DECODING THE VECTOR OF ENERGY POVERTY

Understanding the components of energy systems in the urban-rural context of NCR, India

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Colofon

P5 report
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Acknowledgement

Acha and Amma, this is for you.

This graduation project has seen its fair share of ups and downs. Working with a new approach that is outside my comfort zone, finally came through due to the amazing people I have as my guiding light.

First, I want to thank my mentors Alexander Wandl and Nico Tillie for their constant encouragement, constructive feedback and discussions that helped develop this project. Despite the pandemic, their belief and involvement in my research were invaluable to me.

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I want to thank my colleagues at Starling structures for allowing me to pursue work and research on my terms.

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Motivation

India is my homeland and also the second-most populous country in the world. Around 60% of India lives in rural areas with around 640 thousand villages that use coal-based fuels for their daily lives. Lack of equal access to energy, poor living conditions, poor health care and education is a part of living in rural areas. These people strive hard and head to cities for better livelihoods. Energy is needed for the development of these areas. Access to electricity means students can study better, patients can be treated in hospitals, agricultural machines can be run, daily household chores can be functioned. However, the issue of energy poverty is still prevalent in rural India and despite attempts to curb this, India has not been successful. My motivation for this thesis comes from believing that renewable energy transition is inevitable for addressing climate adaptation, and while the urban cities can afford this transition, the rural areas are affected. This project is based on looking into ways of alleviating energy poverty and promoting a just renewable energy transition.

Abstract

Energy poverty means the lack of access to proper electricity and clean energy fuels. This type of poverty is closely linked to the dichotomy between developed and developing regions. This project argues that tackling energy poverty first needs to be addressed by understanding energy injustice between the urban and rural areas of developing countries. This outlook is significant because energy poverty can be seen as a vector of resource availability, power and spatial needs which is similar to the ideology of the 'poverty vector' (Gupta, S. P,1984). The lack of such a cohesive perspective has led to the ongoing negative impacts on economic development, health and access to basic amenities. The project sheds light on the need for a holistic approach to implement resilient energy networks that emphasises on renewable energy transition and spatial development to address energy poverty. By taking the case of the National Capital Region of India, the project aims to bridge the knowledge gap that exists in creating resilient energy networks in areas that does not have 24x7 access to energy.

Keywords: *Energy poverty, urban-rural divide, renewable energy transition, scenario planning.*

Contents

01

Introduction

1.1 | Understanding the concept of energy poverty

The energy sector has begun to face transformations in the matters concerned with energy security, climate change and energy poverty (González-Eguino, 2015). The study of energy-related aspects of poverty has been under the literary lens since the recent past, also called now as “energy poverty”. (Nakicenovic Nebojsa et al., 2012) discusses the global challenges of poverty and its link to energy, the need for looking into adequate, modern and affordable forms of energy, the structure of future energy systems and looking towards sustainable energy futures and policies related to them.

(Sadath & Acharya, 2017) states that there is no definite definition for energy poverty in literature. In developed countries, the energy deprivation is termed as ‘fuel poverty’ where-as in developing countries, it is ‘energy poverty’. This concept has received great attention in policies and academics, as energy is required for efficient wellbeing of the society (Birol, 2007). United Nations declaration of 2012 (International Year for Sustainable Energy for all), emphasized the pressing need for energy access and affordability in the development of the wellbeing of society. Studies have shown that use of biomass, such as cow dung or fire-wood, creates smoke that is harmful to women, leading to chronic respiratory issues. Lack of access to electricity or blackout situations is not a conducive environment for agriculture, learning, healthcare, economic development and more (Global Network on Energy for Sustainable Development, 2013). Although energy poverty is closely linked to the broader problem of poverty, this project does not aim towards analyzing the cause and consequences of poverty.

For, the purpose of this project, energy poverty shall be defined as explained by (Sueyoshi & Goto, 2018) “the absence of sufficient choice in accessing adequate, affordable, reliable, high-quality, safe and environmentally benign energy services to support economic and human development”. This definition provides an overview of the theme of this project, which is to look at the potential of clean and sustainable energy services to address the issue of energy poverty. The idea of an absence of choice emphasizes the need for looking into supplying energy in a just manner.

> “the absence of sufficient choice in accessing adequate, affordable, reliable, high-quality, safe and environmentally benign energy services to support economic and human development
>
> - Energy Poverty (Sueyoshi & Goto, 2018)”

Fig 1.1: Use of kerosene lamps for nightly chores. Source:www.tes.com

1.2 | Looking at energy poverty through a global perspective

When the night sets or when a room is dark, we immediately go to switch the lights on without batting an eyelid. Electricity and access to energy for daily uses have become so ingrained in our lives that access to energy is no more a privilege but our right. The world is progressing on the production and utilization of energy, so it seems difficult to believe that developing countries around the world still suffer from energy poverty. Since the Sustainable Development Goal (SDG) 7 included the motive of providing energy access to all, the number of people suffering from energy poverty has significantly reduced. However, 600 million in Sub-Saharan Africa and 35 million people in developing Asia are deprived of electricity. In addition, lack of access to clean cooking fuel around the world is at 2.7 billion people (IEA, 2018).

The consequences of energy poverty is seen on health, the economy and the environment. (González-Eguino, 2015) informs about health research that show that indoor air pollution due to energy poverty can cause more deaths than malaria and tuberculosis. There are hopes that access to better income and modern services in many of the developing countries will alleviate the problem. But the improvements will have to account for the growing population in the countries as well. Energy poverty impacting economy is by limiting the potential for production sectors and overall development. Especially in the agricultural field, which is one of the most staple sectors face problems of very low energy input for production and rely on human and animal labour. Economic progress along such a path is strenuous. The environmental impacts of energy poverty are the regarding land use. The poor depend on woodlands for fuel and along with this lack of protection of green cover leads to lesser forest area over time. Deforestation will also affect the $C0_2$ absorption rate.

Climate change is the phenomenon that is under everyone's attention right now. With extreme climatic conditions like floods, drought, global warming and unpredictable snow, people suffering from energy poverty are affected more than the 'privileged' folk. Attempts to alleviate energy poverty through the expansion of the energy network and consumption of energy resources will just promote to the increase in carbon emissions (Sadath & Acharya, 2017). The authors are referring to the fact that most of the countries have energy networks that run on fossil fuels, for example, in India, it is predicted that coal will be half of the energy mix by 2040. In such cases, the solution should be focused on the efficiency and flows of the energy network and how the transition to renewable can take place in a just manner.

Thus, the global energy system faces three major strategic challenges in the coming decades: the growing risk of disruptions to energy supply; the threat of environmental damage caused by energy production and use; and persistent energy poverty (Birol, 2007). This project will mainly focus on electricity production and consumption, and its role in facilitating the alleviation of energy poverty.

Fig 1.2: Countries highlighted showing fossil fuel as the main source of power
Source: www.gocompare.com

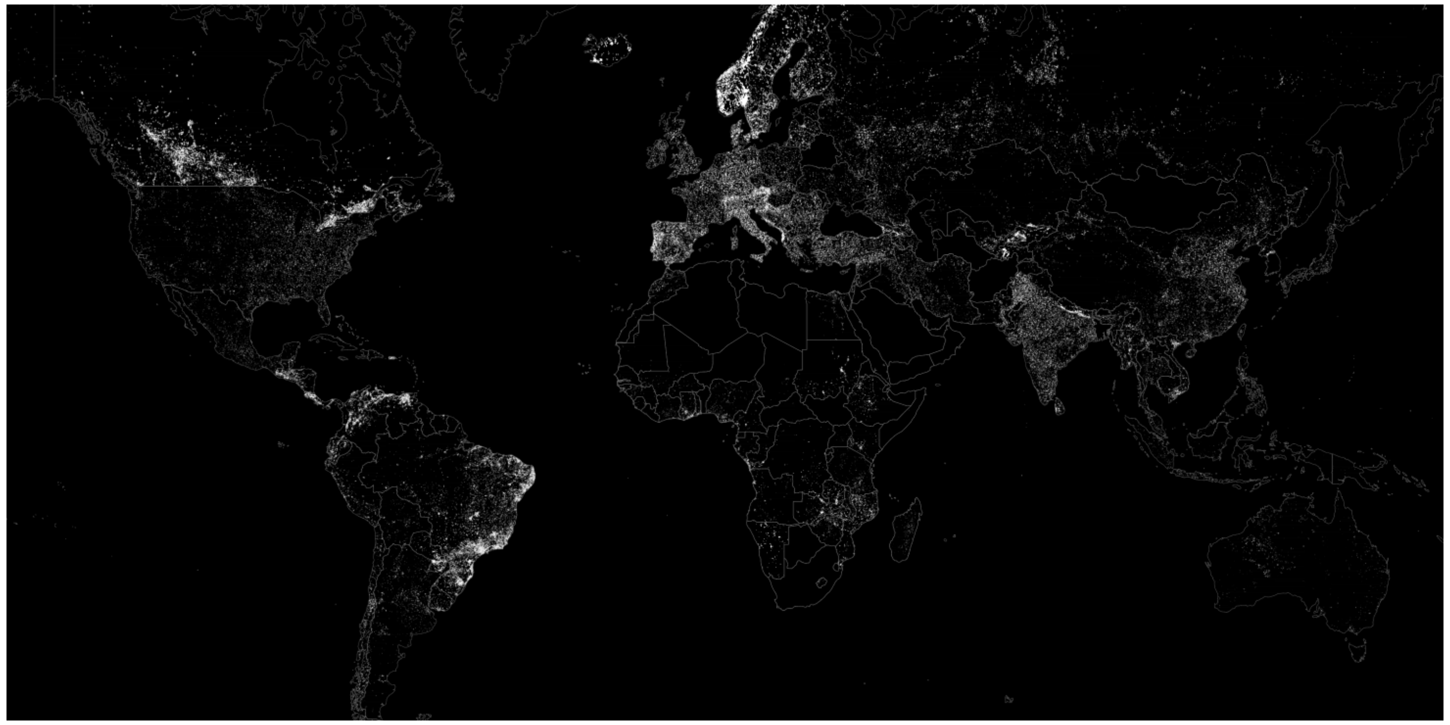

Fig 1.3: Situation if fossil fuels were erased today, the areas of the world that would be powerless

02

The Indian Perspective: Problem Field

2.1 | Questioning the existance of persistent energy poverty in India

Energy access in the rural areas of India has always been a problem. During the post-independence period (after 1947), most of the major government initiatives were focused on the development of major cities hubs. The late 1970s was when attention was truly given to the development of rural areas. One of the major initiatives towards this was addressing the isssue of energy poverty. India has progressed from 1% of electrified villages in 1947 to 93% electrified urban areas and 73% rural areas in 2010. However, despite many attempts over the past seventy years, more than 250 million people have no access to basic electricity and 870 million rely on biomass as the main cooking fuel (Aklin, Bayer, Harish, & Urpelainen, 2018). The fact hides the point that this is not the case with all rural areas. States like Tamil Nadu, Kerala and Punjab have over 100% electrified areas. But, according to Government of India (based on 2011, census) Uttar Pradesh, Bihar, parts of Rajasthan and few other northern states still suffer from low rates of 37% electrification.

The latest addition to this is the "Power for All" initiative, where the government has made claims to provide 100% electricity to all areas by linking them to the national grid. With the idea of expanding grids, comes the fact that highest transmission and distribution losses are seen in India. In 2010, losses hit 24% as compared to the world average of 10% (Aklin et al., 2018). To top it all, to meet the supply demands, coal-based thermal generation is critical to cover the baseload in order to achieve electricity access to all and to meet the excessive energy consumptions in the urban areas(Seth Block et al., 2019).

> [..]energy resources, geography, and economic development are seen as fundamental drivers of energy poverty but this has to be layered with political factors
>
> - Prof. Michael Aklin (Aklin et al., 2018)

Note:
The reason behind the strong demarcation in this project between urban and rural is due to the difference in classification by the Indian government. According to (Alexander Wandl et al., 2014) the urban-rural classification is too rigid when considering the aspects of spatial planning and design. Even though rural areas can be seen as an extension from the city, the socio-economic differences in India are too wide. This makes the divide between urban and rural areas very evident even in spatial development.

