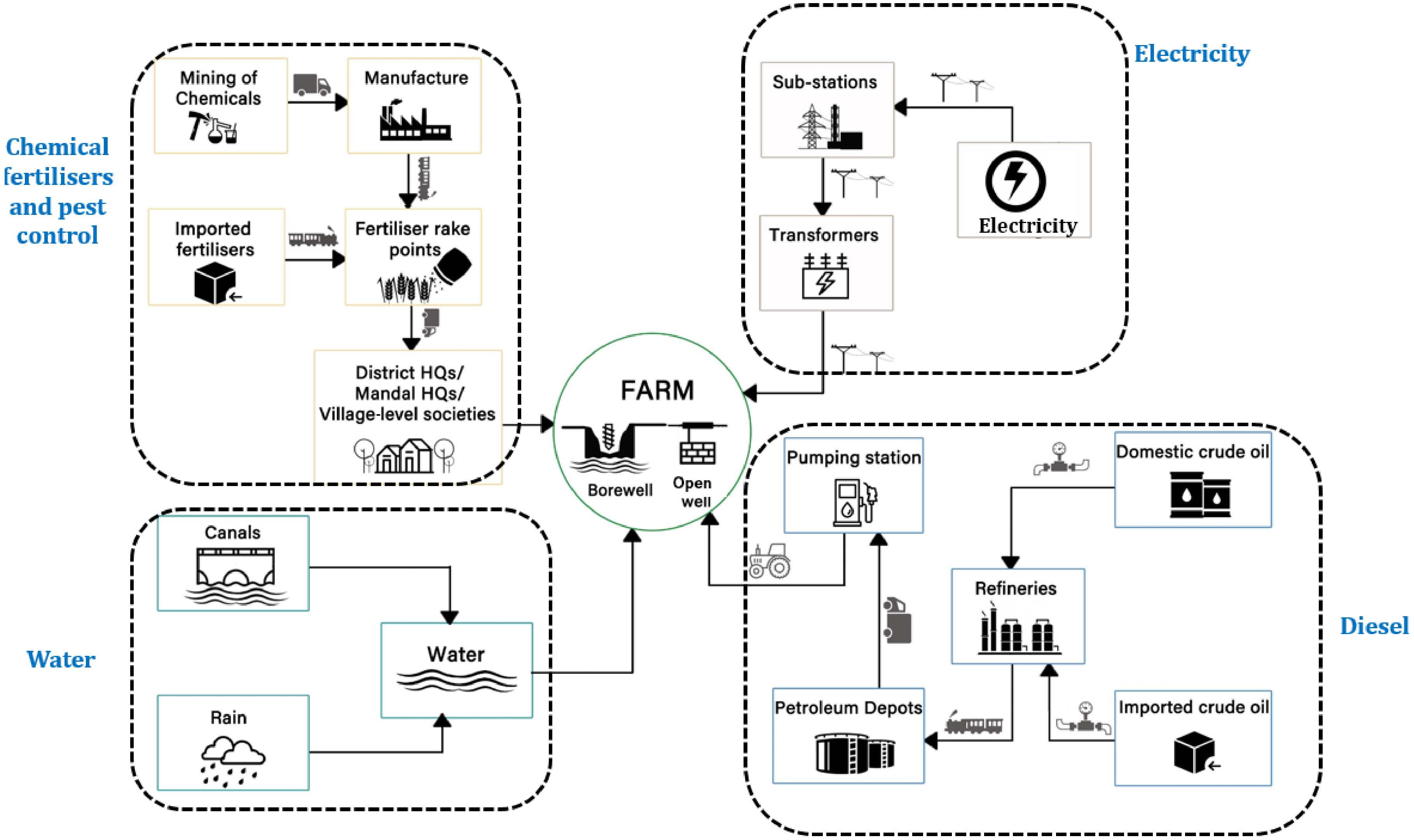

Figure 2.1: Methodology to assess the life cycle energy and emissions for non-ZBNF

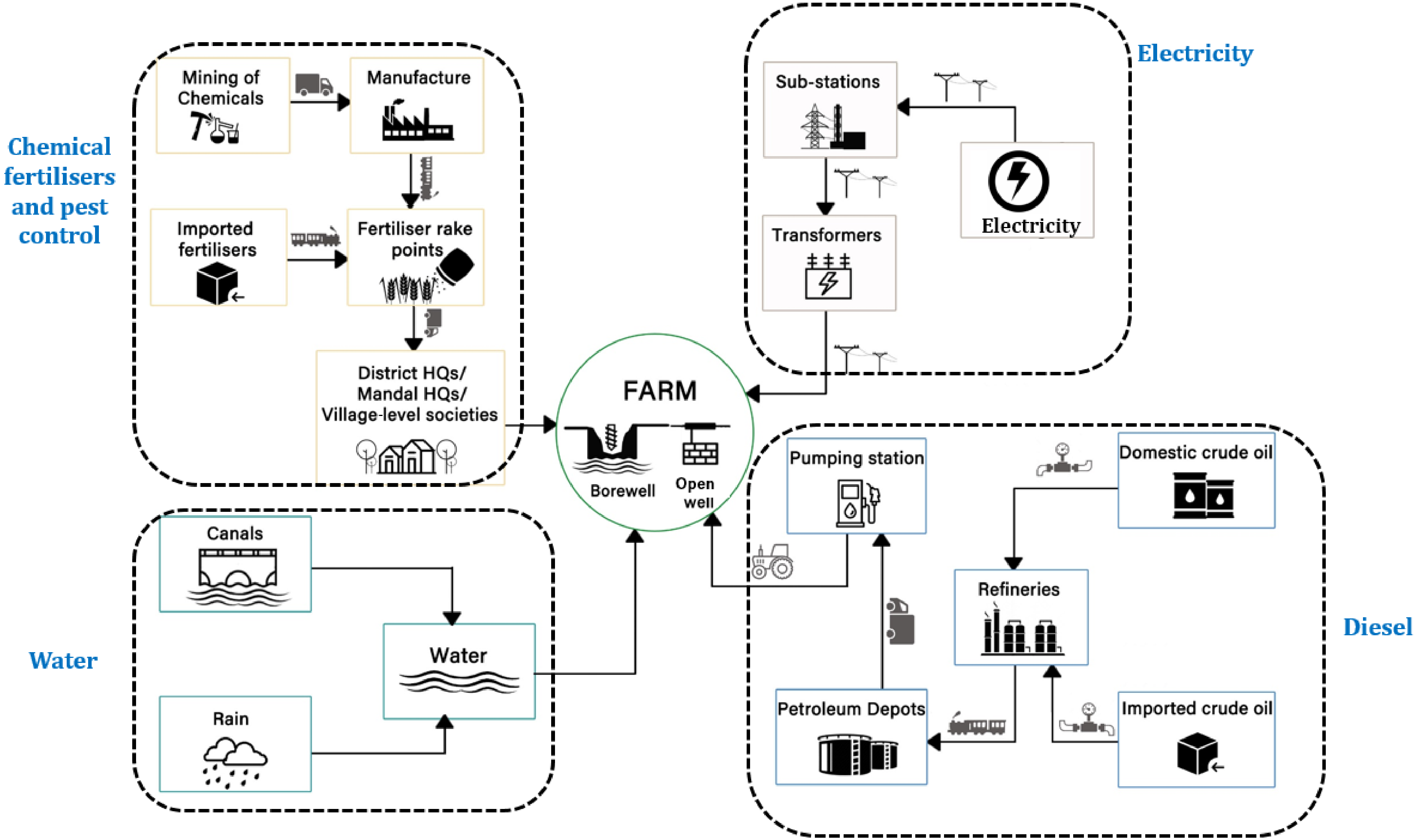

Figure 2.2: Methodology to assess the life cycle energy and emissions for ZBNF

2.2. Energy and Emissions

Energy and emissions assessment considers parameters such as **electricity**, **diesel**, and **nutrient and pest management** inputs, as applicable in ZBNF and non-ZBNF. Additionally, the energy estimates also take into account the **human and bullock labour**, and emissions include **crop emissions** and **residue burning**.

2.2.1. *Electricity*

The life cycle energy and emissions associated with electricity is apportioned for only pump-based irrigation. Electricity assessment considers factors such as crop water requirement, water discharge rate, water table depth, and pump capacity. Pump capacity depends on the water table depth and discharge rate. Theoretically, pump capacity estimation considers factors such as suction head, elevation head, flow rate, pressure, and friction losses. This is assessed as,

$$Pump\ capacity\ (HP) = \frac{Flow\ rate\ (gpm) \times Dynamic\ head\ (ft)}{3960 \times Pump\ efficiency} \tag{3}$$

Electricity consumption by the pump depends on the water requirement for the crop, water discharge rate, and pump capacity. This is estimated as,

$$Electricity\ consumption\ (kWh) = \frac{Water\ requirement\ (m^3) \times pump\ capacity\ (HP) \times 0.746}{water\ discharge\ rate\ (m^3/h)} \tag{4}$$

Given that 90% of electricity in the state is generated from coal (TERI, 2019), the energy and emissions assessment considers coal as the primary fuel. The **life cycle analysis** considers the **energy** and **emissions** from mining of coal (**cradle**) to production of electricity (**gate**).

The total life cycle energy to generate the required electricity is estimated as,

$$Life\ cycle\ energy\ for\ electricity\ (MJ) = Total\ electricity\ consumption\ (kWh) \times \sum_{Cradle}^{Farm} Energy\ required\ (MJ/kWh) \tag{5}$$

Similarly, the total life cycle emissions from electricity is estimated as,

$$Life\ cycle\ emissions\ of\ electricity\ (kg\ CO_{2e}) = Electricity\ consumption\ (kWh) \times \sum_{Cradle}^{Farm} Emissions\ (kg\ CO_{2e}/kWh) \tag{6}$$

The detailed methodology for the calculation of life cycle energy and emissions of electricity has been provided in Annexures (see Section 8.2).

2.2.2. *Diesel*

Farm activities require diesel for machinery-based (such as tractors) tilling/harvesting and diesel-based water pumps. The diesel requirement for the distribution of materials is discussed in the next section. The energy and emissions assessment for diesel considers only **tractor-based activities** as applicable for various crops. The use of diesel-based pumps[6] for irrigation is not considered in the current study.

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[6] Only electrical pumps are considered.

Theoretically, land preparation and harvesting for non-ZBNF employ mechanisation while ZBNF uses lightweight equipment[7]. Therefore, ZBNF's diesel requirement is negligible as it omits tilling. However, the ground-level survey indicates that both the practices often use mechanisation and/or bullock-labour for these activities.

Diesel consumption at the farm is estimated as,

$$Diesel\ consumption\ (l) = \sum_{Activitiy\ 1}^{Activity\ N} \frac{Speed\ of\ the\ tractor\ \left(\frac{km}{h}\right) \times Activity\ time\ (h)}{Mileage\ \left(\frac{km}{l}\right)} \tag{7}$$

The LCA for energy and emissions of diesel considers all processes from the extraction of crude oil (**cradle**) to its use at the **farm**. India heavily relies on imports (~85%) for crude oil (PPAC, 2018). The present study considers the energy and emissions assessment of diesel distribution only from the national ports (after importing) to the farm. The distribution energy and emissions involved from supplying countries to India is not considered.

The life cycle energy for diesel is estimated as

$$Life\ cycle\ energy\ (MJ) = Diesel\ consumption(l) \times \sum_{Cradle}^{Farm} Energy\ (MJ/l) \tag{8}$$

Similarly, the life cycle emissions from diesel are estimated as,

$$Life\ cycle\ emissions\ (kg\ CO_{2e}) = Diesel\ consumption(l) \times \sum_{Cradle}^{Farm} Emissions\ (kg\ CO_{2e}/l) \tag{9}$$

The detailed methodology for the calculation of life cycle energy and emissions of diesel has been provided in Annexures (see Section 8.2).

2.2.3. *Nutrient, Pest, and Weed Management (NPWM)*

The main difference between ZBNF and non-ZBNF lies in the NPWM ingredients. Non-ZBNF uses inorganic chemicals, while ZBNF uses natural products[8] for managing nutrients and controlling pests and weeds. The on-farm energy for the application of NPWM has been accounted for in the form of indirect energy (human). The methodology for energy and emission assessment has been provided below.