According to the Indian government, areas with a population around 5000 people and with 25% of the population working in agriculture are termed as rural areas.

Fig 2.1 : Newspaper clipping explaining the actual situation of energy poverty.

Source :
a) www.downtoearth.org.in
b) www.downtoearth.org.in
c)GARV (Rural electrification corporation)

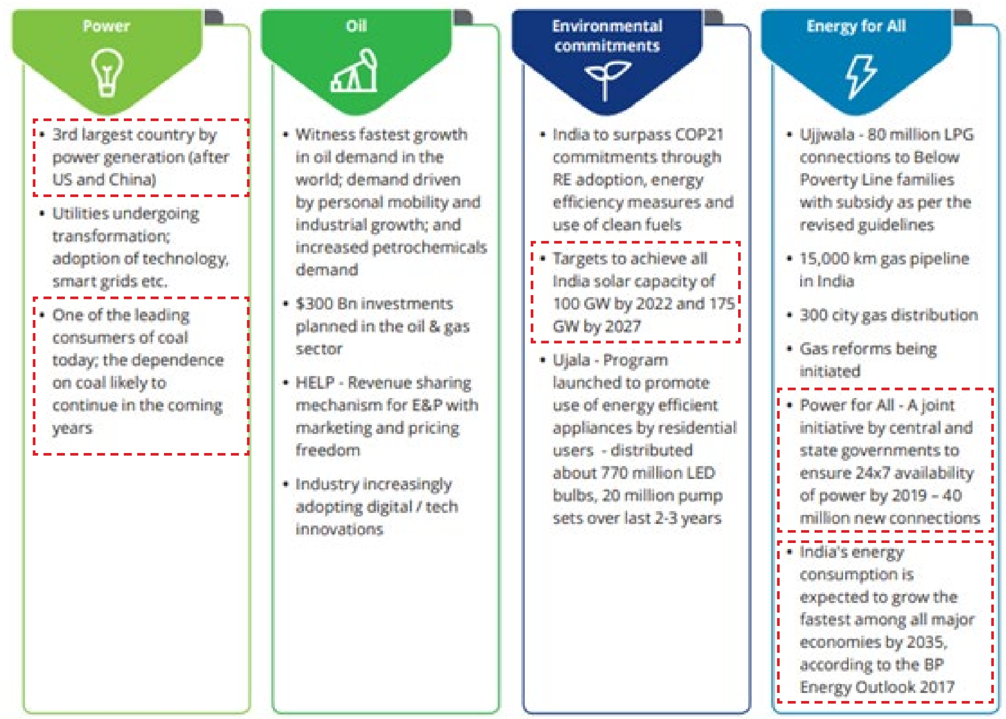

Fig 2.2 : Nutshell overview of the future commitments.
Source : India's energy transition, 2018

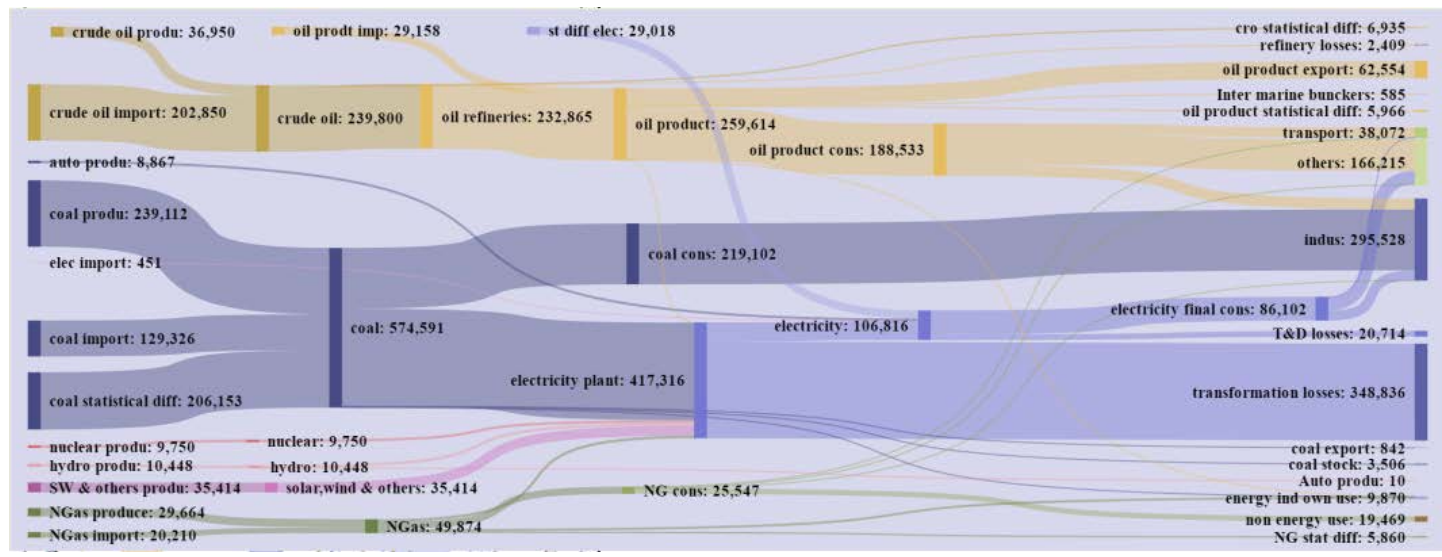

Fig 2.3 : Flow diagram showing the amount of transmission and distribution losses.
Source : Energy statistics India report, 2018
http://mospi.nic.in

2.2 | The National Capital Region of India : Area of focus

The National Capital Region (NCR) is an agglomeration formed by New Delhi and its surrounding region and stands as the fourth largest in the world of its kind (Bansal, 2017). The region encloses parts of three other states in India: Uttar Pradesh, Haryana, and Rajasthan. At its center lies the Indian capital Delhi or NCT. Apart from Delhi, the main cities in the region include Gurgaon, Faridabad, Noida, Ghaziabad, Alwar, and Bhiwadi. The city of New Delhi features the executive, judiciary and legislative branches of the Government of India. But the region falls under four different state assemblies, with a common development plan for the NCR.

During the partition post-independence in 1947, a large number of refugees migrated to Delhi, resulting in a rapid population growth of around 90% in the region. Hence, an Interim General Plan (IGP-1956) for Delhi was prepared in 1956 which focussed mainly on the regional planning for Delhi. Following the IGP-1956, a Master Plan for Delhi (MPD-1962) for the perspective year 1981 was also prepared which further stressed on the need for a regional planning for Delhi. A High Powered Board, under the chairmanship of the Union Home Minister, was also later setup in 1961 based on the draft Master Plan for Delhi. The Board underwent several changes in the following years and is now under the Ministry of Urban Development. The Town and Country Planning Organisation (TCPO) was entrusted with the preparation of a comprehensive Regional Plan and the Regional Plan-1981 for NCR, prepared by TCPO in 1973, was approved by the then High Powered Board.

The vision of "**a balanced and harmoniously developed region, leading to dispersal of economic activities and immigrants to Delhi, thereby leading to a manageable Delhi**" was the main focus of the Regional Plan-2001, which was approved by the Board in November 1988. The Plan proposed "**a policy of strict control on creation of employment opportunities within the Union Territory of Delhi, moderate control in the Delhi Metropolitan Area and, encouragement with incentives, in the areas outside Delhi Metropolitan Area within the NCR**" (NCRPB, 2013).

> "
>
> a balanced and harmoniously developed region, leading to dispersal of economic activities and immigrants to Delhi, thereby leading to a manageable Delhi
>
> - (NCRPB, 2013)
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> "

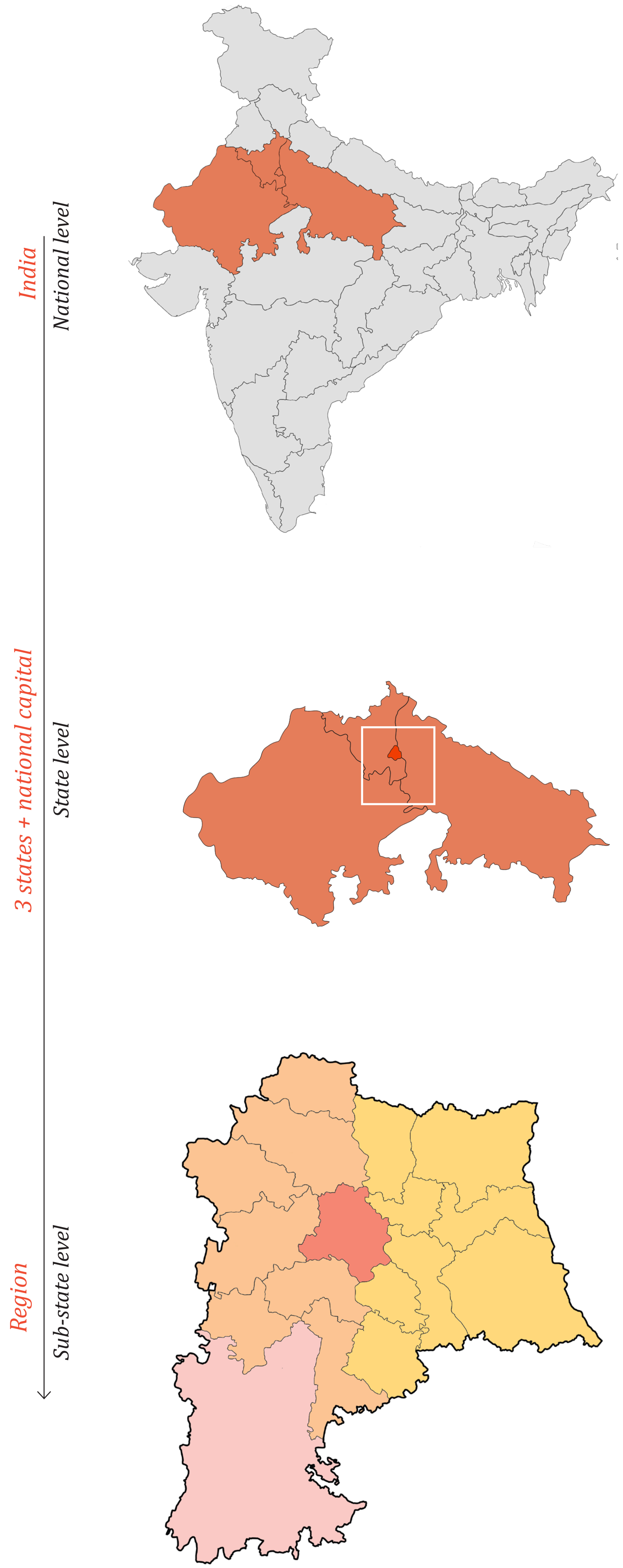


Fig 2.4 : Looking through scales
Source : Author

2.3 | Urban growth in the region

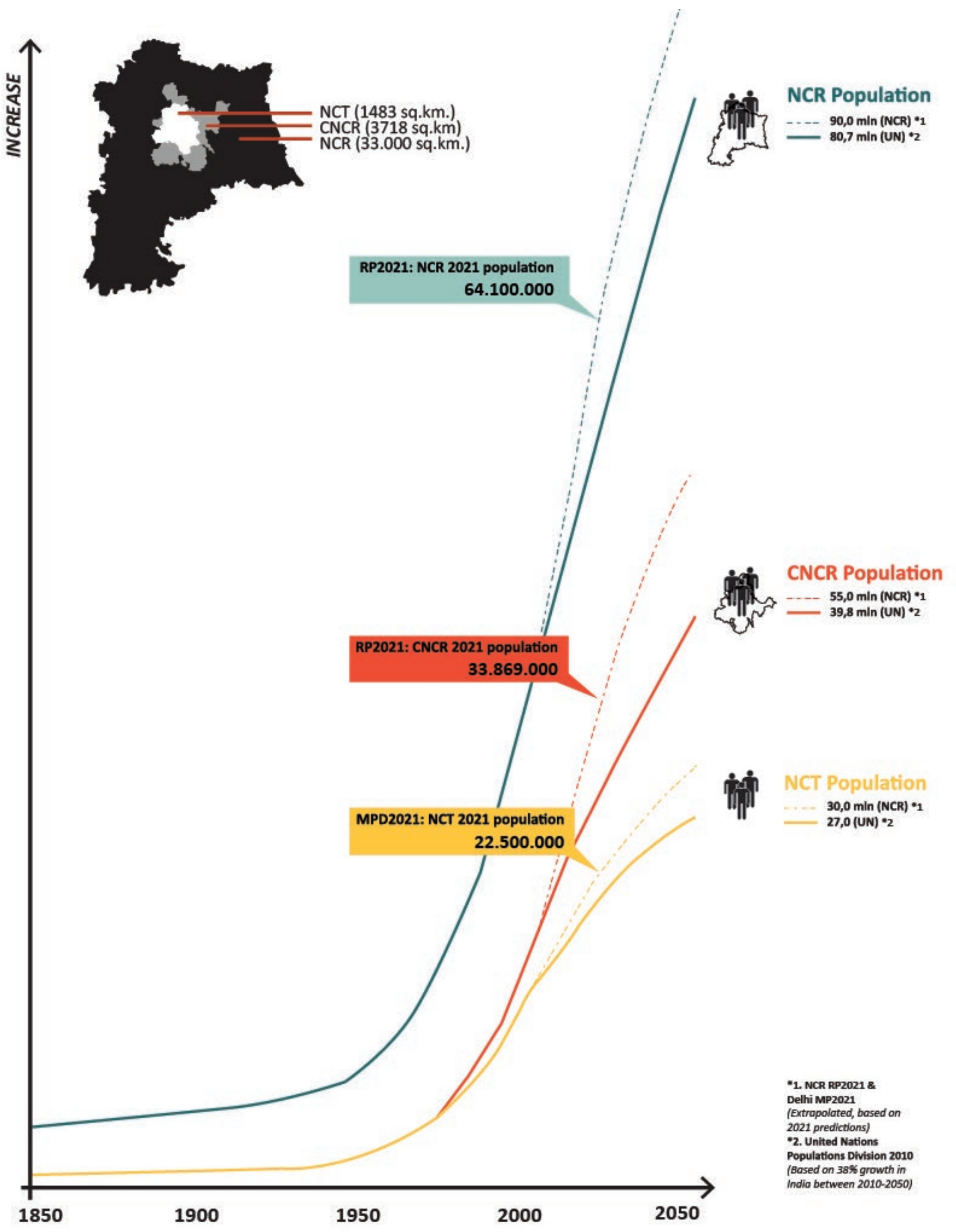


Fig 2.5 : Population increase in NCR
Source : Delhi 2050 report

NCR has grown in population by 9 million between the years 2001 and 2011. It is predicted that by 2021, the urban population would reach 45 million. Delhi is the center for the concentration of urban population with around 56% of the total population. Congestion in the city has lead to the development of suburbs or new satellite towns around like Gurgaon, Faridabad and other neighbouring cities. Rapid urbanisation has lead to increased migration and forced evictions leading to slums, poor peri-urban and rural area development. This has also created increased energy demands in the city, problems of energy deficiency and energy poverty among the urban and rural poor.

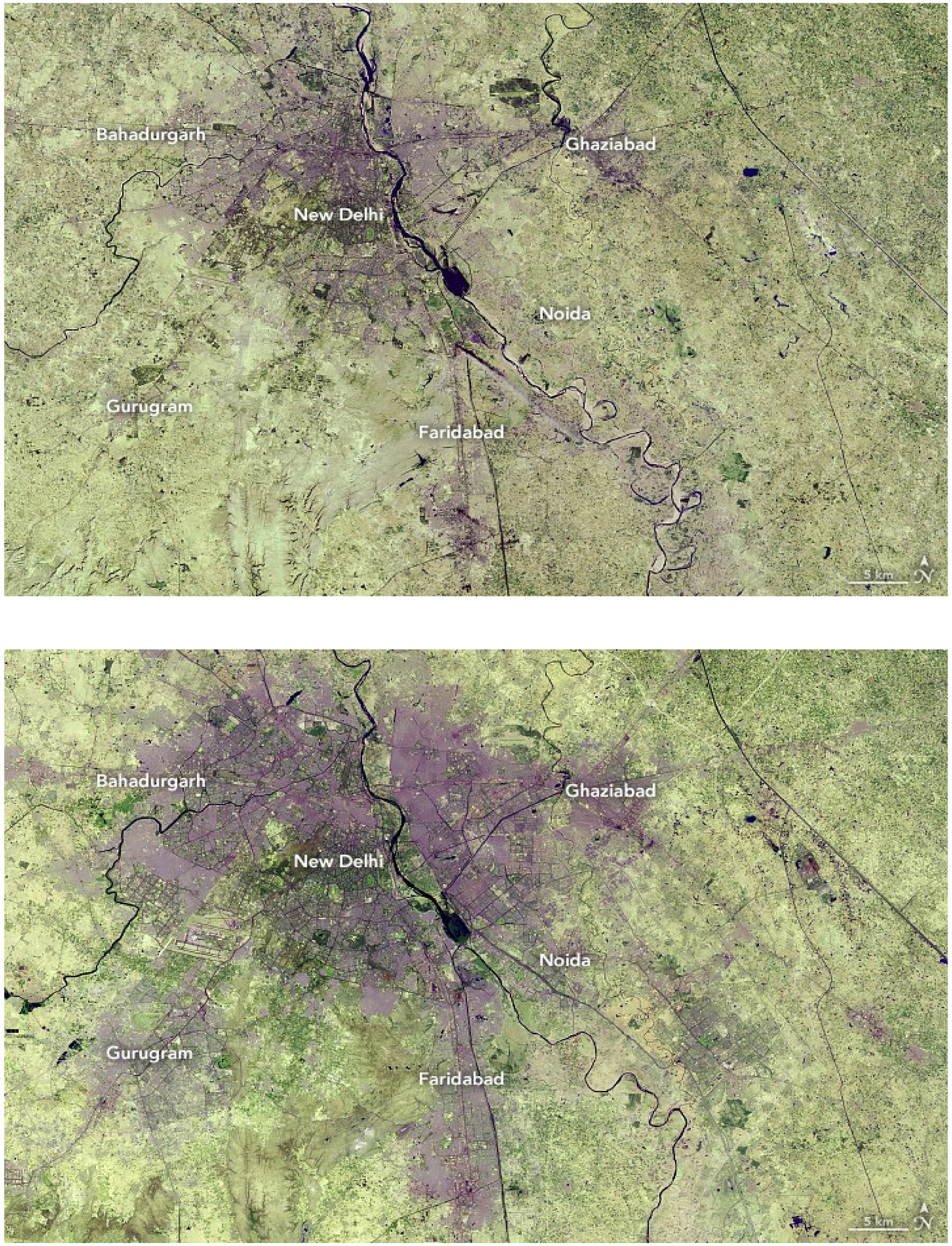


Fig 2.6: December 5, 1989 and June 5, 2018 - Growth of Delhi in the NCR region
Source: https://earthobservatory.nasa.gov

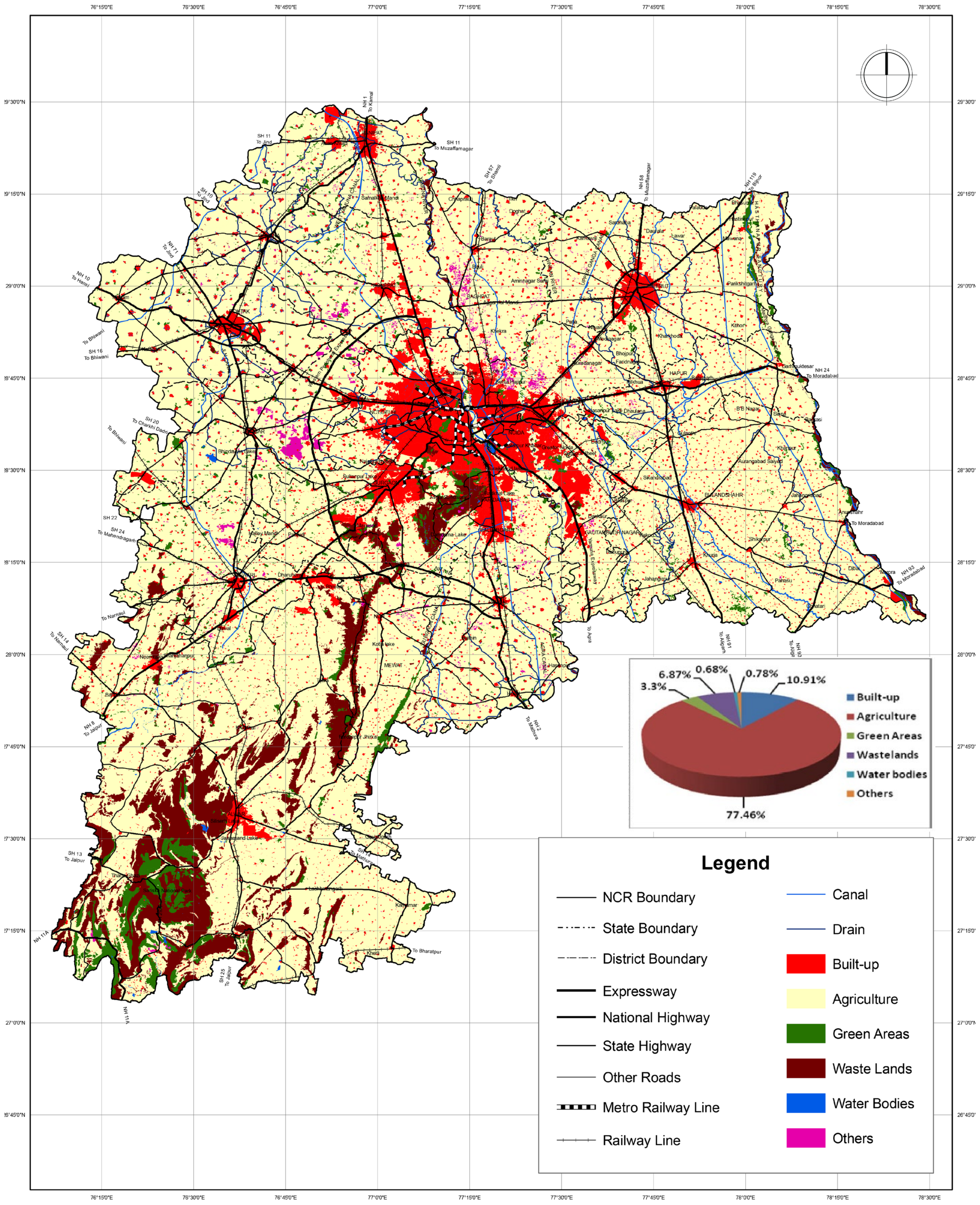


Fig 2.7: Existing landuse plan as of 2012
Source: NCR Regional Plan 2021

URBAN-RURAL DIVIDE

The NCR comprises around 7.6% of India's urban population and 2.1% of India's total rural population. India is considered to be the largest democracy in the world and the Indian economy has been consistently growing since its independence. India has made considerable achievements in various fields and contributes greatly to the global economy. In terms of scientific and technological workforce, India is considered the third largest; in terms of agricultural produce, India has large scale production of sugar, groundnut, tea, fruits, rice, wheat, vegetables and milk; and in terms of demography, around two-thirds of the Indian population live in urban areas. In spite of these developments, there is a significantly large gap between the urban and rural India with respect to technology, living condition, economic development, etc. This is evident from the fact that majority of Indian rural population do not have adequate access to facilities such as education, nutrition, health care, sanitation, land, etc. and many also suffer from energy vulnerability.