Non-ZBNF:

In this practice, inorganic-based nutrients such as urea, single superphosphate (SSP), triple superphosphate (TSP), Muriate of potash (MOP), and zinc sulphate are used. Other nutrients such as sulphur, magnesium, calcium, and zinc are applied in minor quantities. Additionally, pest and weed management uses inorganic chemical-based herbicides and pesticides.

For all the inorganic-based ingredients used in the practice, the life cycle energy and emissions estimation considers the procurement of raw materials (**cradle**), manufacture in industries

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[7] Bullock labour-based

[8] Technically, cow dung is also a chemical but it is naturally available.

(**gate**), **distribution** to the farms, and end utilisation (**farm**). The assessment considers key emissions of GHG—N_2O, CH_4, and CO_2.

The life cycle energy and emissions (per acre) for a unit of inorganic chemicals is estimated as,

$$Life\ cycle\ energy\ (MJ) = \sum_{Chemical1}^{Chemical\ N} Quantity\ (kg) \times \sum_{Cradle}^{Farm} Energy\ (MJ/kg) \tag{10}$$

$$Life\ cycle\ emissions\ (kg\ CO_{2e}) = \sum_{Chemical1}^{Chemical\ N} Quantity\ (kg) \times \sum_{Cradle}^{Farm} Emissions\ (kg\ CO_{2e}/kg) \tag{11}$$

The detailed methodology for the calculation of life cycle energy and emissions involved in nutrients, pesticides, and herbicides has been provided in Annexures (see Section 8.2).

ZBNF:

In ZBNF, nutrient management employs naturally-prepared ingredients (primarily using cow dung and urine) such as Bijamrita[9] and Jiwamrita[10]. In addition, other naturally-prepared concoctions—Neemastra, Brahmastra, and Agniastra—are used as pesticides. The detailed composition of these concoctions and recommended usage quantities are provided in Annexures (see Section 8.1). Energy and emissions assessment considers only cow dung, given its major share in ingredients.

The **energy** assessment considers various factors: energy for **fodder production**, **fodder consumption**, and **energy utilisation for milk and cow dung** production. The following assumptions have been made for the energy estimation:

- The energy used for cow dung production is based on the energy associated with the cow's fodder intake and the energy apportionment for cow dung.
- There are two modes of fodder collection: *procured* and *open-grazing*. Usual procured fodder types are paddy straw, groundnut stalks, maize/*jowar* straw, *ragi*, and Napier grass, which require external energy inputs for their growth. Barring Napier grass, the remaining fodders are by-products of agro-crops.
  The energy input for growing open-grazing fodder is not taken into account as the fodder growth is mainly dependent on rainfall and requires no external inputs.
- The analysis assumes the intake of fodder by cattle - 50% (procured) and 50% (open grazing).
- The assessment considers the share of fodder production from different crops in AP.

The energy associated with the required cow dung per acre is estimated as follows,

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[9] Seed treatment method for effective germination of seeds
[10] Method to increase the microorganisms and nutrients in soil

$$Energy\ required\ for\ cow\ dung\ (MJ) = Cow\ dung\ required\ (kg) \times Ratio\ of\ fodder\ to\ cow\ dung \times factor \times Energy\ for\ fodder\ production\ (MJ/kg) \tag{12}$$

where, the *factor* accounts for procured fodder, energy in fodder utilised for cow dung, and source of water.

Emissions assessment considers **emissions** from cow's **enteric fermentation** and **manure decomposition.** The natural digestion process with microbial activity (called enteric fermentation) in cattle rumens releases methane. As per IPCC, indigenous dairy cattle emits 28 kg CH_4 / head/ year (Ministry of Environment and Forests, 2004). Further, the microbes in the dung release methane and nitrous oxide upon use in agriculture. The typical annual emission factors for manure management of dung from indigenous dairy cattle are 3.5 kg CH_4 per head and 0.006 kg N_2O per head (IPCC, 2006).

The livestock emissions are estimated as below,

$$\begin{aligned} &Cattle\ and\ manure\ emissions\ (kg\ CO_{2e}) \\ &= \{No.of\ cattle \times Emissions\ from\ cattle\ (kg\ CO_{2e}/cattle)\} \\ &+ \{Cowdung\ required\ (kg) \times Emissions\ from\ cow\ dung\ (kg\ CO_{2e}/kg)\} \end{aligned} \tag{13}$$

2.2.4. *Indirect Energy*

Indirect energy is the amount of energy expended by **human** and **animal labour** towards farm activities (expressed in labour-hours). It considers factors like labour requirement (type and number), time taken for the activities, and energy equivalent factors for labour (human and animal).

The total indirect energy is calculated as,

$$Energy\ (MJ) = \sum_{Activity1}^{Activity\ N} \sum_{Labour\ type1}^{Labour\ type\ N} (No.of\ labourers \times time \times Energy\ factor) \tag{14}$$

2.2.5. *Crop and Residue Burning emissions*

The other emissions involved—apart from the energy-related parameters—are crop emissions (applicable only for paddy) and residue-burning emissions.

Crop Emissions

Water management plays a key role in determining crop emissions. Out of the selected crops, **paddy** is grown under submerged conditions. This leads to release of methane (by methanogenic bacterial[11] activity). Water management practices differ in ZBNF and non-ZBNF. This will affect crop emissions from paddy fields. The crop emissions are determined, based on the type of irrigation practices (flooded, single-aeration, and multiple-aeration).

These emissions are determined as below,

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[11] A special group of bacteria (active in submerged conditions) responsible for the release of methane via metabolic activity

$$Crop\ emissions\ (kg\ CO_{2e}/acre) = Methane\ emissions\ (kg\ CH_4/acre) \times 28 \tag{15}$$

Residue Burning Emissions

Crop residue is termed as the biomass post- harvesting and processing of the produce. There are two types of crop residues: *primary* (e.g., straw and stalks) and *secondary* (e.g., husk and shells). Part of the primary residue (unused) is typically burnt to clear the field for the next crops. The quantity of primary residues is estimated considering the crop production and residue-to-crop ratio.

The emissions from residue burning are estimated as,

$$\begin{aligned} &Residue\ burning\ emissions\ (kg\ CO_{2e}/acre) \\ &\quad = Quantity\ of\ residues\ burnt\ (kg/acre) \times Emission\ factor\ (kg\ CO_{2e}/kg) \end{aligned} \tag{16}$$

ZBNF encourages the reuse of crop residues as inputs (for mulching) in the next cropping cycle. Thus, the study assumes residue-burning emissions only for non-ZBNF practice.

2.3. Cost of Cultivation and Net Revenue

The cost of cultivation and net revenue are calculated on a per-acre basis for each crop, considering the following response-based inputs:

- Procuring requisite seeds and NPWM ingredients
- Machinery and bullock-labour use
- Electricity for water pumping (electricity for farmers is free in AP)
- Human and animal labour
- Net revenue

Cost of cultivation and net revenue are estimated as,

$$Cost\ of\ Cultivation\ (INR) = \sum_{input\ 1}^{input\ N} Quantity\ of\ input \times Unit\ cost \tag{17}$$

$$Net\ Revenue\ (INR) = Revenue\ from\ produce\ (INR) - Cost\ of\ Cultivation\ (INR) \tag{18}$$

2.4. Social-Impact Assessment

The study is designed to assess the following:

- **Production methods** (ingredient preparation, effectiveness on the crop, time for preparation, etc.)
- **Financial aspects** (subsidies, revenue, loans, etc.)
- **Social aspects** (involvement of women, role of local community-based groups)
- **Health aspects** (quality of produce and health)

The social impacts are determined from statistical analysis on the data. A *three-level Likert scale* is used to analyse the socio-economic outlook of the farmers.

2.5. Assumptions for the Study

The study considers the following assumptions:

- The assessment for each crop is performed on a per-acre basis
- Electric pump sets were considered, instead of diesel sets
- Ideal ZBNF emphasises not using heavy mechanised systems. Bullock-labour is assumed for tilling for theoretical scenarios
- Water requirement for paddy is assessed based on depth of irrigation using survey data; theoretical indicators were considered for other crops
- The estimation of energy and emission factors for transportation is based on the short-term data available
- Pest- and disease-control preparations are used once during the growth period, for theoretical estimates
- Energy and emission factors for complex fertilisers are arrived at using single-nutrient fertilisers
- Average energy and emission factors are considered for some pesticides and herbicides for which adequate data is not available
- Manpower requirement is also an indicative representation; it may vary crop-to-crop
- Tilling time per acre using tractor is considered to be one hour
- Farmer adherence to prescribed methods (multiple-aeration, mulching, etc.) for determining emissions
- All costs considered in the study are constant prices (based on farmer responses)

2.6. Limitations

The limitations of the study are:

- The crop characteristics are based on sample survey performed in four districts of AP. No other spatial and temporal variations are considered in the study
- Survey sample size is small (~120)
- Soil carbon sequestration not considered
- Evapotranspiration losses are not accounted for water estimation
- Electricity for lift irrigation was not considered
- Seasonal variations are not captured (only Kharif season is considered)

Chapter 3

Data for the Study

3. Data for the Study

3.1. Primary Data

The primary data for the study was obtained through a ground-based anecdotal survey in AP. The physical survey was conducted in four districts: **West Godavari**, **Prakasam**, **Vizianagaram**, and **Anantapuramu**. The districts were chosen based on variations in the agro-climatic zones[12], farming techniques, production, and social aspects. A questionnaire (detailed in Section 8.6) was designed to collect the following information:

- Crop-wise input quantities required during different stages of cultivation
- The cost incurred for cultivation
- Variations in crop types and irrigation types
- Social outlook of the farmers towards the farming practices

Table 3.1 specifies the parameters considered for the survey.

Table 3.1: Parameters considered for the survey

Districts	Crops	Source of water
1.Anantapuramu	1. Rice	1. Irrigated
2.West Godavari	2. Cotton	2. Rainfed[13]
3.Prakasam	3. Groundnut	
4.Vizianagaram	4. Chilli	
	5. Maize	

3.2. Secondary Data

The study performed a detailed literature review aiming to obtain secondary data on the following:

- Agri-statistics (net sown area, area under irrigation: pumped/canal, etc.)
- Nature of inputs and quantity (fertilisers, pesticides, etc.) used
- Energy and emission factors for various inputs used

The life cycle energy and emission parameters (**cradle** to **farm**) are collected/assessed for agro-supplements along with electricity and diesel. See Section 8.3 in Annexures for details about the energy and emission factors (AP Vision 2029, 2018; CEA, 2017; CII, 2017; E. Audsley, 2009; Fluck, 1992; Furuholt, 1995; IPCC, 2006; Niti, 2019; Planning Commission, 2006).

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[12] Temperature in the state ranges from 15 °C to 50 °C (DES, 2018)

[13] The state receives an annual rainfall of 800–900 mm (Department of Agriculture, 2016)

Chapter 4

Farm-Level Analysis and Results

4. Farm-Level Analysis and Results

The study assesses parameters such as water, energy, emissions, cost of cultivation, and yield for the chosen crops for both ZBNF and non-ZBNF. As mentioned in Section 2, the LCA for parameters relating to energy and emissions have been calculated (see Section 8.2 in Annexures). A comparative analysis considers both theoretical and survey-based data for each crop. The survey considers various sizes of land parcels, which are normalised to one acre for comparing ZBNF and non-ZBNF.

The parameters for all crops chosen under the study are analysed in detail. However, for the results section, paddy is chosen as a model crop owing to its importance to the agricultural scenario. Additionally, a summary has been presented for the other crops.

Figure 4.1 presents the water sources for the selected crops in Andhra Pradesh. Paddy, chilli, and maize are largely irrigated crops; groundnut and cotton are rainfed crops.

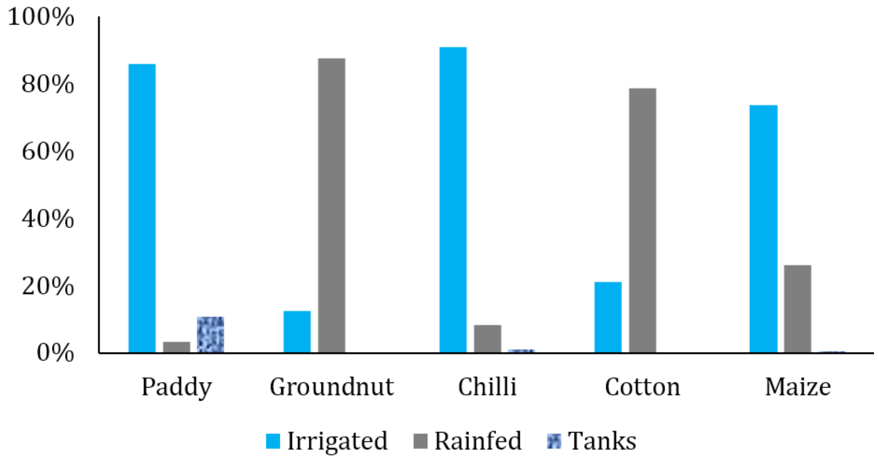

Figure 4.1: Source of irrigation for the select crops in Andhra Pradesh

4.1. Water, Energy, and Emissions for Select Crops

4.1.1. *Paddy*

Paddy is a major crop of AP, covering 35% of its net sown area. The cropping period is 100–120 days. The key parameters for paddy are assessed below.