"The sharp increase in rural urban disparities in India after decades of planned development is alarming". India had introduced centralised planning, which included five-year as well as annual plans, post-independence, in order to narrow down such disparities and for the overall socio-economic development of the country. An overall direction and basic framework for policies, programmes and schemes for ministries are provided by the five-year plans. Significant budget allocations addressed the rural urban divide in India during the planning process, over the last six decades. However even today, significant differences exist (Das & Pathak, 2012).

The land-use shows that there is a clear urban center with satellite towns and villages around, and on the absolute periphery are the rural areas with agricultural value. This is further divided into controlled/development area and the rest of the rural context is left outside development boundaries.

"

[..]As, urban-rural systems are linked across sectors, space and time; the optimal use of environmental assests by the systems will principally determine their coping capacities..

- (Sukhwani et al; 2019)

"

The socio-economic development of a region or a country depends on several factors and electricity is considered to be one of the crucial factors. The recent electricity demands have witnessed a surge in all economic sectors which can be attributed to the liberalisation of the economy that facilitated industrial and commercial activities. Electricity has become a necessary commodity in our lives and access to affordable, reliable and quality electricity for all households should be ensured while considering the inclusive growth. The NCR experiences frequent power cuts due to an overall shortage in the northern power grid from where the region draws its power, which severely disturbs daily life as well as affects the economic productivity in the region. Alleviating energy poverty also means more electricity demand.

This can be considered as an example of poor infrastructural planning which did not take into account the increasing population and the growth of economic activities in the NCR while setting up the power supply in the region. The need for considerable improvements in the power generating capacity as well as in the transmission and distribution system is urgently necessary in order to ensure "balanced and harmonized development of the National Capital Region"(NCRPB, 2013).

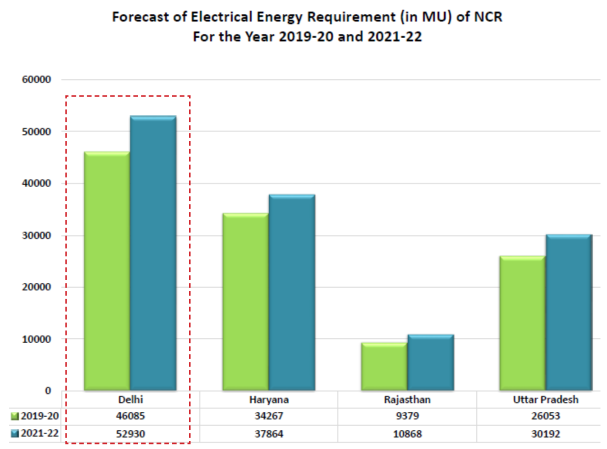


Fig 2.8 :Forecasts show increase in energy requirement and consumption in the the NCR
Source: MoP, 2019

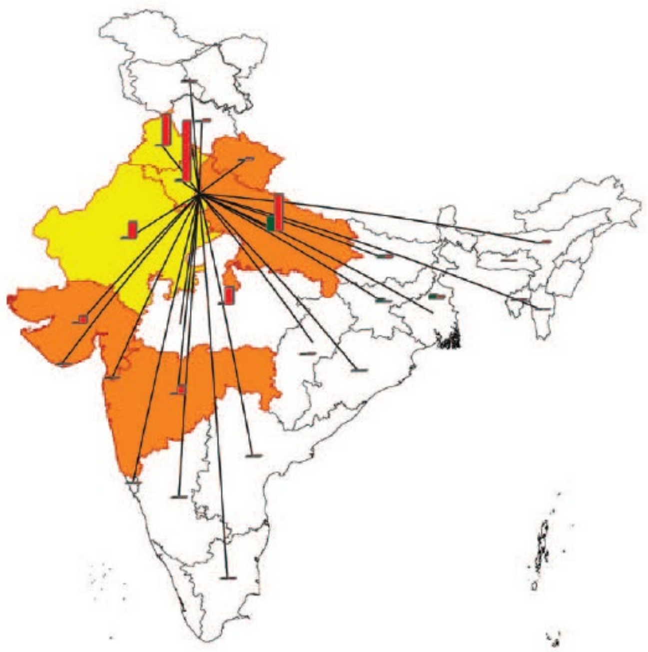


Fig 2.9 : Trans-boundary water withdrawal by state to support Delhi's electricity and agri-food supply - the map shows that water is extracted from areas of water shortage to meet the delhi demands
Source: (Ramaswami et al., 2017)

IEEFA report: Major water shortages and other stressors raise risks for India's coal sector

Over-capacity, drought, and rising renewables increase pressure on coal-fired generators

"The energy landscape has changed dramatically in recent years and there are increasing stressors, particularly on the thermal coal sector, that require urgent attention, water being one of the most prominent," said David Schlissel, co-author and IEEFA's director of resource planning analysis.

Water shortages are one of the major stressors on India's thermal coal industry

Fig 2.10: Headlines from Institute of Energy Economics and Financial analysis report (IEEFA) September, 2019

Delhi's date with Zero Day: Frightening reality can hit Capital by 2020

Delhi and 20 other cities in India are likely to run out of ground water in less than two years' time, according to a report by Niti Ayog.

ET Online | Updated: Jun 26, 2018, 01.07 PM IST

Fig 2.11: News Article regarding the problems of water shortage in Delhi
Source : www.economictimes.indiatimes.com

As Delhi chokes due to air pollution, power plants are set to miss emissions deadline

1 min read . Updated: 11 Nov 2019, 03:50 PM IST

Eight of the plants, operating near Delhi, have yet to order the required flue-gas desulfurization units, according to the Central Electricity Authority (CEA) **(Photo: Reuters)**

Fig 2.12: News article on Delhi's air pollution
Source: www.livemint.com

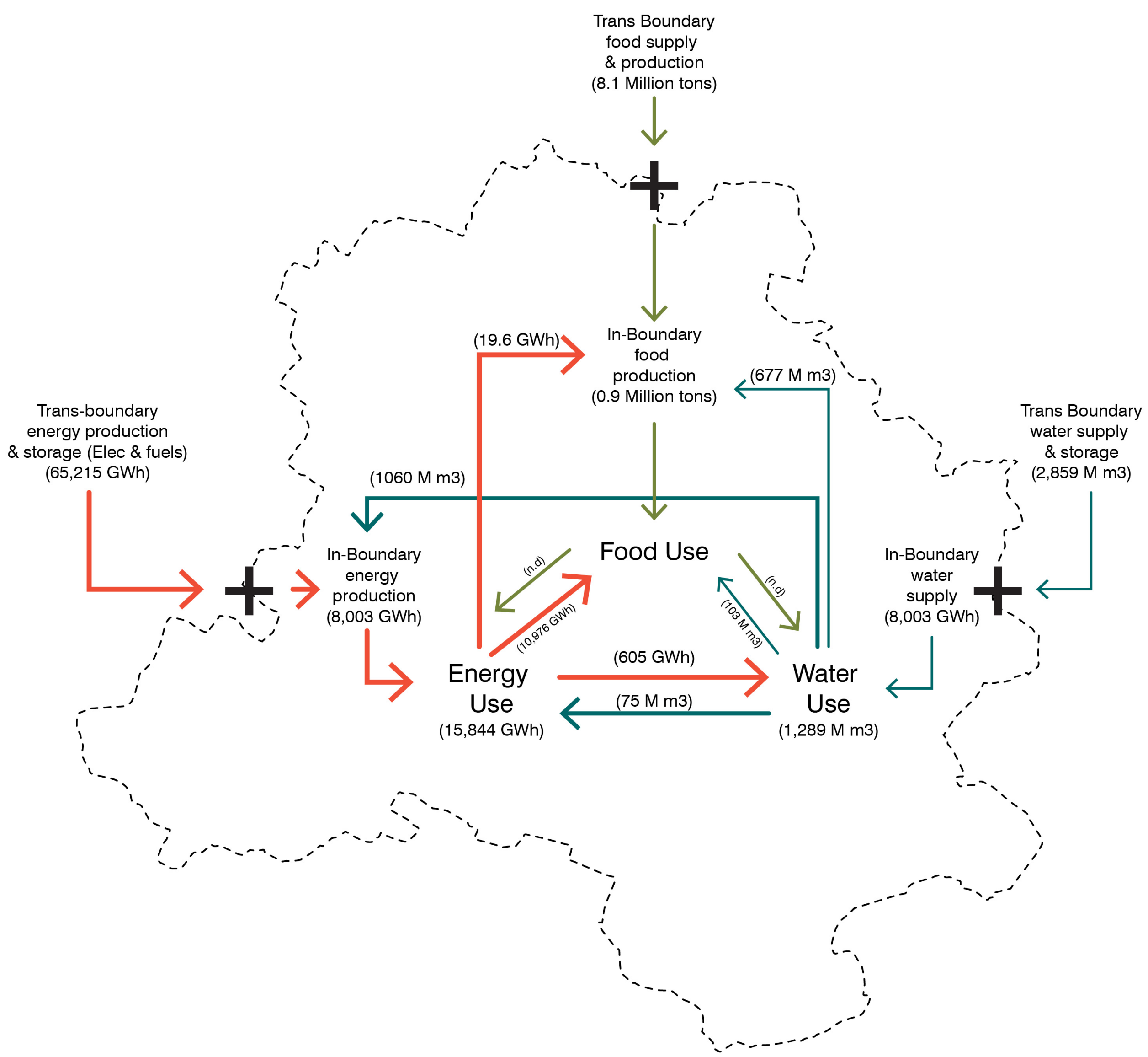


Fig 2.13: Energy and water use (withdrawal) associated with FEWsupply to Delhi.
Source: (Ramaswami et al., 2017)

Another aspect is the pressure by energy network has on the food and water system; the FEW nexus. As mentioned in section 1.2, energy poverty has an impact on the environment. So, addressing energy poverty must take into account the impacts on food and water network. However, this aspect has not been considered. This sectoral division in development will not be able to foster a resilient development model (Sukhwani, Shaw, Mitra, & Yan, 2019). For example, the energy chain in Delhi is also closely linked to the issues of overdrafting of water in Haryana and Uttar Pradesh. The underlaying problem of vastness and the spatial extend over three states and NCT-Delhi, makes it difficult for an integrated development approach.

The rural areas are mostly involved in agriculture, i.e., food production. Electricity is used intensively for crop production. For irrigation, electricity is required and water is needed to produce this electricity. This electricity is currently supplied by using groundwater pumping and this causes groundwater overdraft, which in many states are high as they supply more than 75% of Delhi's food.

On a local scale, Delhi produces only 10%, 24%, 0% and 14% of food, electricity, other fuels and water, respectively, to meet its needs. Remaining is completely dependent on trans-boundary supply (Ramaswami et al., 2017).

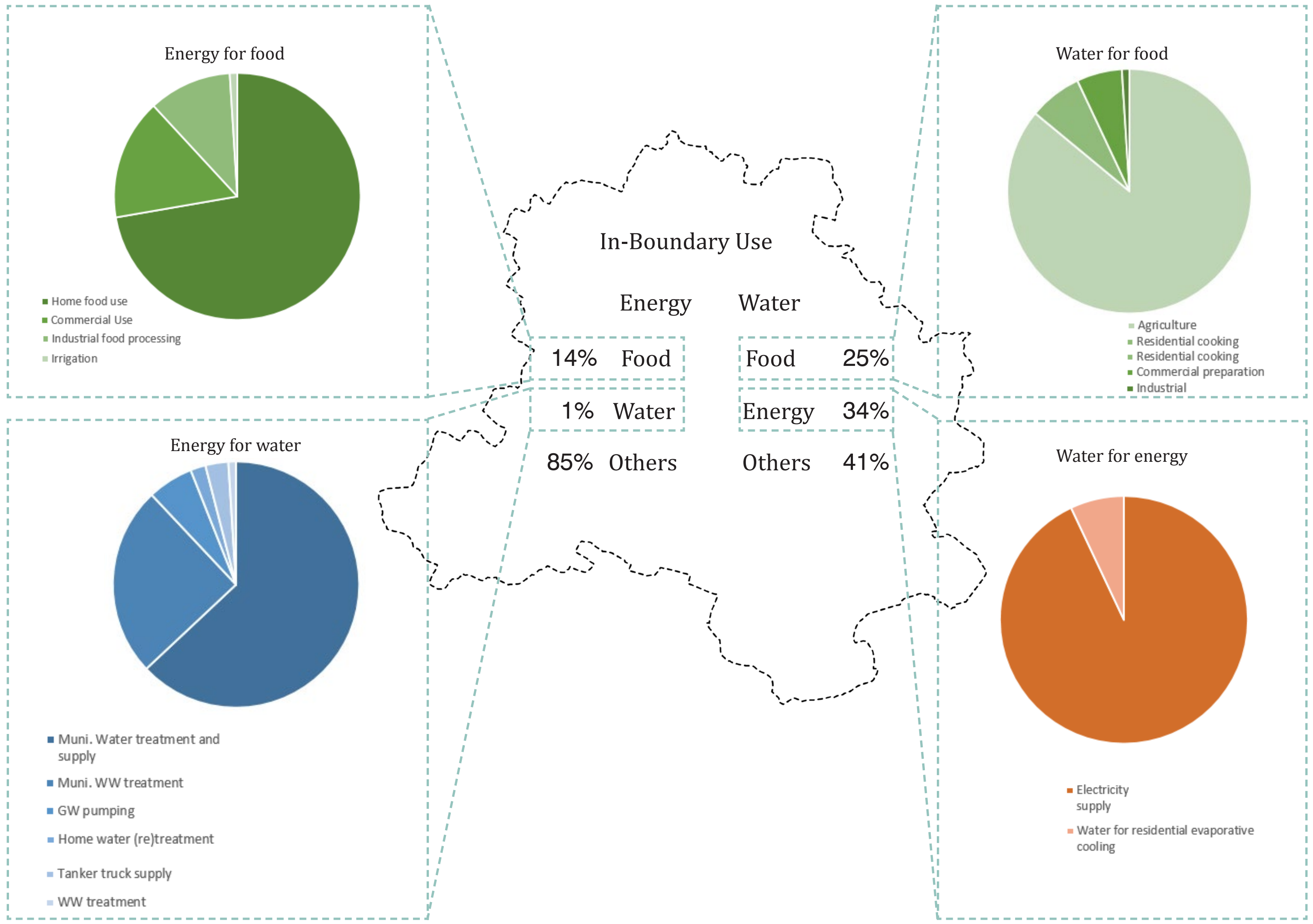


Fig 2.14: Map showing in-boundary usage of energy and water
Source: (Ramaswami et al., 2017)

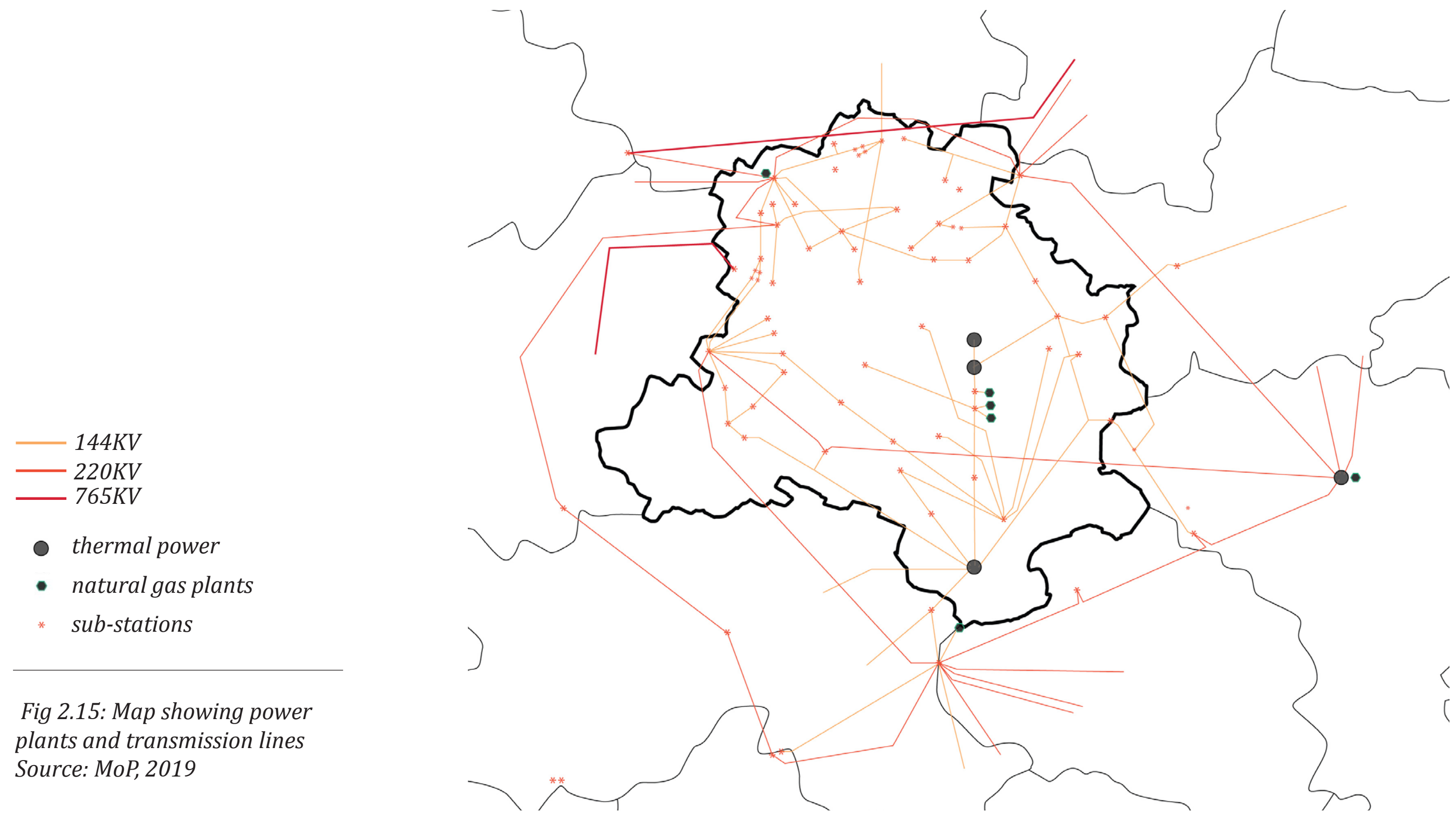


Fig 2.15: Map showing power plants and transmission lines
Source: MoP, 2019

2.5 | Energy Poverty and governance

With the government policy of "Power for All" extending and increasing network connections to all regions, little thought is given to energy efficiency and renewable energy transition in the region. The varying policies of different states across the region creates issues such as excessive extraction of one resource to fuel the energy demands of the city.

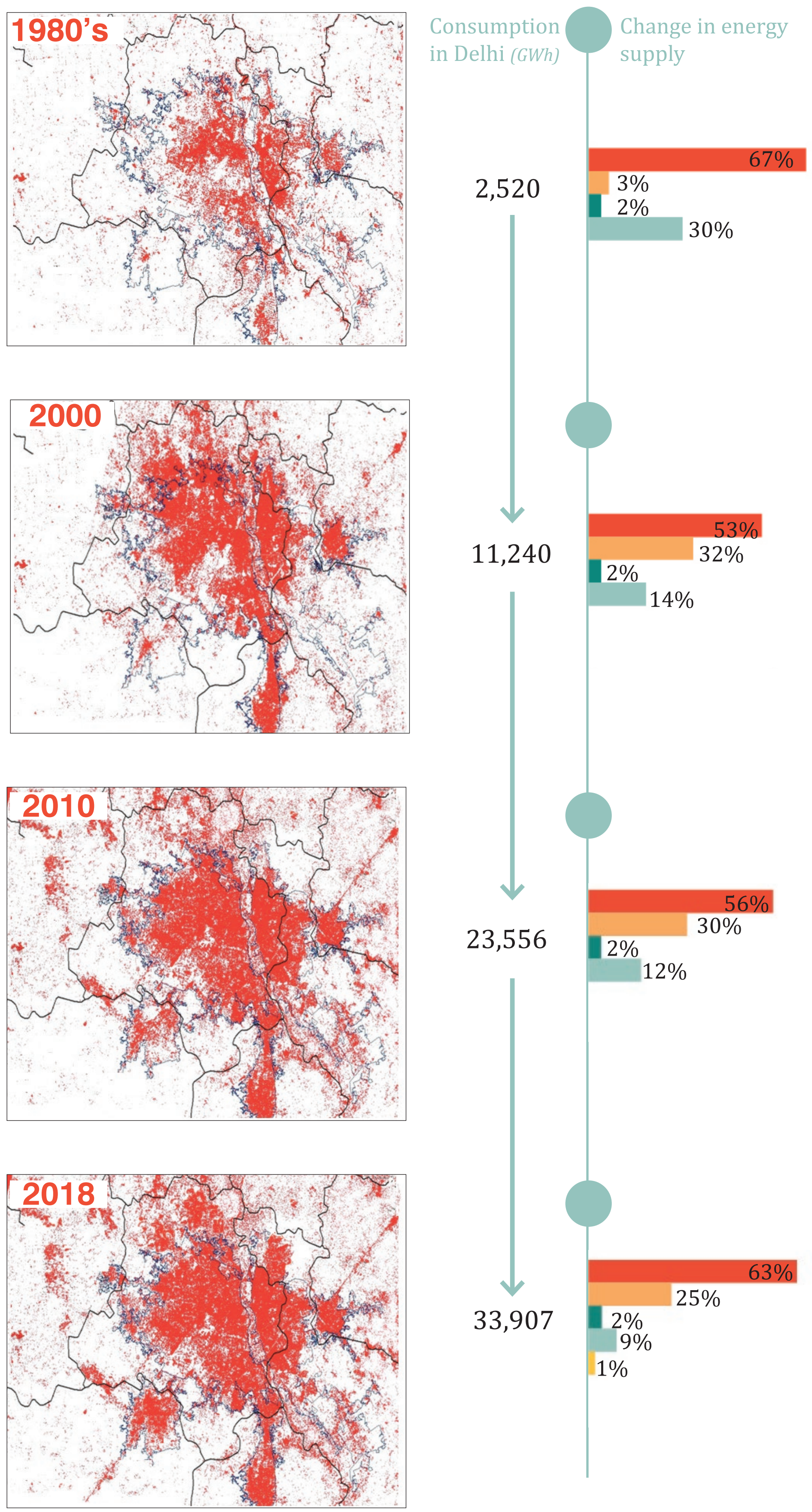
According to Prof.Michael Aklin, the persistent problem of energy poverty in India should also be looked from a political and economic point of view. He studied this through 3 categories:
1) Government interest; i.e., "degree of a government's interest in eradicating energy poverty",
2) Institutional capacity "determines the ability of the government to enact and implement coherent, effective, and affordable policies that eradicate energy poverty over time."
3) Local accountability "ensures that national policies are properly implemented in energy-poor communities in terms of both information transmission and the incentives of local officials." (Aklin et al., 2018).

Based on the conclusions of the study, it can be seen that local accountability has always been a down side in the political front. Addressing energy poverty, would also mean looking at ways to improve the policy to implementation process.

Fig 2.16:Women carrying wood to use as fuel for daily activities. Source: www.mailtoday.com

Spatial | **Resource** | **Policy**

Looking into Rural Electrification (National Level)



Government started taking interest in rural electrification during late 1970's, to strengthen their political agendas.