Water

The water consumption for paddy depends on the depth and frequency of irrigation (FoI). Theoretically, the field is flooded at a depth of 2–3 inches during the growing period. The survey indicates that the depth of irrigation was 1–2.5 inches in ZBNF and 1–5 inches in non-ZBNF farms. In addition, the FoI followed in both the practices were recorded as daily, day-by-day, once in three days, etc. However, the farmers were unable to provide details on water replenishment in each instance of irrigation. Therefore, an FoI of 5 days has been assumed, with complete replenishment of water depth in each instance of irrigation.

In the case of ZBNF, the recommended FoI is 9 days (Palekar, 2019). Therefore, two scenarios have been developed: *Scenario 1 (S1)*—FoI as 9 days, and *Scenario 2 (S2)*—FoI as 5 days, to assess the water consumption. Based on this, a weighted-average scenario was considered for evaluating the water requirements in ZBNF.

Figure 4.2 presents the water consumption (average, minimum, and maximum) by paddy (during the cropping period) for both the practices, considering theoretical and survey data. It reveals that ZBNF requires (average per acre) less water than non-ZBNF: 1,400 k*l* as per theory, and 3,500 k*l* (S1) as per the survey, considering the average values. For non-ZBNF, water requirement is high given the FoI is less (5-6), though it involves single aeration. ZBNF emphasises multiple aeration, but the FoI is more (8-10). The reduction in water consumption through ZBNF would potentially play a significant role in paddy cultivation upon scaling up.

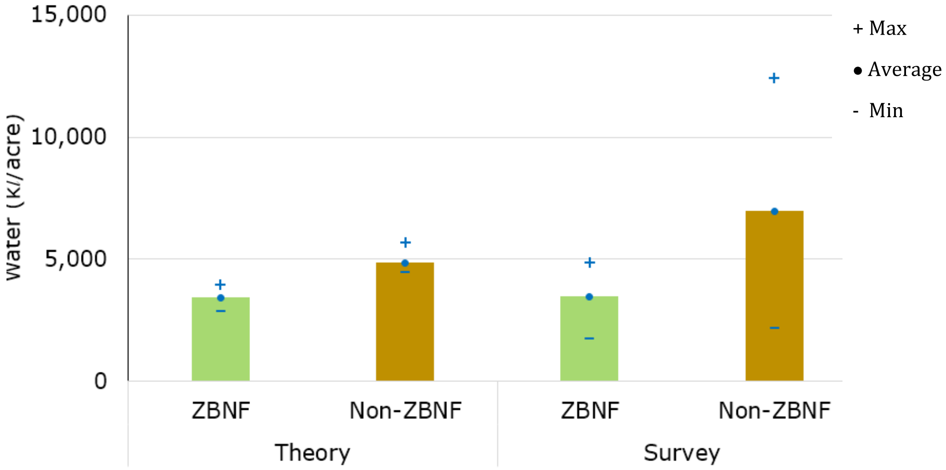

Figure 4.2: Water consumption in paddy

Energy and Emissions

As mentioned in Section 2.2, energy and emissions assessment considers **electricity, diesel, and inputs for nutrient, pest and weed management (NPWM)** as applicable in both ZBNF and non-ZBNF. Human and bullock labour are considered as indirect energy. Crop and residue burning emissions are also considered for the emissions estimate.

Electricity: In both practices, electricity is considered only for water pumping from tube-wells/open-wells. Figure 4.3 presents the electricity consumption for paddy cultivation through ZBNF and non-ZBNF. As per the analysis, electricity consumption in ZBNF is less than that in non-ZBNF, by 1,500 kWh theoretically and by 3,900 kWh as per the survey.

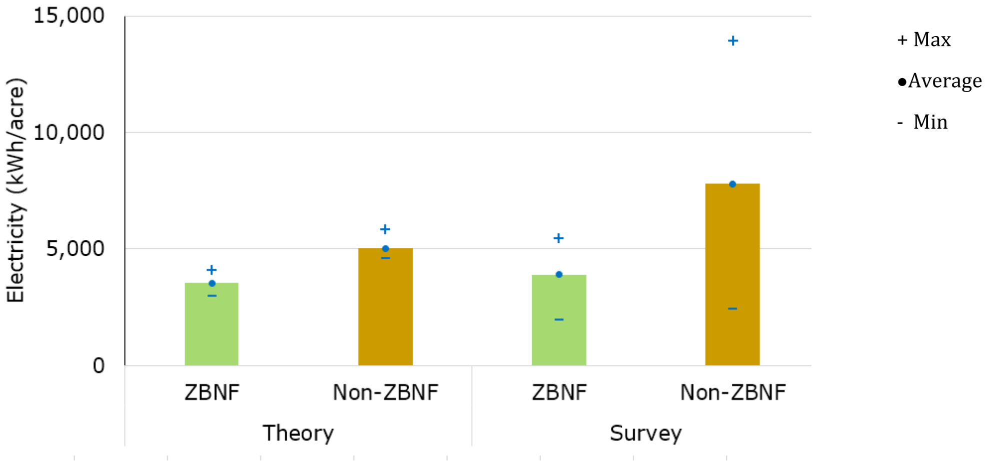

Figure 4.3: Electricity consumption in paddy

Diesel: As indicated earlier, lightweight equipment[14] is assumed in ZBNF for theoretical estimations. Therefore, diesel requirement for tilling is considered to be negligible in ZBNF and has been omitted.

Theoretically, the requirement of mechanisation for tilling in non-ZBNF is about 13 hours per acre during the crop period. The survey indicates that two modes (mechanisation and bullock labour) of tilling are employed for tilling in both practices. For ZBNF, the total mechanisation for tilling per acre is observed to be 3–7 hours and for non-ZBNF, the same is about 5-12 hours. To supplement[15] mechanisation, bullock labour is witnessed in both the practices (3–5 hours in ZBNF and 5–23 hours in non-ZBNF).

NPWM: Urea, superphosphate, and potash are the major nutrients used in non-ZBNF. Apart from these, pesticides, herbicides, and fungicides are used to control pests, weeds, and fungal diseases. Table 4.1 presents the theoretical recommendations and survey (average representation) observations of NPWM requirements. A significant variation in NPWM usage is visible between the theoretical and survey values. Further, the individual survey samples indicate that the consumption of fertilisers is less than the recommended dose. This could probably be due to a lack of affordability or awareness among the farmers about the type and quantity to be used. In ZBNF, cow dung and other natural ingredients (see Section 8.1 in Annexures) replace the inorganic-based NPWM. The composition of these solutions will remain the same irrespective of the crop type. However, there could be variations in the necessary quantities depending on the type of crop and the infesting pests.

Table 4.2 presents the quantities of natural ingredients used in ZBNF. A marginal variation can be seen between the theoretical and survey values.

Table 4.1: NPWM usage in non-ZBNF paddy

Parameter	Theory	Survey
Urea (kg)	78	38
Super phosphate (kg)	150	67
Muriate of potash (kg)	40	33
Thiram/Captan (kg)	30	-

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[14] Bullock labour

[15] Instead of or in addition to mechanisation

Other fertilisers[16] (kg)	-	186
Other pesticides (*l*)	28	1
Herbicides (kg)	4.5	-

Table 4.2: NPWM usage in ZBNF paddy

Parameter	Theory	Survey
Bijamritam (*l*)	30	14
Ghanajivamritam (kg)	200	280
Dhravajivamritam (*l*)	635	540

Indirect energy: The study theoretically determined that an acre of land requires an active work participation of about 80 hours (*h*) from men and 90 *h* from women per crop cycle, for non-ZBNF. Similarly, ZBNF theoretically requires about 110 *h* of work from men, 125 *h* of work from women, and 80 *h* of work from bullock labour (Palekar, 2019; Rythu Sadhikara Samstha, n.d.).

The survey indicates that 110 *h* of work from men, 530 *h* of work from women, and 40 *h* of bullock labour are used in non-ZBNF. Similarly, 60 *h* of work from men, 800 *h* of work from women, and 10 *h* of bullock labour are used in ZBNF. The indirect energy of human and bullock labour is accounted for in the total energy.

Figure 4.4 presents the life cycle input energy (considering all the relevant parameters indicated above) for paddy. It is to be noted that the minimum, maximum, and average values represent the range of overall life cycle energy. The preliminary results from both theory and survey indicate that ZBNF requires 45%–50% less energy than non-ZBNF. Electricity contributes approximately 96% energy in ZBNF and 77%–95% in non-ZBNF, while NPWM accounts for less than 1% energy in ZBNF and 5%–20% in non-ZBNF. The NPWM energy share obtained from the survey is less than the theoretical values because of the lower use of fertilisers.

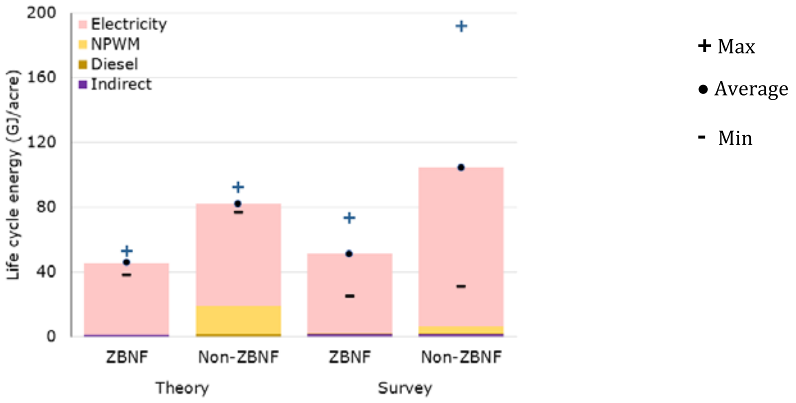

Figure 4.4: Life cycle input energy for paddy

Figure 4.5 presents the life cycle emissions in paddy. All the energy-related parameters other than indirect energy contribute to emissions. As can be seen in Figure 4.5, emissions from electricity are significant. Additionally, crop emissions, NPWM, and burning of unused residues contribute to the total emissions.

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[16] Complex fertilisers such as 14-35, 20-20, 28-28-0, DAP, 30-80-80.

In ZBNF, the paddy field is flooded the same as in conventional practice, but it is assumed to follow multiple-aeration method (as prescribed in the methodology) instead of single aeration. Water is drained out from the field every 8–10 days and then the field is refilled with fresh water. This helps reduce microbial activity and methane emissions[17]. The released emissions are 204 kg CO_{2e}/acre from multiple aeration fields and 1,800 kg CO_{2e}/acre from flooded aeration (Ministry of Environment & Forests, 2012).

The study assumed that 10% of the unused crop residues are burnt[18] for clearing the field in non-ZBNF. This contributes about 180–250 kg CO_{2e}/acre (see Section 8.4 for details).

The initial analysis indicate that ZBNF results in 55%–62% lower emissions than non-ZBNF. The contribution of electricity to the total emissions is about 92% in ZBNF (~3,600 kg CO_{2e}) and about 66% in non-ZBNF (~6,100 kg CO_{2e}). NPWM contributes to about 2% (50–90 kg CO_{2e}) in ZBNF and about 12% (1,050 kg CO_2e) in non-ZBNF. Crop (methane) emissions contribute to 6% in ZBNF (*multiple aeration*) and approximately 20% in non-ZBNF (*single aeration*). Thus, crop emissions are reduced by about 89% in ZBNF, compared with non-ZBNF.