Government Interest : High
Institutional Capacity : Medium
Local Accountability : Low

Government Interest : High
Institutional Capacity : High/Medium
Local Accountability : Low

Government Interest : High
Institutional Capacity : High/Medium
Local Accountability : Low

Government Interest : Very High
Institutional Capacity : High
Local Accountability : Low

Built up area in the NCR region

Fig 2.17: the growth of Delhi center into other regions of Haryana and Uttar Pradesh Source: www.censusindia.gov.in

Legend :
Coal
Gas
Nuclear
Hydro
Other renewables like solar, wind etc

Source : MoI, 2019
Data calculated based on national energy supply and energy mix based on delhi energy generation & assuming a constant 3% share for Delhi.

Note : During 1947–1965's
Government Interest : Low
Institutional Capacity : Low
Local Accountability : Low

Source : (Aklin et al., 2018)

Fig 2.18 (a): Students in urban areas have access to better ways of studying than in rural areas. This causes under development of youth in these areas. Source: www.thebetterindia.com

Fig 2.18 (b) : Difference in the way of cooking in urban and rural areas. The use of chulhas or firewood for cooking and heating casues a lot of health issues. Source: excerpt from the Access film : Realities and Challenges of Energy Access in Rural India

Fig 2.18 (c): Ways of transporting LPG gas from cities to rural areas for cooking. These fuels are more costly than getting firewood. Hence, most of the rural areas resort to firewood or coal. Source: excerpt from the Access film : Realities and Challenges of Energy Access in Rural India

Fig 2.18 (d): Bill gates speaking in a TED Talk
Source: Energy poverty talk on gates notes, 2016

These images show the stark difference between the urban and rural areas. Its not just in terms of urbanisation but also in their way of life. If we could make energy affordable and reliable in such areas, then that is the way forward.

Currently, the issue of energy poverty is looked at mainly from a social point of view by linking it to the broader problem of poverty or merely by thinking that providing a grid connection is sufficient. The underlying issue of the efficiency of the grid system and energy sources, understanding the issues behind failing policies and the cause of the spatial divide between the urban and rural areas are overlooked

This project adds to the knowledge gap by taking look at energy poverty from an integrated point of view. This project aims at addressing the problem of energy poverty by looking into three main components, resource component, spatial needs component and the policy component. This project will take an approach that looks through types of energy systems, spatial development and governance initiatives that can alleviate energy poverty and help promote clean energy transition in the urban and rural areas.

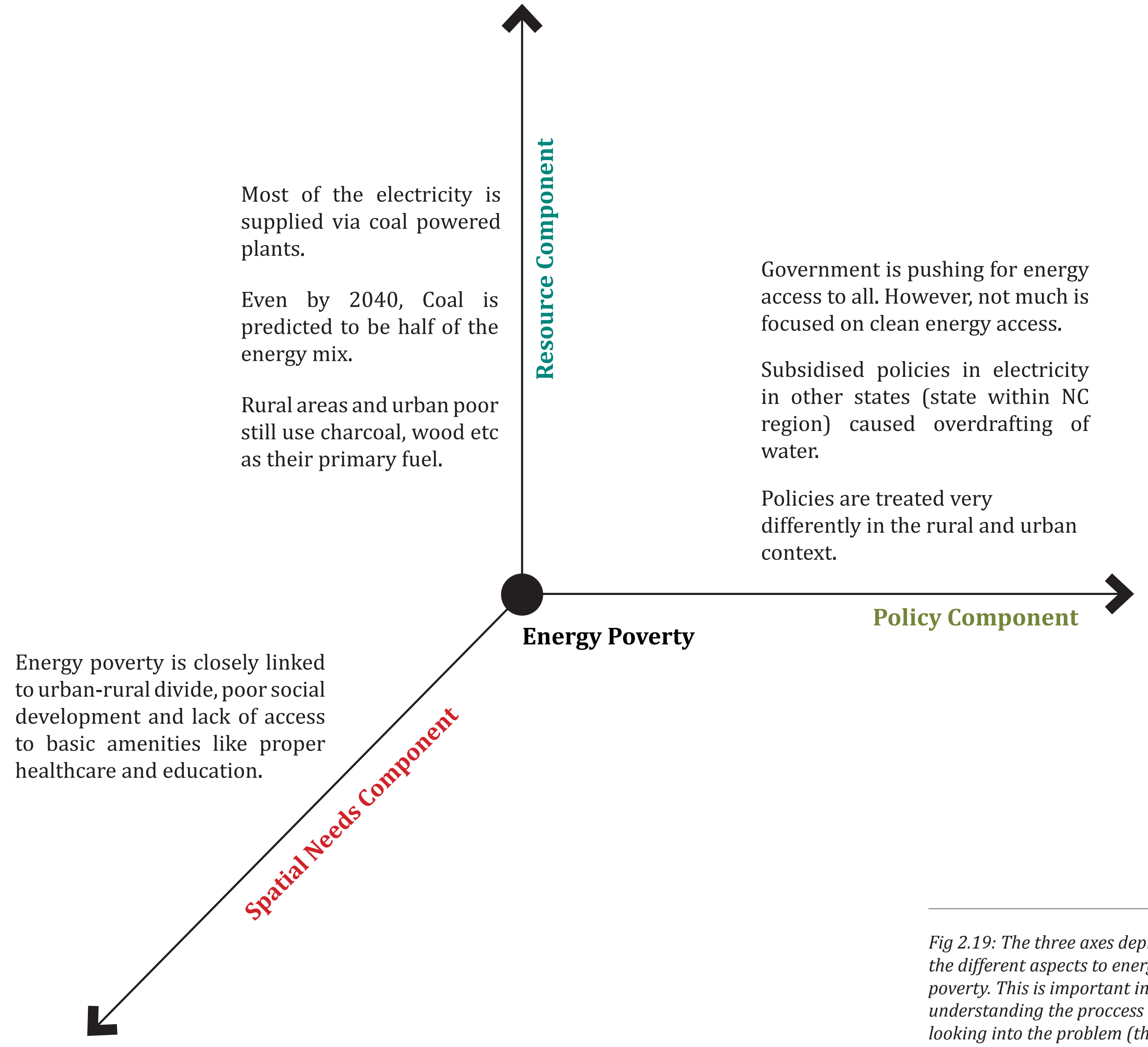


Fig 2.19: The three axes depicting the different aspects to energy poverty. This is important in understanding the proccess of looking into the problem (the meeting point of the axes - energy poverty)
Source: Author

Fig 2.20:Cartoon showing the situation of inefficiencies of electrical systems in India
Source: www.mailtoday.com

Fig 2.21:Cartoon indicating the need for human development along with negating energy poverty
Source: www.mailtoday.com

Fig 2.22 : The state of rural areas that claims to be connected to the grid.
Source: www.mailtoday.com

2.6 | Problem focus and research question

| Problem statement

The National Capital region of India, is looking to negate energy poverty by merely extending existing energy networks. However, as city hubs continue grow and consume large amount of energy resources, the urban-rural system suffer in terms of energy injustice. This issue is over laid with poor attempts to address energy poverty that pay little attention to the growing urban-rural divide, the need for clean energy transition and the pressure caused on the FEW nexus.

| Research aim

To illustrate the scope and application of energy systems between urban and rural areas to facilitate a resilient, inclusive and just renewable energy transition in NCR, India

| Research questions

What are the reasons behind energy poverty and urban-rural divide in NC region?

What are the barriers that prevent renewable energy transition in the region?

What are the spatial implications of renewable energy transition in the urban-rural context?

How can a regional energy system between urban and rural areas be designed for a just renewable energy transition in NC region, India ?

What are the scenarios that can help create a develop the urban-rural area with resilient energy systems?

What are the ways of designing energy systems to reduce impacts on the FEW nexus?

What governance initiatives can enable inclusive participation to reduce energy poverty?

03

Frameworks

To access the areas of resource, policy and spatial needs of energy poverty, the below theories are taken into consideration. The theory of urban nexus can be used for the anaysis of a specific region and flows within. However, looking into the broader understanding of flows and its gegraphic locations, the concept of territorial metabolism seems apt. This does not negate the idea of nexus from the framework because urban nexus links discuss the connections between various ideas. The concept of transitions, particularly 'just' transitions in nessasary in addressing energy poverty.

Energy poverty

Energy poverty shall be defined as explained by (Sueyoshi & Goto, 2018) as "the absence of sufficient choice in accessing adequate, affordable, reliable, high-quality, safe and environmentally benign energy services to support economic and human development". This definition provides an overview into the theme of this project, which is to look at the potential of clean and sustainable energy services to address the issue of energy poverty. The idea of absence of choice emphasizes why governance policies must be considered to investigate equal access to energy for all.

Under this broad umbrella, the first aspect is to look into energy services and the context in which it exists.

Territorial metabolism

"[...]urban metabolism analysis, the flow of all materials into and out of a well-defined urban area are accounted for, but this might become either impractical or lack sufficient detail to be of use if applied at the larger scale of a region. In order to reduce the complexity of the system, while maintaining pertinent details, a scaling concept is applied to define the territory. [...], the territorial scale, or 'production territory', for the purposes of this work will be defined as the aggregated individual producers and the land within their geographic delineations contained in a defined region." (Fig 28) (Sohn, Vega, & Birkved, 2018)

(Sohn et al., 2018) describes the need for looking at regional flows through the concept of territorial metabolism. The Food Energy Water systems and energy impacts are better understood when an entire production, supply and consumption chain can be studied. The requires moving out of a defined boundary and to the geographical location of each element in a system. For this project, when applied to the case of NCR, the energy flows originate from other areas. This creates a trans-boundary interaction, that can be well analysed through the concept of territorial metabolism.

Fig 3.1 : Five streams of ideas informing the nexus approach in an urban context
Source: (ESCAP, 2016)

Nexus

""The Urban NEXUS, [..]guides stakeholders to identify and pursue possible synergies between sectors, jurisdictions, and technical domains so as to increase institutional performance, optimize resource management, and services quality. It counters traditional sectoral thinking, trade-offs, and divided responsibilities that often result in poorly coordinated investments, increased costs, and underutilized infrastructures and facilities. The ultimate goal of the Urban NEXUS approach is to accelerate access to services, and to increase service quality and quality of life within our planetary boundaries." (ESCAP, 2016)
[...] nexus analysis at a city level ('intra-urban nexus') will have to pay attention to themes commonly associated with other scales ('nested urban nexus') such as geopolitics (global), whole-of-government policy integration (national), and ecosystem approach (sub-national and regional)" (ESCAP, 2016).

This idea is countered by (Sukhwani et al., 2019) saying to look at not only the urban system but also the rural areas (which is essentially, the city and its hinterlands). And to pay attention to the each sector of Food, Energy and Water to completely design a resilient urban rural system. "The dichoto- mist approach to urban-rural development so far and the sectoral approach to FEW nexus has led to transformation inconsistencies due to which the rural systems today are disproportionately affected by climate change."(Sukhwani et al., 2019). "Applying the trans-boundary, multi-sector, multi-impact FEW analysis framework in Delhi,India, enables future assessment of system dynamic interactions [...]"(Ramaswami et al., 2017) .

The concept of nexus is useful in addressing energy poverty by looking at energy services, and to do an impact assessments on the existing energy flows within the urban or rural contexts, and to see what causes the pressure on the FEW system.