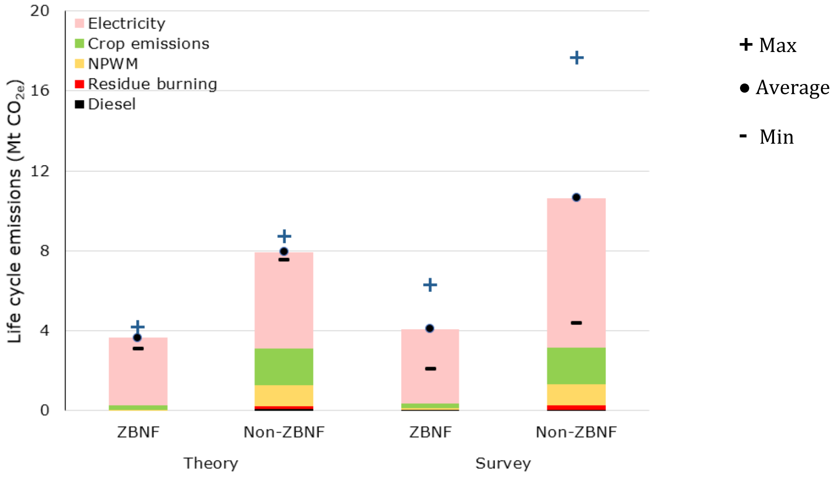

Figure 4.5: Life cycle emissions in paddy crop

4.1.2. *Other Crops*

The other crops of interest are irrigated—chilli and maize; and rain-fed—cotton and groundnut.

Chilli and maize (irrigated): Figure 4.6 presents the life cycle input energy for chilli and maize. Based on initial findings, ZBNF requires 53%-70% less energy in chilli and 60% less in maize (than in non-ZBNF).

Electricity is seen to contribute 90% of the total energy for chilli and 95% for maize in ZBNF, while in non-ZBNF, it is observed to be contributing 57%-86% for chilli and 76% for maize. In chilli, NPWM accounts for 1% in ZBNF and 11%-40% in non-ZBNF. For maize, NPWM accounts for less than 2% and 23% in ZBNF and non-ZBNF, respectively.

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[17] Flooded irrigation releases 66 kg CH_4/acre and multiple aeration releases 7.28 kg CH_4/acre (Ministry of Environment & Forests, 2012)

[18] Every one kg of residue releases about 1.6 kg CO_2 (Jain, Bhatia, & Pathak, 2014)

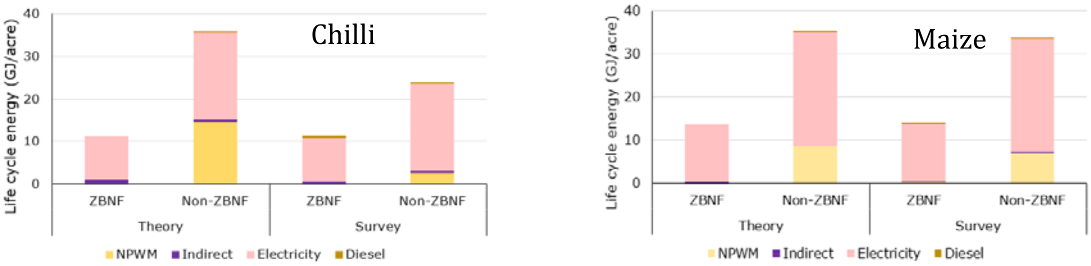

Figure 4.6: Life cycle input energy for chilli and maize

Figure 4.7 presents the life cycle emissions for chilli and maize. Overall, ZBNF results in 54%–68% lower emissions than non-ZBNF for chilli and 66% for maize. Electricity contributes to 92% of total emissions in ZBNF and about 65% in non-ZBNF for chilli, while for maize, it contributes 92% in ZBNF and 54%–70% in non-ZBNF. The NPWM share is less than 10% in ZBNF for both the crops. In non-ZBNF, the NPWM share ranges from 30% to 70% in chilli and is about 35% in maize.

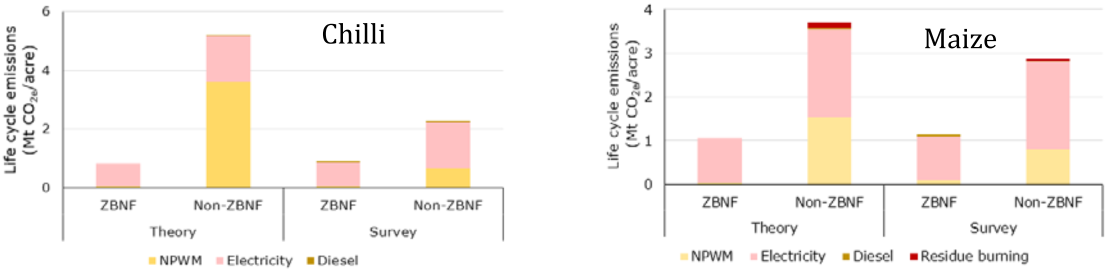

Figure 4.7: Life cycle emissions for chilli

Groundnut and Cotton (rainfed): Figure 4.8 presents the life cycle input energy for groundnut and cotton. ZBNF requires 90% less energy for groundnut and 42%–76% less energy for cotton, than non-ZBNF.

In groundnut, NPWM accounts for 9%–38% in ZBNF and about 87% in non-ZBNF. For cotton, NPWM accounts for about 12% and 75% in ZBNF and non-ZBNF, respectively.

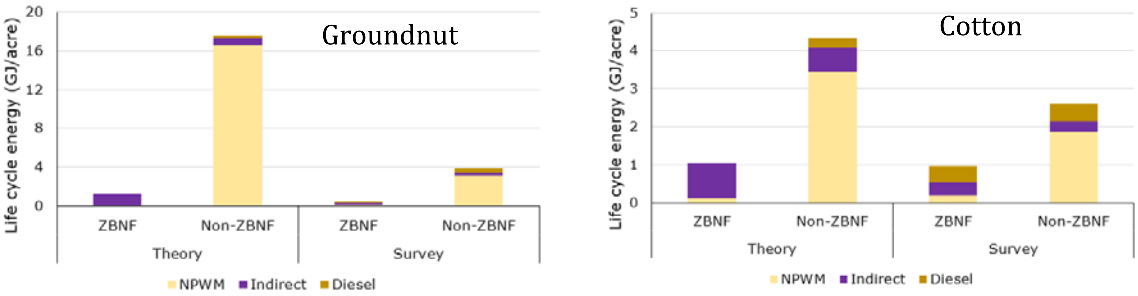

Figure 4.8: Life cycle input energy for groundnut and cotton

Figure 4.9 presents the life cycle emissions for groundnut and cotton. Overall, ZBNF results in 90% lower emissions for groundnut and 98% for cotton, compared with non-ZBNF. The NPWM share is 70%–90% in ZBNF for both the crops. In non-ZBNF, the NPWM share ranges from 90% in groundnut to 3%–45% in cotton. Residue-burning emissions in cotton contribute to 97% of the total emissions in cotton.

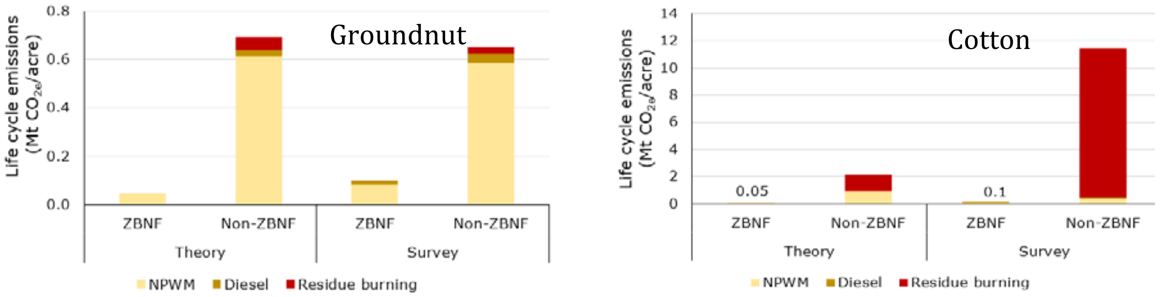

Figure 4.9: Life cycle emissions for groundnut and cotton

4.2. Cost of Cultivation, Yield, and Revenue

The cost of cultivation, yield, and revenue constitute the parameters that are of the utmost importance, especially considering their impact on the social and economic lifestyle of farmers. As mentioned in Section 4, the cost of cultivation and revenue have been analysed for irrigated (paddy, chilli, and maize) and rainfed (groundnut and cotton) crops for both ZBNF and non-ZBNF. The cost of cultivation indicates the input cost (tilling, seeds, NPWM, labour, etc.) for the cultivation process. The net revenue is estimated, considering the revenue from the sale of produce and the cost of cultivation. Figure 4.10 and Figure 4.11 compare the average cost of cultivation in irrigated and rainfed crops for ZBNF and non-ZBNF. Materials cost comprises chemicals (natural and inorganic as applicable), seeds, water, and miscellaneous expenditure.

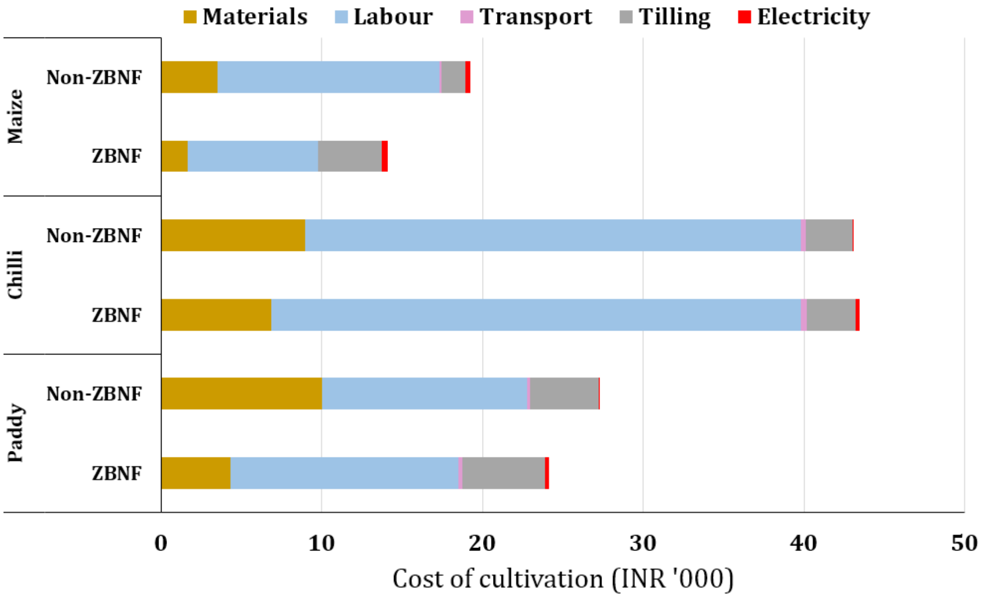

Figure 4.10: Cost of cultivation in irrigated crops

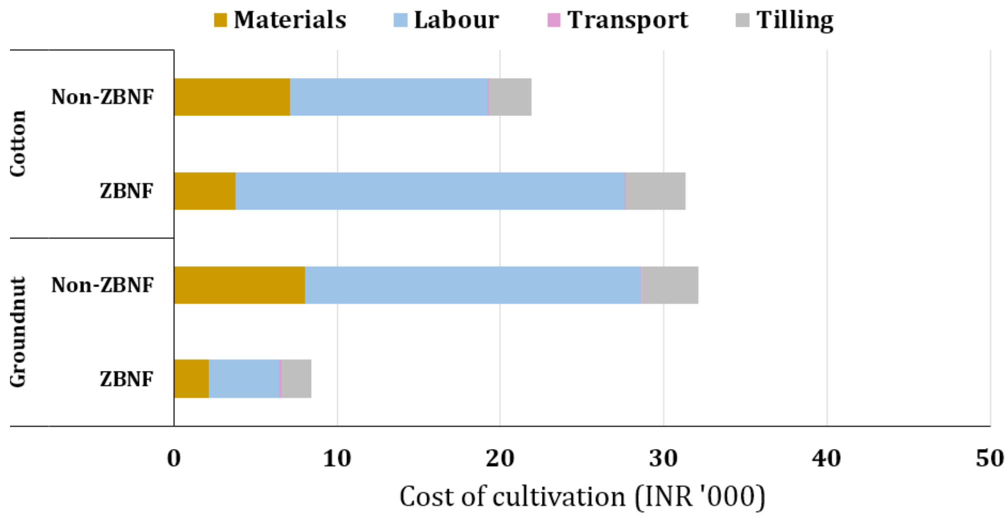

Figure 4.11: Cost of cultivation in rainfed crops

Fertilisers' contribution to the materials cost is 10%–20% in ZBNF and 50%–70% in non-ZBNF. Among the remaining inputs, seeds are the major contributor to materials cost. Overall, the cost of cultivation is observed to be lower in ZBNF than in non-ZBNF for paddy, maize, and groundnut. This higher cost in non-ZBNF paddy is attributed to the use of fertilisers. In groundnut and maize, the higher cost in non-ZBNF is because of the higher labour engagement and use of fertilisers.