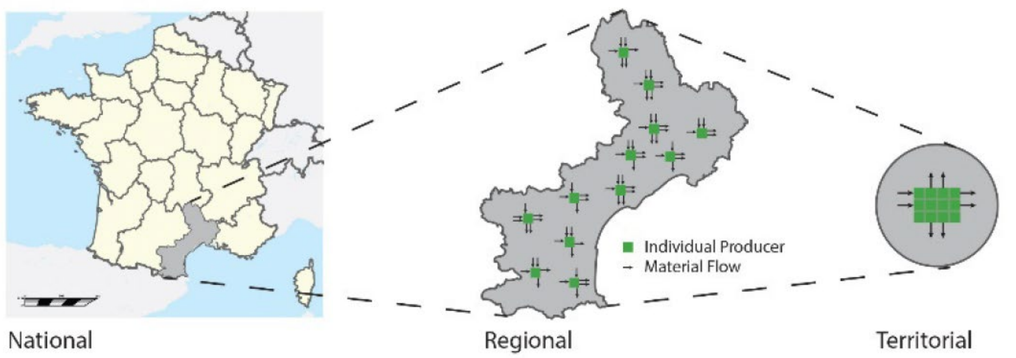


Fig 3.2: Scaling concept from national to regional allowing a process based aggregation of individual producers, shown in theoretical form for the Languedoc-Roussillon region in France.
Source: (Sohn et al., 2018)

'Just' transition

The term 'just' transition is most frequently used in addressing the shift towards a low carbon economy. According to the UN discussion at the climate change convention held in 2010, the "idea of 'just transitions': interpreted as how to ensure moves towards a low carbon economy are equitable, sustainable and legitimate in the eyes of their citizens" (Newell & Mulvaney, 2013).

As an urban designer, it was also imperative to look into what a 'just' energy transition for landscape would mean. The book sustainable energy landscapes describes a sustainable energy landscape as "a physical environment that can evolve on the basis of locally available renewable energy sources without compromising landscape quality, biodiversity, food production, and other life-supporting ecosystem services."(Stremke, Sven ; Dobbelsteen, 2013). The books goes on to calling on designers to "aim for a socially fair, environmentally sound and economically feasible transition".

The word 'just' is linked to being equitable, sustainable, legitimate, environmentally sound, economically viable. This means addressing energy poverty and energy injustice in a socially equitable manner in a world where high levels of inequality is seen. Create an environmentally kind system that can provide energy in an equitable manner, in a place where there is so much dependency on fossil fuels and look at ways in which all this can be done in an economical method. Design of such a 'just' energy system to alleviate energy poverty would also mean to take a deeper look at what the broadly used term 'sustainable' contains.

Sustainability

Sustainability or sustainable development is an amalgamation of words that constituted the word 'just' seen in the previously mentioned theory. Sustainability "as the balanced integration of economic performance, social inclusiveness, and environmental resilience, to the benefit of current and future generations" (Geissdoerfer, Savaget, Bocken, & Hultink, 2017).

Sustainability is where the responsibilities are shared by all in a community and aims creating environmental, social and economic benefits. Apart from looking at the 3 different pillars of sustainability, it matters to look into the venn diagram of sustainability. The intersections talk about equitable, bearable and viable (Brusseau, 2019).

Equitable sustainability is about in the societies are made to promote responsible consumption of resources and promote better well-being. Bearable is when resources are shared amongst the society in a fair and equal manner. This promotes to better standard of living and reducing social inequality and poverty. Viable is when economic growth and development are pursued with the need to create jobs, contribute to country's GDP through sustainable resources. With the problem field giving rise to 3 components resource, spatial needs and policy. The aspects of sustainability will be useful in linking together the

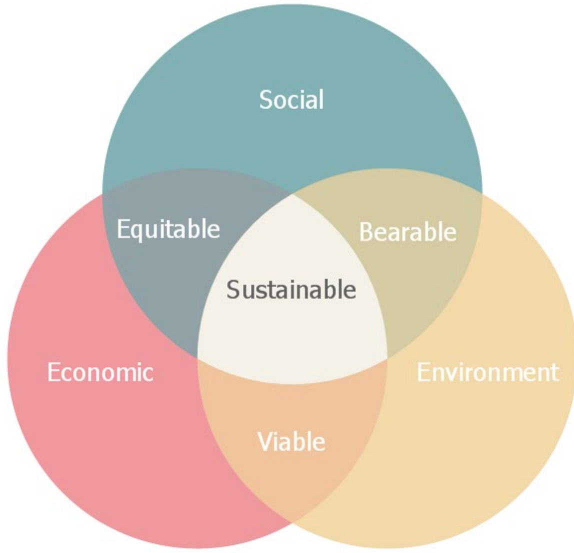


Fig 3.3 : Sustainability venn diagram
Source: www.conceptdraw.com

components of resource and policy-economic; and spatial needs and policy both involving the society- social sustainability.

Environmental sustainability is more than switching to renewable sources. It has to be linked to the flow of resources. Here the concept of circular economy comes into play.

Circular economy

(Geissdoerfer et al., 2017) refers to Circular Economy as "a regenerative system in which resource input and waste, emission, and energy leakage are minimised by slowing, closing, and narrowing material and energy loops. This can be achieved through long-lasting design, maintenance, repair, reuse, remanufacturing, refurbishing, and recycling."

The focus of circular economy is purely on environmental performance. It is based on preserving and reusing the resources that exist. Resources used as materials and energy are renewable and reusable with non-toxic properties. And waste from production and consumption are sources that are either recycled for same resource production or reused for generating secondary resources. This approach can give more insights into the resource component of energy poverty.

Conclusions

This section discussed the links between looking at energy flows, integrating nexus and just transitions as a theoretical base for addressing the problem of energy poverty. The theoretical underpinnings of sustainability and circular economy paves the way for looking at the impacts of energy systems in the urban-rural setting in the pretext of energy poverty. The separate view-point of circular economy is necessary during the study as it is important to even look at a possibility where existing fossil power plants can be re-used, or the impacts on the environment reduced till complete renewable energy transition takes place. Despite agreeing to the above theories, the need to also investigate fossil power and its impacts in addressing energy poverty is important. A comparative analysis of the difference in impacts between renewables and non-renewables will help in drawing wholistic conclusions.

3.2 | Conceptual Framework

The vector diagram represents the approach to be considered while addressing energy poverty. The concept of "vector of energy poverty" as mentioned earlier is a derivative of the vector of poverty (Gupta, 1984) .

Based on the problem statement, the problem of energy poverty has three main axes 1) the resource component 2) the spatial needs component 3) the policy component which is looked as separate lines going in different directions.

Based on theoretical framework, it is clear that the energy flows need to be analysed, and optimised among the urban and rural systems. Territorial metabolism urges to have a transcalar approach and look towards designing a just energy system. The approach in this project is by considering the point of energy poverty as a null point, gives the project direction in looking for ways to move away from it. And reimagine a point in space, that would be an intersection between resource, space and policy. And this point would be achieved by basing the methods used on the theoretical underpinnings.