In the case of chilli, the difference in the cost of cultivation between the two practices is almost inconsequential. The slight increase in the cost of cultivation is attributed to the use of higher-priced seeds in ZBNF and less labour use in non-ZBNF.

The cost of cultivation for cotton is seen to be higher in ZBNF, owing to the higher labour and mechanisation engagement.

Figure 4.12 compares the yield of the select crops for ZBNF and non-ZBNF. The values in the figure represent the average yield of the total survey samples. The average yield for chilli and paddy are observed to be nearly the same from both practices. For the remaining crops, a higher yield is observed in non-ZBNF, with an increase in the range of 0.3 Mt/acre to 0.7 Mt/acre. However, some of the cases in ZBNF show higher yields than non-ZBNF and vice versa. The standard deviation from the average indicates that both practices show a similar dispersion rate, except for groundnut and maize.

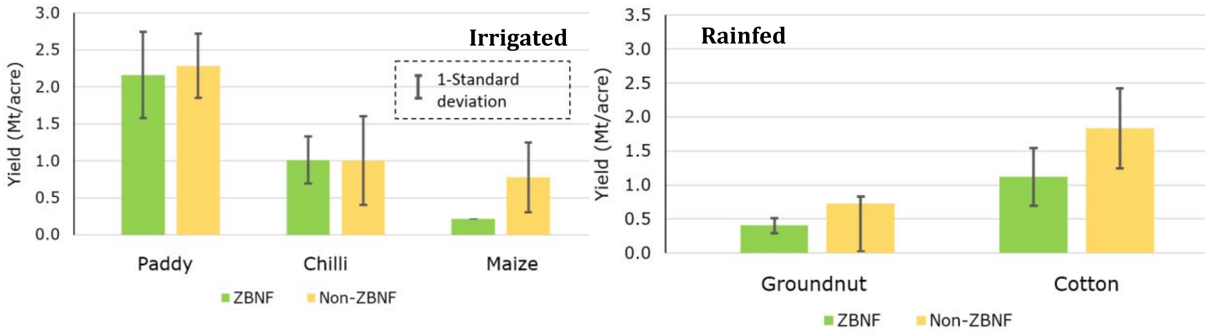

Figure 4.12: Average yield in selected crops

Figure 4.13 compares the net revenue of the select crops for ZBNF and non-ZBNF (Table 4.3 presents the selling price of produce). The figure reveals that ZBNF practitioners seem to gain a greater revenue than non-ZBNF practitioners, except in the case of cotton. This greater revenue may be primarily attributed to the lower cost of cultivation associated with ZBNF (even though the yields per acre from ZBNF crops are less than those of non-ZBNF, and the selling price of produce is nearly the same for both). However, in the limited sampled cases, maize cultivation showed losses under both farming practices[19].

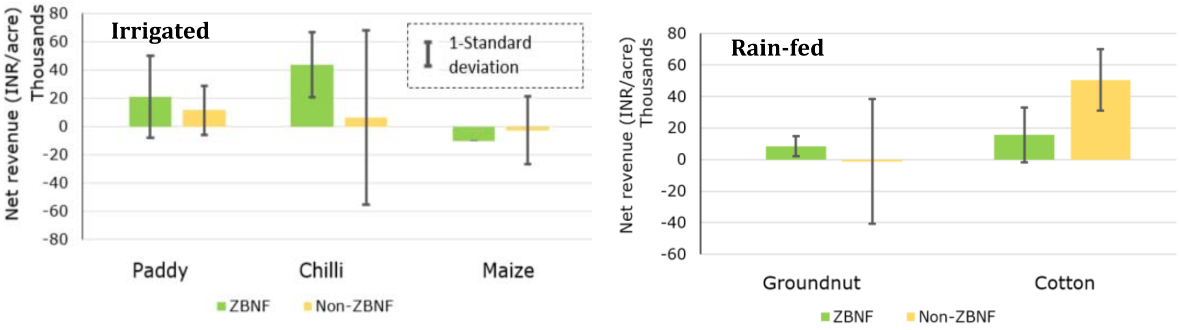

Figure 4.13: Net revenue in selected crops

As seen from Figure 4.13, ZBNF shows less dispersion in net revenue while non-ZBNF shows more dispersion in net revenue for chilli, maize, and groundnut. This indicates that farmers practising ZBNF are less prone to the risks, in terms of revenue, than those practising non-ZBNF. Thus, farmers shifting to ZBNF from non-ZBNF would be more likely to increase their revenue with reduced risks.

Table 4.3: Selling price of produce in selected crops

	Selling price (INR/Mt)	
Crop	ZBNF	Non-ZBNF
Paddy	20,800	17,000
Chilli	86,000	76,000
Maize	18,000	30,000
Groundnut	42,000	38,000
Cotton	37,000	40,000

4.3. Social Impact

As mentioned earlier, an attempt was made to understand farmers' outlook on ZBNF. Table 4.4 lists the four primary aspects considered for the social outlook.

Table 4.4: Parameters considered for social outlook

Production aspects	Availability of guidance, difficulty in preparing the required ingredients, soil-quality improvement, effectiveness against pests, adaptability to natural calamities, and time-intensive nature of preparation of the natural ingredients
Financial aspects	Subsidies for switching to ZBNF, revenue generation, reduction of loan burden, and cost intensiveness of inputs
Health aspects	Production of healthier produce, improvement in the health of farmers

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[19] Indicated responses by the seven farmers interviewed

Social aspects	Women involvement, use of family as workforce (thereby reducing outside labour involvement), and involvement of self-help groups (SHGs) to promote ZBNF

Figure 4.14 and Figure 4.15 show the result of the social-impact assessment. The Y-axis indicates the number of responses by various farmers.

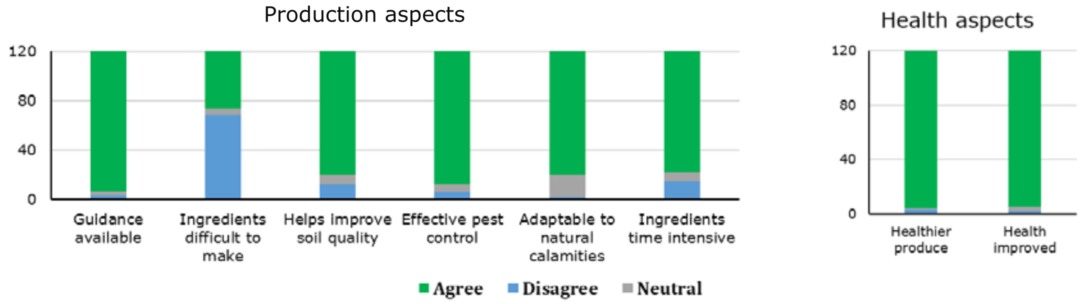

Figure 4.14: Outlook on production methods of ZBNF and health aspects

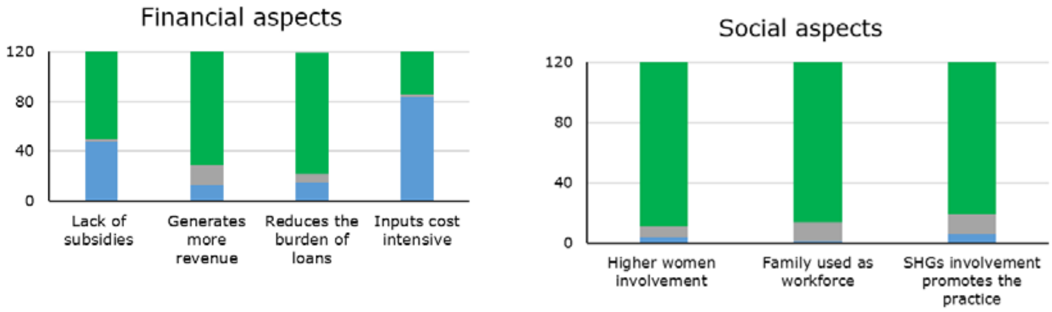

Figure 4.15: Outlook on financial and social aspects in ZBNF

The outlook shows the propensity of the farmers to switch to ZBNF. However, a large number of farmers indicated that the preparation of ingredients is difficult. In terms of financial aspects, the farmers had mixed opinions, mainly due to the lack of subsidies and the requirement of cost-intensive and critical inputs[20] (seeds, pulses, cow dung, urine, etc.) in ZBNF. Despite such constraints, the farmers expressed an interest in shifting to ZBNF practice, because of better yields, health, and social aspects.

The responses of the farmers present only an outlook towards the switch in practice. It cannot be considered as a definitive inference regarding the switch to ZBNF across the state.

4.4. Summary

Table 4.5 presents the potential impact of a shift to ZBNF from non-ZBNF on a per-acre basis. Average values are indicated in the table (see Section 4 for details on minimum, average, and maximum), and theoretical values are shown in parentheses.

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[20] Availability of desi cow dung and urine is a challenge.

Table 4.5: Impact of shift to ZBNF from non-ZBNF per acre of land

	Paddy	**Groundnut**	**Chilli**	**Cotton**	**Maize**
Water savings (*kl*)	3,500 (1,400)	NA	790 (790)	NA	1,000 (1,000)
Electricity savings (kWh)	3,900 (1,500)	NA	820 (820)	NA	1,050 (1,050)
Energy savings (GJ)	53 (36)	3.4 (16.4)	12.6 (24.7)	1.1 (3.3)	19.6 (21.6)
Emissions reduction (Mt)	6.6 (4.2)	0.5 (0.6)	1.4 (4.4)	11.3 (2.0)	1.7 (2.7)
Yield (Mt)	-0.12	-0.32	0.01	-0.71	-0.56
Net Revenue (INR)	9,660	9,720	37,000	-34,800	-7,300

Chapter 5

Conclusion

5. Conclusion

With the State Government promoting the transition from conventional farming to ZBNF, there are a lot of studies/exercises being undertaken by various organisations to assess the impact of this practice. However, there is lack of evidence-based studies to examine from an energy/emission viewpoint. This exploratory study is probably a first attempt to assess the life cycle potential benefits of ZBNF for energy/emission, combining anecdotal and theoretical approaches.

This study, conducted in Andhra Pradesh, has gathered information from farmers to understand the practical execution of this rudimentary practice. The initial results indicate that the switch from non-ZBNF to ZBNF can potentially save up to an average of 1,400–3,500 *kl* of water and about 12–50 GJ of energy, coupled with a 1.4–6.6 Mt CO_{2e} emission reduction per acre in a crop period in irrigated crops. Rainfed crops can ideally save up to 1.1–16 GJ of energy and reduce 0.5–11 Mt CO_{2e} of emissions. Further, ZBNF is seen to increase the net annual revenue of farmers by about INR 4,500 per acre.

The results, however, seem to indicate a reduction in yield in ZBNF (compared with non-ZBNF), except in rice and chilli (which showed a minimal variation). This may be due to—(1) shorter period of ZBNF practice (started 1-2 years ago in the state), (2) absence of adoption of precise farming techniques, (3) soil accustomed to inorganic fertilisers, and (4) transition period of soil to rejuvenate microbes.

6. Way Forward

This report could be used as a framework for conducting further analyses with larger sample sizes and contextual factors, for more robust results, as the preliminary results indicate potential benefits.

A long-term study would be essential to further verify and validate the scientific nature of ZBNF prior to large-scale adoption. Further, the applicability of single-solution methods of ZBNF should be tested on different crops and soil types to determine its efficacy and replicability.

A continued effort in this direction would help in realising the true potential of ZBNF as an alternative to existing conventional practices.

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8. Annexures

8.1. Annexure 1: Practices in ZBNF

Key Pillars of ZBNF:

Table 8.1 presents the details of ZBNF preparation (Palekar, 2016). Bijamritam is used for treating seeds to increase the germination and avoid pest attack. **Ghana-jiwamritam** and **Dhrava-jiwamritam** are used for nutrient management. **Bramhastra, Agniastra,** and **Neemastra** are used for managing pests.

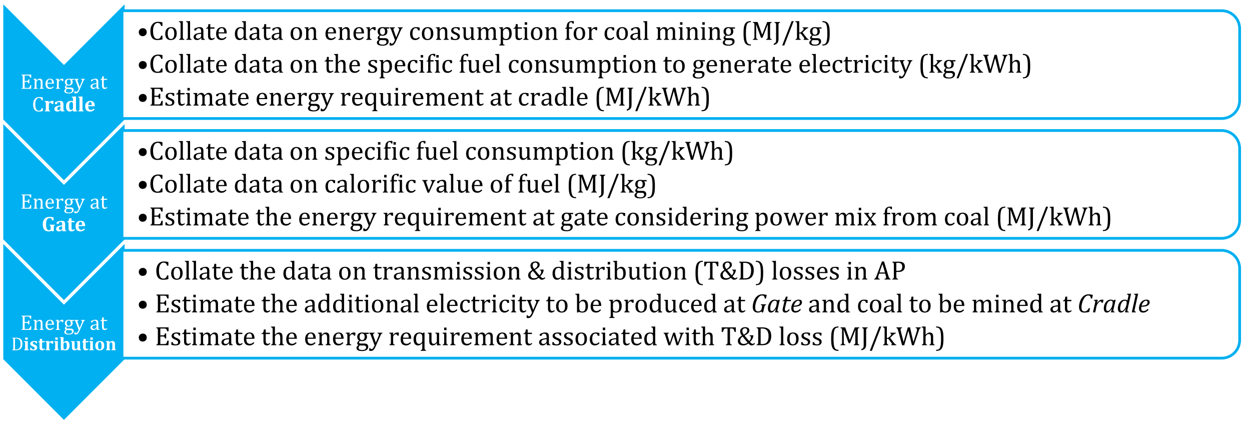
Table 8.1: The key preparations of ZBNF

Bijamritam		**Ghana-jiwamritam**		**Dhrava-jiwamritam**	
Water	20 *l*	Cow dung	100 kg	Water	200 *l*
Cow dung	5 kg	Jaggery	1 kg	Cow dung	10 kg
Cow urine	5 *l*	Pulses flour	1 kg	Cow urine	5-10 *l*
Lime	50 g	Bund soil	200 g	Pulses powder	2 kg
Bund soil	0.5 kg	Cow urine	10 *l*	Jaggery	2 kg
				Bund soils	0.5 g
Brahmastra		**Agniastra**		**Neemastra**	
Cow urine	10 *l*	Water	100 *l*	Cow urine	10 *l*
Neem leaves	5 kg	Cow urine	5 *l*	Green chilli	500 g
Custard apple leaves	2 kg	Cow dung	5 kg	Neem leaves	5 kg
Papaya leaves	2 kg	Neem leaves	5 kg		
Pomegranate leaves	2 kg				
Guava leaves	2 kg				
Lantana camera leaves	2 kg				
White datura leaves	2 kg				

Water and Soil Management:

Mulching and **waaphasa** are techniques used to decrease the water requirement of crops and improve soil health. Crops prosper when the soil has a mixture of 50% air and 50% water vapour at its upper layer (Palekar, 2016). Further, the roots that take up the water are located at the outer canopy of the plant. Therefore, ZBNF insists on irrigating the plants only in the alternate furrows in the case of ridge-based irrigation (FAO, 2019). In the case of paddy (flooded irrigation), the stagnant water is evacuated and freshwater is refilled periodically (once in 8-10 days).

8.2. Annexure 2: Methodology to Assess Energy and Emissions

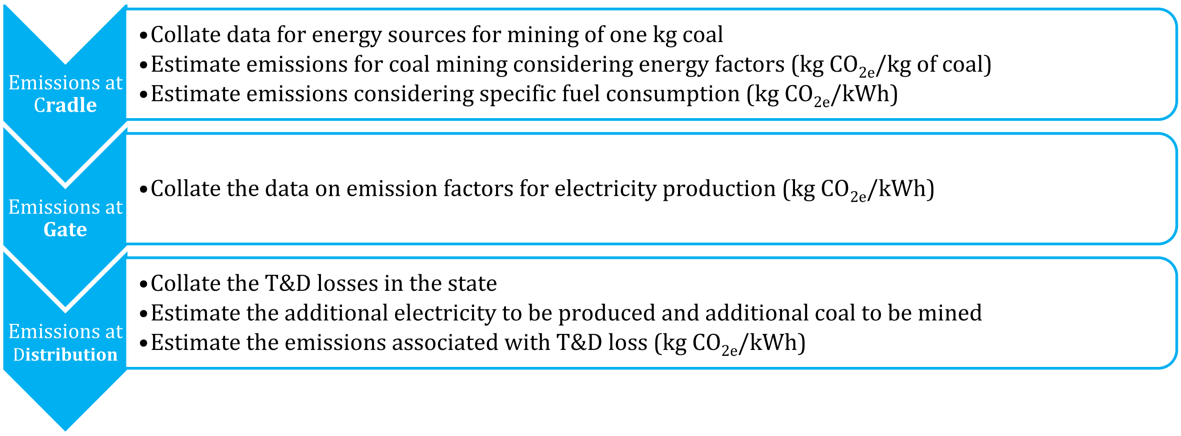


- Collate data on energy consumption for coal mining (MJ/kg)
- Collate data on the specific fuel consumption to generate electricity (kg/kWh)
- Estimate energy requirement at cradle (MJ/kWh)

- Collate data on specific fuel consumption (kg/kWh)
- Collate data on calorific value of fuel (MJ/kg)
- Estimate the energy requirement at gate considering power mix from coal (MJ/kWh)

- Collate the data on transmission & distribution (T&D) losses in AP
- Estimate the additional electricity to be produced at *Gate* and coal to be mined at *Cradle*
- Estimate the energy requirement associated with T&D loss (MJ/kWh)

Figure 8.1: Life cycle energy assessment for electricity

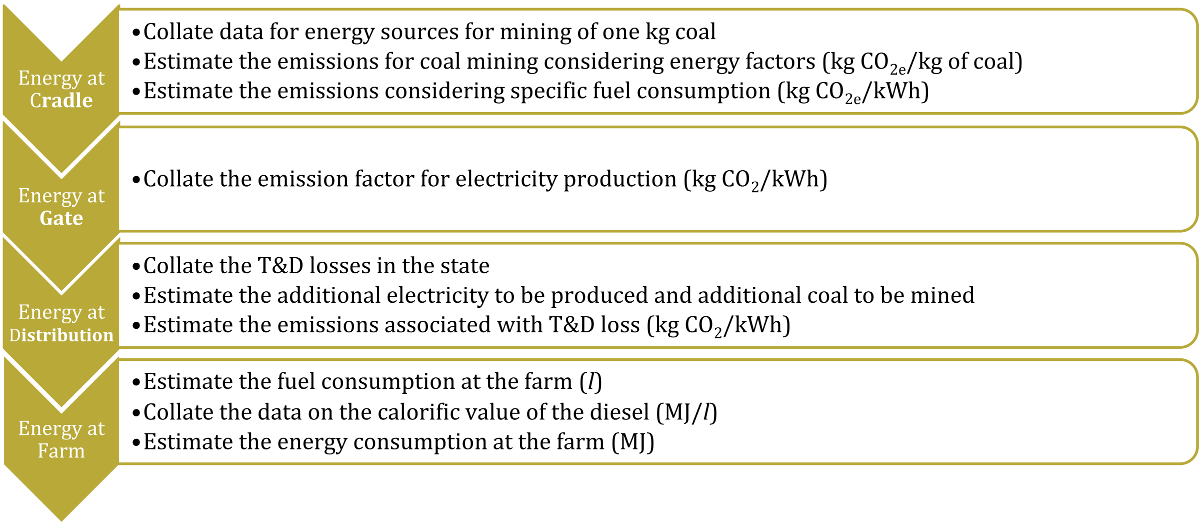


- Collate data for energy sources for mining of one kg coal
- Estimate emissions for coal mining considering energy factors (kg CO_{2e}/kg of coal)
- Estimate emissions considering specific fuel consumption (kg CO_{2e}/kWh)

- Collate the data on emission factors for electricity production (kg CO_{2e}/kWh)

- Collate the T&D losses in the state
- Estimate the additional electricity to be produced and additional coal to be mined
- Estimate the emissions associated with T&D loss (kg CO_{2e}/kWh)

Figure 8.2: Life cycle emissions assessment for electricity



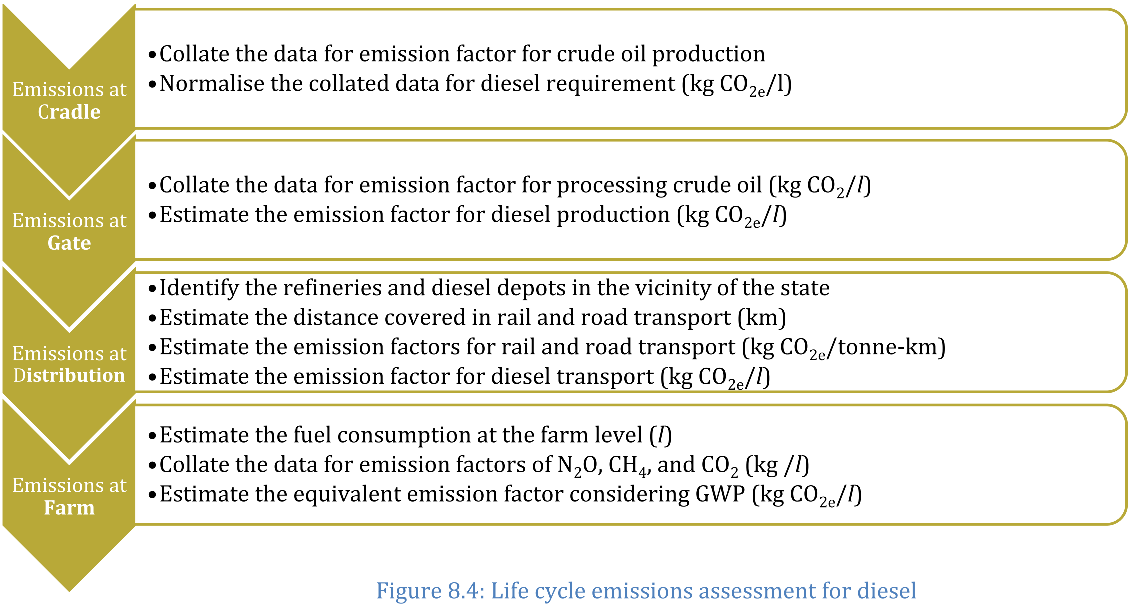
- Collate data for energy sources for mining of one kg coal
- Estimate the emissions for coal mining considering energy factors (kg CO_{2e}/kg of coal)
- Estimate the emissions considering specific fuel consumption (kg CO_{2e}/kWh)

- Collate the emission factor for electricity production (kg CO_2/kWh)

- Collate the T&D losses in the state
- Estimate the additional electricity to be produced and additional coal to be mined
- Estimate the emissions associated with T&D loss (kg CO_2/kWh)

- Estimate the fuel consumption at the farm (*l*)
- Collate the data on the calorific value of the diesel (MJ/*l*)
- Estimate the energy consumption at the farm (MJ)

Figure 8.3: Life cycle energy assessment for diesel



Emissions at Cradle

- Collate the data for emission factor for crude oil production
- Normalise the collated data for diesel requirement (kg CO_{2e}/l)

Emissions at Gate

- Collate the data for emission factor for processing crude oil (kg CO_2/*l*)
- Estimate the emission factor for diesel production (kg CO_{2e}/*l*)

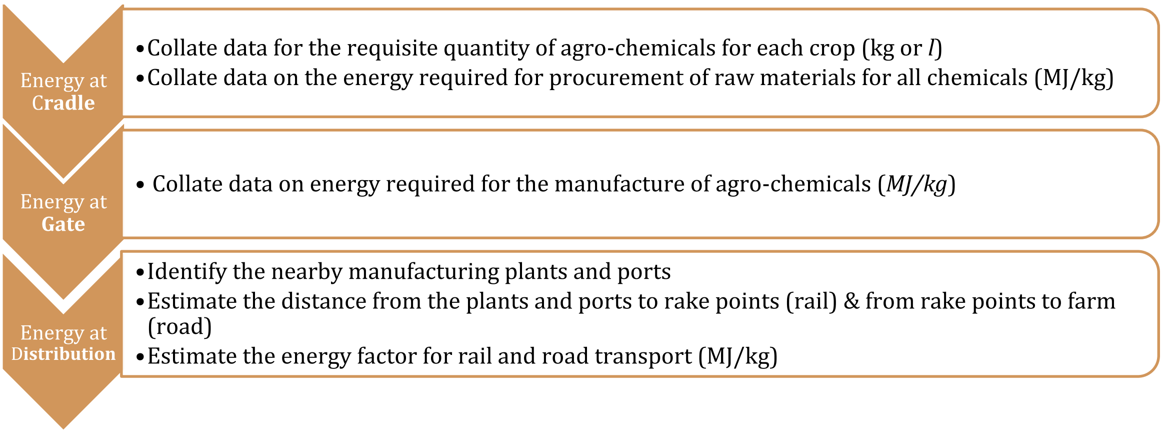
Emissions at Distribution

- Identify the refineries and diesel depots in the vicinity of the state
- Estimate the distance covered in rail and road transport (km)
- Estimate the emission factors for rail and road transport (kg CO_{2e}/tonne-km)
- Estimate the emission factor for diesel transport (kg CO_{2e}/*l*)

Emissions at Farm

- Estimate the fuel consumption at the farm level (*l*)
- Collate the data for emission factors of N_2O, CH_4, and CO_2 (kg /*l*)
- Estimate the equivalent emission factor considering GWP (kg CO_{2e}/*l*)

Figure 8.4: Life cycle emissions assessment for diesel



Energy at Cradle

- Collate data for the requisite quantity of agro-chemicals for each crop (kg or *l*)
- Collate data on the energy required for procurement of raw materials for all chemicals (MJ/kg)

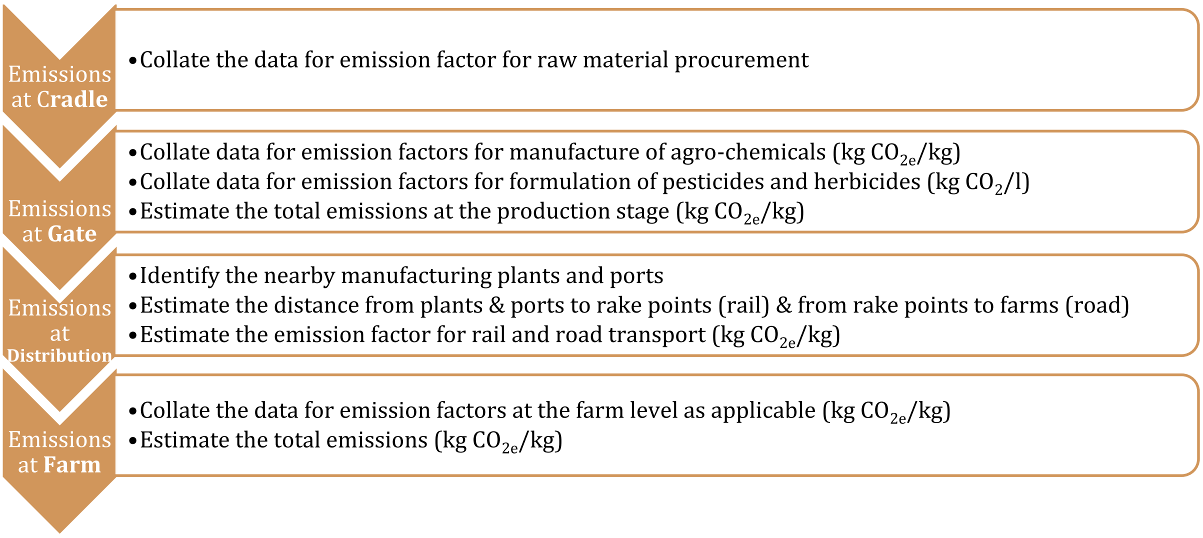
Energy at Gate

- Collate data on energy required for the manufacture of agro-chemicals (*MJ/kg*)

Energy at Distribution

- Identify the nearby manufacturing plants and ports
- Estimate the distance from the plants and ports to rake points (rail) & from rake points to farm (road)
- Estimate the energy factor for rail and road transport (MJ/kg)

Figure 8.5: Life cycle energy assessment for inorganic chemicals



Emissions at Cradle

- Collate the data for emission factor for raw material procurement

Emissions at Gate

- Collate data for emission factors for manufacture of agro-chemicals (kg CO_{2e}/kg)
- Collate data for emission factors for formulation of pesticides and herbicides (kg CO_2/l)
- Estimate the total emissions at the production stage (kg CO_{2e}/kg)

Emissions at Distribution

- Identify the nearby manufacturing plants and ports
- Estimate the distance from plants & ports to rake points (rail) & from rake points to farms (road)
- Estimate the emission factor for rail and road transport (kg CO_{2e}/kg)

Emissions at Farm

- Collate the data for emission factors at the farm level as applicable (kg CO_{2e}/kg)
- Estimate the total emissions (kg CO_{2e}/kg)

Figure 8.6: Life cycle emissions assessment for inorganic chemicals

8.3. Annexure 3: Energy and Emission Factors

Table 8.2: Energy and emissions factors for various input parameters

		Energy factors (MJ/ unit)					Emission Factors (kg CO$_{2e}$/ unit)				
Name of chemical	**Unit**	**Cradle**	**Production**	**Distribution**	**Utilisation**	**Total**	**Cradle**	**Production**	**Distribution**	**Utilisation**	**Total**
Non-ZBNF: Fertilisers/Pesticides/Fungicides/Herbicides											
Urea	kg	23		1.85	-	24.85	2.50	0.91	0.22	4.22	7.85
SSP	kg	1.4		1.85	-	3.25	0.21		0.22	0.01	0.44
TSP		2		1.85	-	3.85	0.02	0.26	0.22	0.01	0.51
MOP	kg	3.75		1.85	-	5.60	0.30	0.25	0.22	0	0.77
Zinc Sulphate	kg	20.9		1.85	-	22.75	-	-	-	-	-
DAP		12.35		1.85	-	14.2	1.66		0.22	1.7	3.5
Phorate granules	kg	90.3	118.7	1.85	-	230.85	4.2		0.22	-	4.82
Dimethoate	*l*	214.4		1.85	-	236.25	4.6		0.22	-	4.82
Carbaryl 5 %	kg	85	68	1.85	-	174.85	3.1		0.22	-	3.72
Carbofuran	kg	201	253	1.85	-	475.85	9.1		0.22	-	9.72
Imidacholprid	*l*	27.77		1.85	-	49.62	4.6		0.22	-	4.82
Thiomethoxam	g	3.85		1.85	-	25.70	4.6		0.22	-	4.82
Cartap	kg	214.4		1.85	-	236.25	4.6		0.22	-	4.82
Mancozeb	kg	280		1.85	-	281.85	4.6		0.22	-	4.82
Thiram	kg	173		1.85	-	194.85	4.8		0.22	-	5.02
Captan	kg	52	63	1.85	-	136.85	2.3		0.22	-	2.7
2,4 DPAA	kg	39	48	1.85	-	108.85	1.7		0.22	-	2.32
Glyphosate	kg	126	328	1.85	-	475.85	9.1		0.22	-	9.72
Aldrin	kg	264.5		1.85	-	286.35	4.4		0.22	-	4.62
Atrataf Taphizin	kg	112	76.3	1.85	-	210.15	3.8		0.22	-	4.42
ZBNF: Fertilisers/Pesticides/Fungicides											
Bijamritam	kg	0.086				0.086	0.033			0.004	0.0371
Ghanajiwamritam	kg	0.454				0.454	0.174			0.022	0.195
Dravajivamritam	kg	0.0237				0.0237	0.009			0.001	0.0101
Neemastra	kg	0.023				0.023	0.009			0.001	0.01
Other energy inputs											
Electricity	kWh	0.03	10.74	1.77	-	12.54	0.01	0.82	0.13	--	0.96
Diesel	*l*	0.50	1.96	1.04	37.77	41.27	0.03	0.65	0.12	2.66	0.79
Labour-man	*Man hour*				1.96	1.96					
Labour-woman	*Woman hour*				1.57	1.57					
Labour-bullock	*Animal hour*				8.07	8.07					

8.4. Annexure 4: Crop Characteristics

Paddy:

Paddy is one of the largest cultivated crops in AP. It is grown both in Kharif (72%) and Rabi (28%) seasons (Department of Agriculture, 2016) and is largely an irrigated crop. The annual production of paddy is around 120 lakh tonnes. The major fertilisers used in non-ZBNF are urea, SSP/TSP, and MOP. Typically, 10% of the residue is left on the field, which is later burnt to clear the field. Figure 8.7 presents the typical quantities of nutrients used in non-ZBNF paddy.

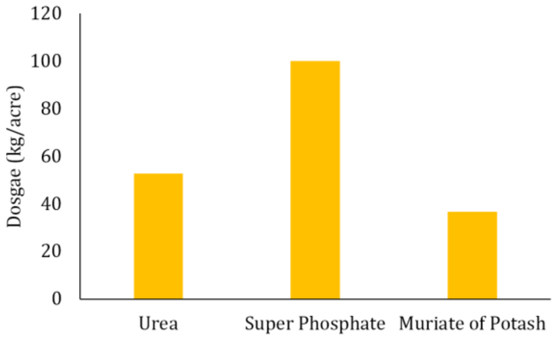


Figure 8.7: Nutrient management in paddy

Paddy is water-intensive, compared to other crops. The field is kept flooded from sowing to till one week before harvesting. The normal depth of water in the field is 50–70 mm during the growth period, and the frequency of irrigation is 5 days. The land area for the nursery is usually 8%–10% of the total crop area (TNAU, 2019). The crop requires a seed requirement of 10 kg per acre. The yield is around 1,500 kg per acre in AP, and farmers selling price of paddy is INR 600-800 per quintal.

Globally, paddy fields are considered to be one of the most prominent sources of methane (IPCC, 1996). The metabolic activities of the methanogen bacteria, a special group of bacteria that is more active in submerged conditions, is majorly responsible for the emission of methane from paddy fields (Patra & Babu, 2017). The difference in water management in paddy fields leads to the difference in methane emissions between ZBNF and non-ZBNF.

Groundnut:

Groundnut is one of the major crops in AP, especially in the Rayalaseema region. It is largely (80%–90%) a rainfed crop, grown in the Kharif season (Bharati, 2009; Govindaraj & Mishra, 2011). There are two main varieties of groundnut: bunch and spreading. The cropping period is around four months.

Figure 8.8 represents the recommended and typically reported usage of nutrients for groundnut crop. Zinc foliar spray of 0.5 kg/ha is usually applied. Phorate granules, dimethoate, and carbaryl are used for pest control. Mancozeb and imidacolprid are the other inorganic chemicals used for disease management. The ethereal solution is used for breaking the dormancy of seeds (in case the seed is dormant).

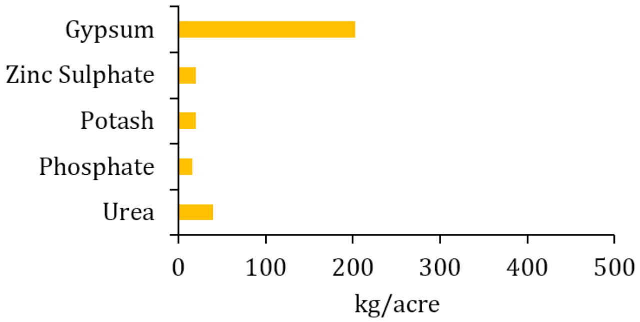


Figure 8.8: Nutrient management in groundnut

The seed rate is typically between 125 kg/ha to 180 kg/ha depending on the variety, type of irrigation, and season. The net sown area of the crop in AP is 10.13 lakh ha, and the production is around 6 lakh tonnes per year (Department of Agriculture, 2016). The typical price per quintal is INR 4,000–INR 5,000. The typical cost spent on labour (human, bullock, and machine) is around INR 20,000 per ha (Govindaraj & Mishra, 2011).

Chilli:

Major chilli cultivating states are AP, Tamil Nadu, Karnataka, and Maharashtra, of which AP contributes to 57% of the produce (DAC&FW, 2009). In AP, the net sown area under the crop is 2 lakh ha and is associated with an average annual production of 9.93 lakh tonnes. Chilli is cultivated in both Kharif and Rabi seasons across India. The cropping period of chilli is 150–180 days depending on the season, fertility, and water management.

The total water requirement is around 1,400 k*l*–1,700 k*l* in non-ZBNF. Fruit development and flowering stages are critical for water management.

The seed rate varies from 650 g/acre for transplanted crops and 2.5 kg/acre for directly sown. The average chilli yield is around 2,000 kg/acre for dry chilli and 8,400 kg/acre for green chilli. The average wholesale price for dry chillies in 2016-17 was INR 9,200–10,700/quintal (Directorate of Economics and Statistics, 2016).

A nursery of 40 m^2 for every acre of the farm is required to nurture the saplings. In the case of non-ZBNF, a total of 48–84 kg N/acre, 16–24 kg P_2O_5/acre and 20–24 kg K_2O/acre is recommended. The farm also uses micronutrients such as zinc and iron. For pest and disease management, Mancozeb, Plantomycin, Captan, Dimethoate, Wettable Sulphur, Carbaryl, and Chlorpyriphos are used.

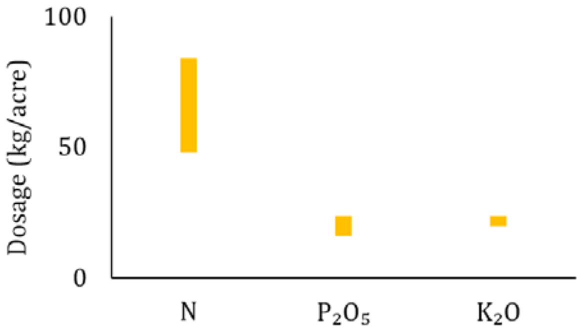


Figure 8.9: Nutrient management in chilli

Cotton:

On a global scale, India has the largest share of area under cotton cultivation, at about 11 million ha. AP has the highest cotton yield in the country (685 kg/ha), followed by Gujarat (671.5 kg/ha) in 2016-17. The total production of cotton in the state is around 19 lakh bales. The net sown area of cotton during 2016-17 was 4.72 lakh hectares, which increased to 6.46 lakh hectare in 2017-18. Typically, the cost per quintal of cotton varies from INR 12,000 to INR 16,000. In AP, about 80% of the land under cotton cultivation is rainfed and about 20% of the land is under irrigation.

The seed rate varies depending on the variety of cotton crop and ranges from one to 5 kg per hectare. Nutrient application rates vary according to the variety and the cultivation practices. Figure 8.10 represents the different fertiliser application rates for the different varieties. Apart from the three primary nutrients, magnesium sulphate (in the form of a spray) and zinc sulphate are applied to provide the necessary micronutrients to the soil.

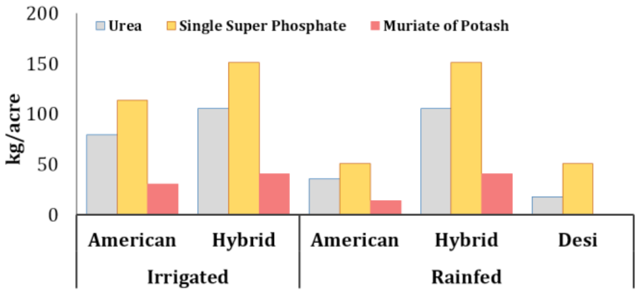


Figure 8.10: Nutrient application rates for different cotton varieties

Maize:

Maize is a major millet crop cultivated in AP, in the districts of West Godavari, Vizianagaram, Kurnool, Guntur, and Krishna. The crop production was 16.53 lakh tonnes during 2016-17 (Directorate of Economics and Statistics, 2016). Of the total production, 78% of the production was from Rabi (yield of 7,900 kg/ha) and the remaining from Kharif (yield of 4,149 kg/ha). AP is one of the high maize productivity states in India (>4 tonnes/ha) (FICCI & PWC, 2018); the average yield for maize was about 6,600 kg/hectare, with an average price of INR 14,000 per tonne in the year 2016-17 (Directorate of Economics and Statistics, 2016).

Nitrogen, phosphorus and potassium are required for maize production in the ratio of 80:60:40. Fertilisers such as urea, SSP, MOP, and zinc are key for maize cultivation. High-yielding maize varieties require more fertilisers than local varieties. For weed and pest management, inorganic chemicals like Carbofuran, Atrataf, Taphizin, Lasso, and Linuron are used.

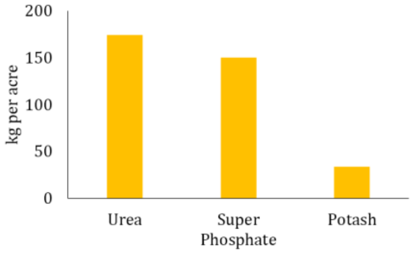


Figure 8.11: Nutrient application rates in maize

Table 8.3 presents the residue-to-crop ratios considered in the study (Hiloidhari, Das, & Baruah, 2014). Paddy, groundnut, and maize contribute unused residues of about 10% and cotton contributes about 80%. The residues from chilli (almost 100%) are used as cooking fuel.

Table 8.3: Residue to crop ratios

Crop	Residue-to-crop ratio
Paddy	1.5
Groundnut	2
Cotton	11.5
Maize	1.5

8.5. Annexure 5: Fertiliser Distribution Model

In India, the movement, distribution, and allocation of inorganic-based fertilisers are controlled by the Ministry of Chemicals and Fertilisers (MoCF). The distribution of fertilisers is carried out in two parts—primary and secondary. Primary movement is by rail from the port or plant to the rake point. Secondary movement is by road from nearest rake points to the block headquarters in the districts (Standing Committee on Chemicals and Fertilizers, 2017). The average railway transport distance is estimated from the Rake Movement Report, 2017.

The rake points are identified in every state based on the availability of railway infrastructure. There are about 65 rake points in AP. Private contractors handle the distribution from the rake points. The district headquarters often have a warehouse where the fertilisers are stored and distributed as and when required. The average distance from the rake points to the district headquarters is collected from the MoCF. The distances from the headquarters to the mandals and farms are collected from the district handbook.

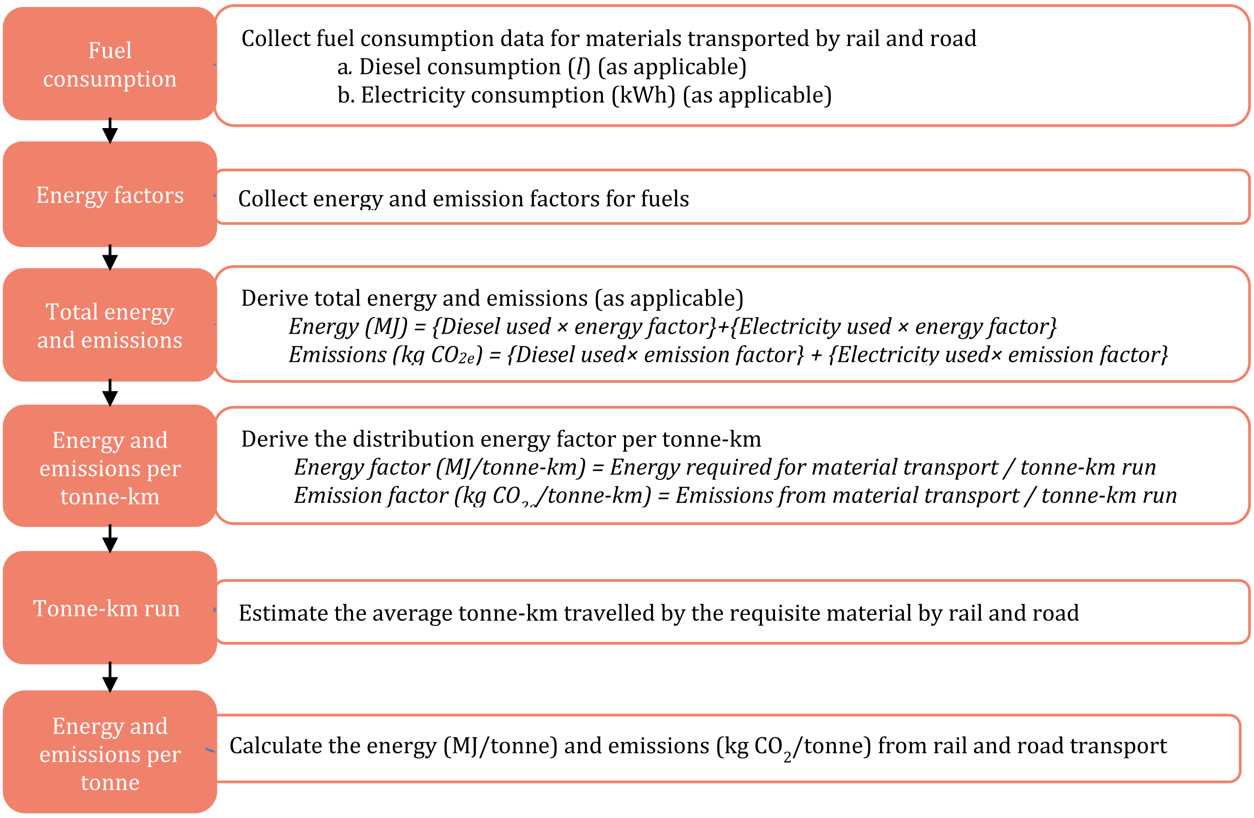
After estimating the distance travelled by the fertilisers by rail and road, the energy consumption and its associated emissions are estimated. Figure 8.12 presents the methodology adopted to estimate the energy consumption from rail transport.

8.6. Annexure 6: Sample Questionnaire

Table 8.4 presents the details covered in the questionnaire for the survey.

Table 8.4: Details covered in the questionnaire

Parameter	Response
1. Socio-demographics	
2. Land area details	
3. Crop area and details	
4. Water (source, depth of irrigation, frequency of irrigation, mode of pumping, etc.)	
5. Energy (water use, pump capacity, mechanisation, quantity of fertilisers, pesticides, herbicides, cow dung, labour)	
6. Yield	
7. Income (gross and net revenue)	
8. Social outlook (production methods of ZBNF, financial aspects, and health aspects)	



Collect fuel consumption data for materials transported by rail and road

a. Diesel consumption (*l*) (as applicable)
b. Electricity consumption (kWh) (as applicable)

Collect energy and emission factors for fuels

Derive total energy and emissions (as applicable)

Energy (MJ) = {Diesel used × energy factor}+{Electricity used × energy factor}

Emissions (kg CO_{2e}) = {Diesel used× emission factor} + {Electricity used× emission factor}

Derive the distribution energy factor per tonne-km

Energy factor (MJ/tonne-km) = Energy required for material transport / tonne-km run

Emission factor (kg CO_2/tonne-km) = Emissions from material transport / tonne-km run

Estimate the average tonne-km travelled by the requisite material by rail and road

Calculate the energy (MJ/tonne) and emissions (kg CO_2/tonne) from rail and road transport

Figure 8.12: Approach to estimate the energy and emission factors for land transport

Table 8.5 and Table 8.6 shows the details of energy consumption and emissions involved in the transport of fertilisers in AP.

Table 8.5: Assessment of energy consumption and emissions from rail transport of fertilisers

	Description	Energy	Emissions
a	Diesel consumption (million *l*)	944	
b	Diesel factor	35.1 MJ/l	2.65 kg CO_{2e}/*l*
c	Electricity consumption (million kWh)	4,017	
d	Electricity factor	3.6 MJ/kWh	0.82 kg CO_{2e}/kWh
e	Tonnage-km run in 2016-17 (million)	19841	
f	Total (a×b)+(c×d)/e	2.39 MJ/tonne-km	0.29 kg CO_{2e}/tonne-km
g	Average rail tonne-kms travelled	708.2	
h	Total value from rail transport f×g	1,699 MJ/tonne	207 kg CO_{2e}/tonne

Table 8.6: Assessment of energy consumption and emissions from road transport of fertilisers

	Description	Energy	Emissions
a	Average fuel efficiency* (*l*/100 tonne-km)	2.71	
b	Diesel factor	35.1 MJ/*l*	2.651 kg CO_{2e}/*l*
c	Total (a×b)	0.95 MJ/tonne-km	0.07 kg CO_{2e}/tonne-km
d	Average road tonne-kms travelled	156	
e	Total value from road transport (c×d)	149 MJ/tonne	11 kg CO_{2e}/tonne

** 2- and 3-axle trucks*

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