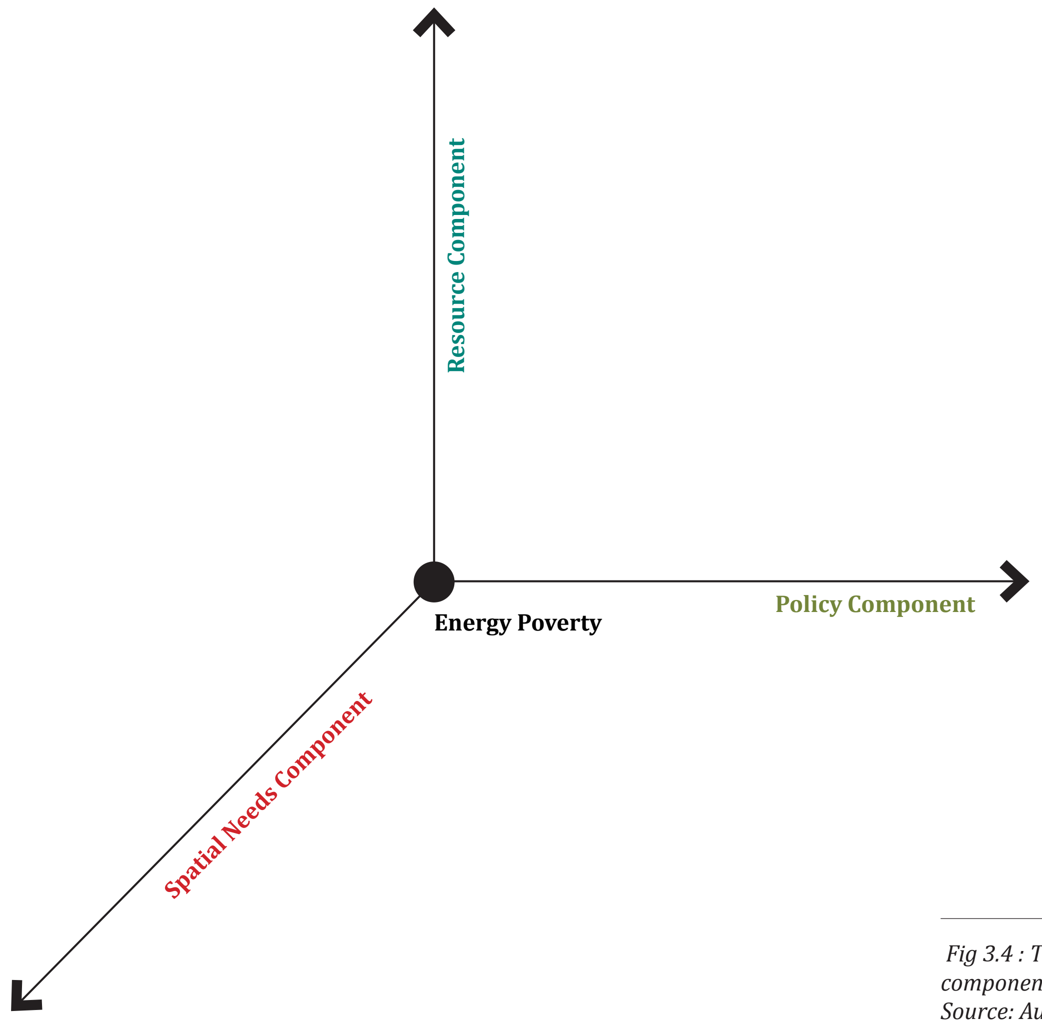


Fig 3.4 : Three separate components of energy poverty. Source: Author

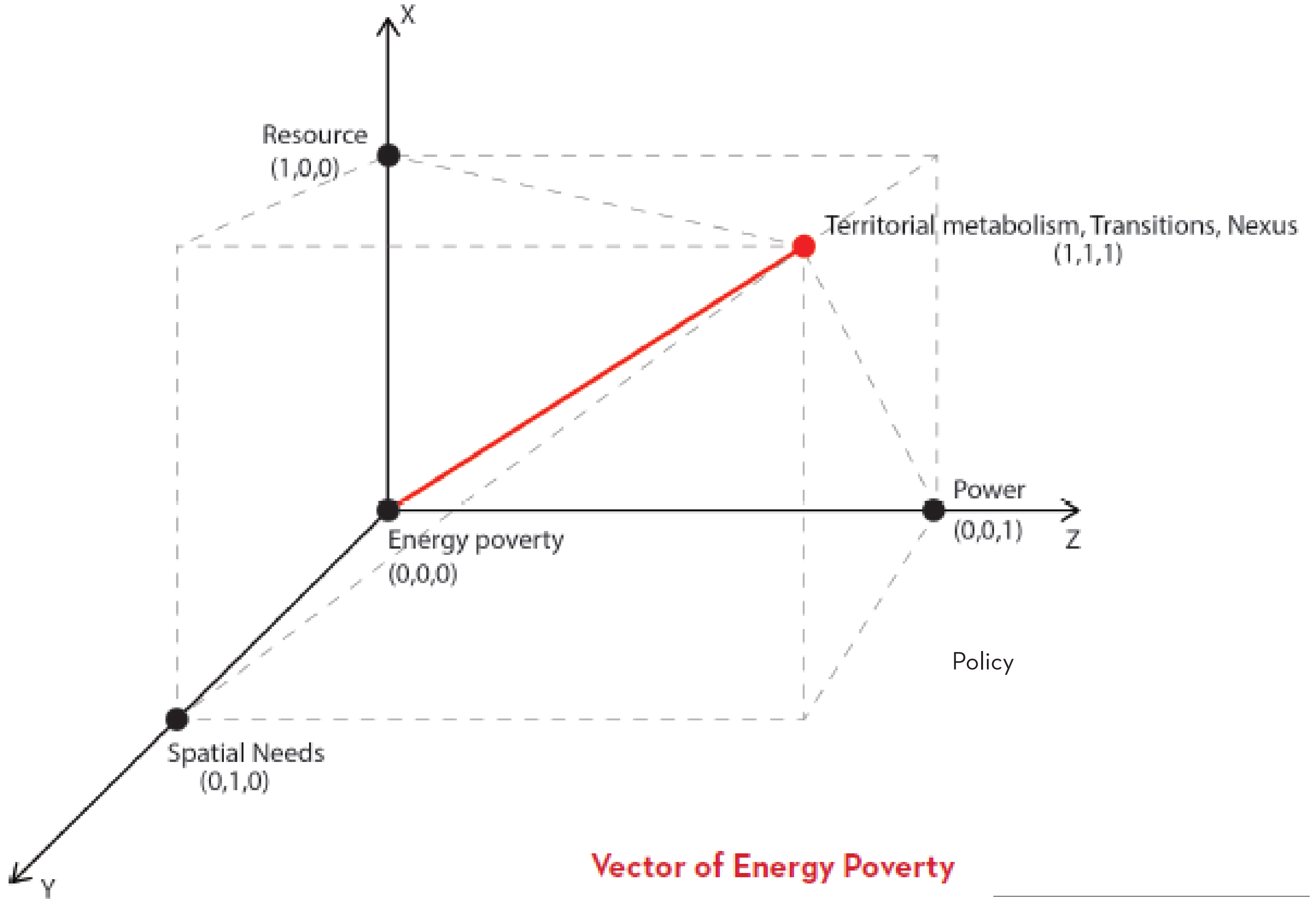


Fig 3.5 : Vector diagram depicting the method of approaching the problem of energy poverty. Source: Author

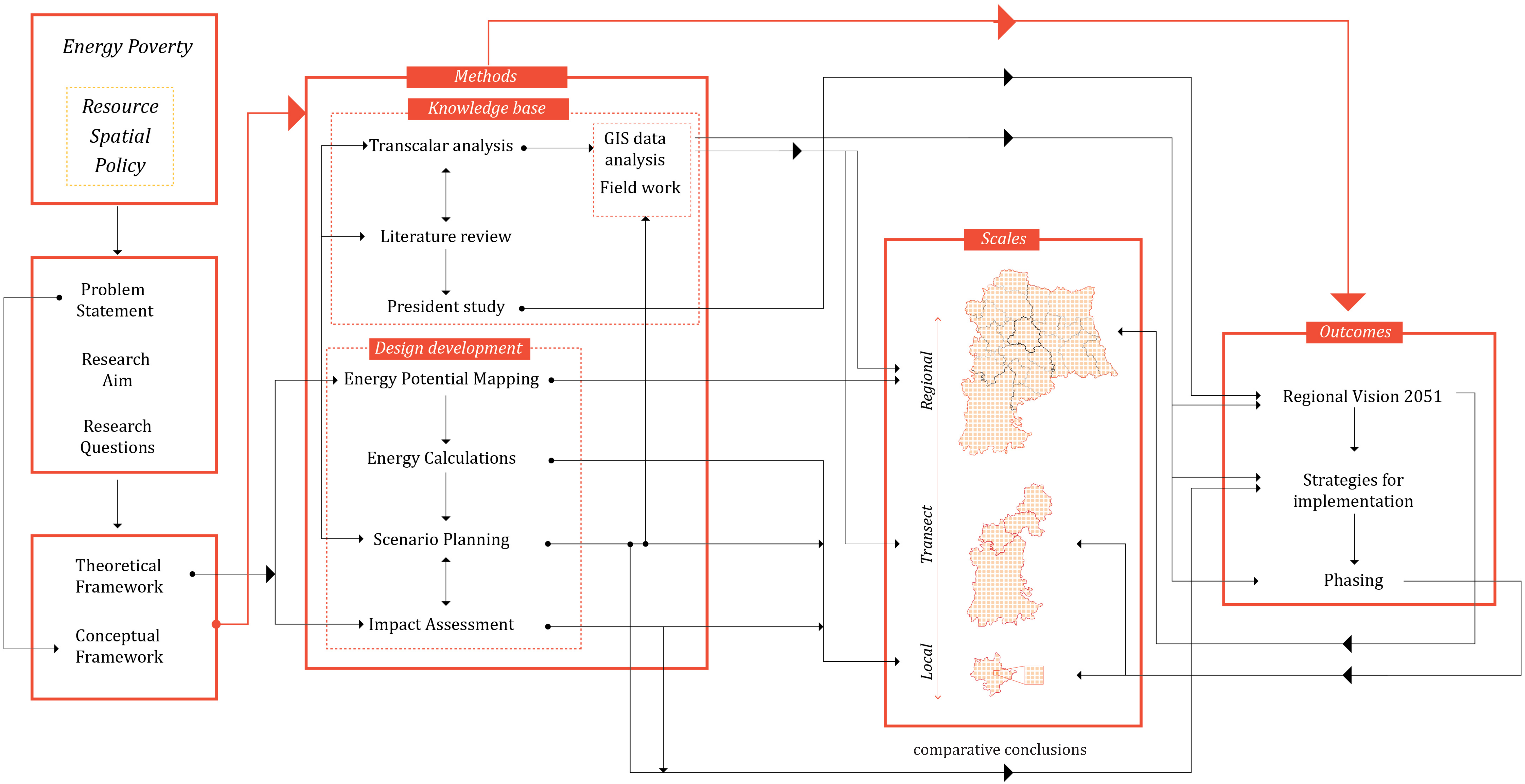
| Conclusions

This chapter studied literature related to the components of energy poverty. The insights gained form the theoretical studies was used to link together the components to create the conceptual framework. The following chapter will present the methodology that is based on the above frameworks.

04

Methodology

4.1 | Research methods and process



The above flow diagram shows the pathway taken in this project. The initial phase of the project involved the formulation of problem focus and research questions from the motivation of addressing energy poverty. Upon adding the framework base of both theory and the conceptual ideas, the design development was elaborated. Steps involved in building the knowledge base and formulating the design development process are explained in detail in the coming sections.

Fig 4.1: Methodology diagram
Source: Author

4.2 | Transcalar Analysis

It is necessary to look at the persistent problem of energy poverty on the national scale to identify the key problems. The focus on the regional scale is multi-layered. Analysing the region using QGIS data and literature reviews gives a picture on the areas that are facing energy vulnerability and an understanding of the overall region and its spatial developments. This scale is important in identifying the energy potentials of the region. Overlaying the outcomes of the regional spatial analysis and energy potentials along with the accessibility to do fieldwork, a transect is chosen. The transect scale is an intermediate scale where a deeper look into the urban-rural systems can be taken. The local scale that is selected from the transect is where the application of scenario planning and energy calculations come into play. Impact assessment of the scenarios on a local scale leads to the development of strategies on the transect and regional scale.

This method aims to provide a proper analysis overlay to fuel the design development process and to see how the outcomes work in different scales. The outcome of the project is focusing on a regional vision, its strategies for implementation and phasing. Here all scales from regional to local scale is addressed.

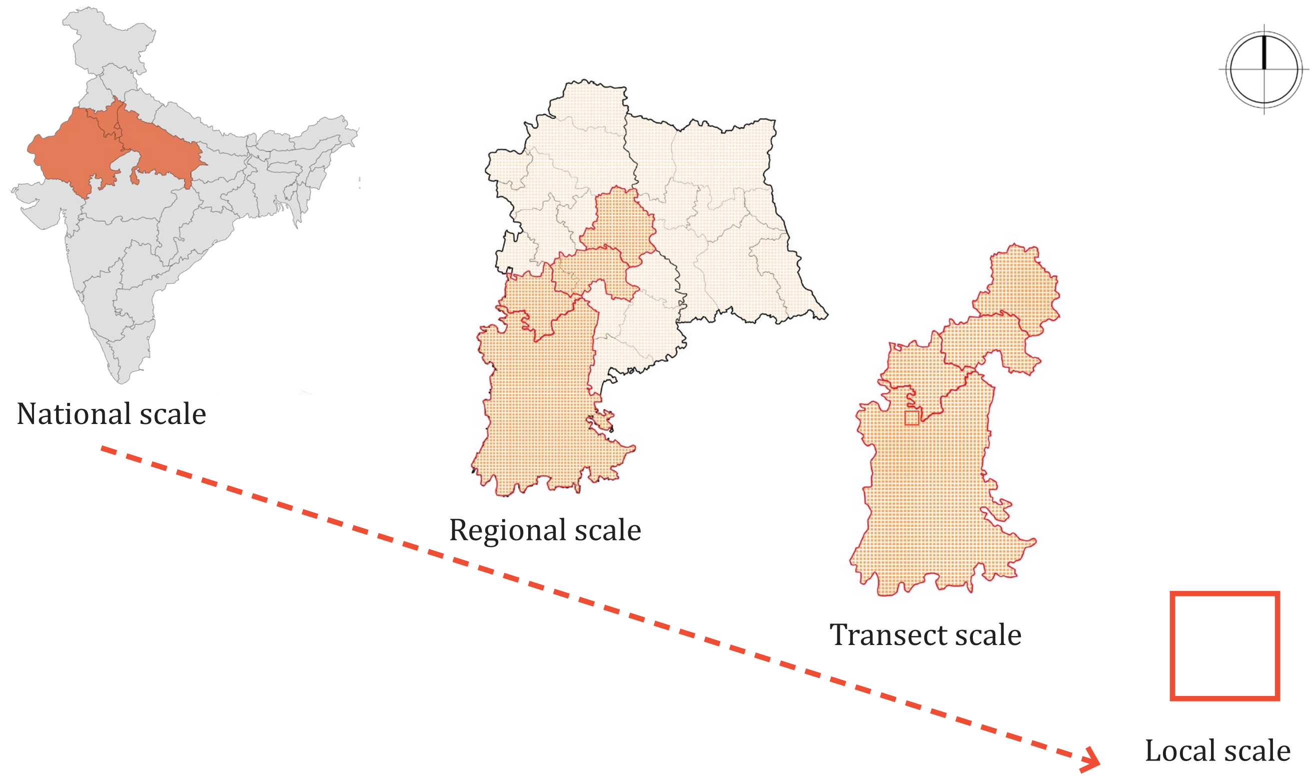


Fig 4.2: Showing scales for transcalar analysis
Source: Author

4.3 | Fieldwork

The field work was conducted in the month of December 2019. The fieldwork involved conducting interviews with various foundations who are involved in sustainable energy, rural electrification, and women empowerment activities. Shakti foundation works in as a guiding consultant for the government in the field of renewable energy. Through them, information regarding the renewable energy transition, barriers faced, and link to governance was discussed. Boond solar and Mr.Keepie foundation are organisations working with rural electrification programs in the NC region. Insights on ground level implementation of solar micro-grids, mobile solar devices, its setting up, process followed and difficulties faced was received from them. SPOWAC shed light on setting up awareness camps, educating the rural villages and ways of empowering women to increase human development in the rural areas.

These insights are the guides to developing deeper understanding of energy poverty and governance, and this influences the final strategies formulated in the project.

BOOND SOLAR

SHAKTI SUSTAINABLE ENERGY FOUNDATION

SOCIETY FOR THE PROMOTION OF WOMEN AND CHILD WELFARE S.P.O.W.A.C.

Mr. Keepi Foundation

Fig 4.3: Interviews with organisations
Source:Author

4.4 | Energy potential mapping and calculations

Satisfying the energy demands of the society by utilising the local area potential is an aspect of circular economy. Channelling this concept, Energy Potential Mapping (EPM) visualises the region's local resource quantity, quality and its ability to meet the local area's demands and supplies (Broersma, Fremouw, & Van Den Dobbelsteen, 2013). This potential is mapped out on the region to understand the "richness" and "poorness" of resources in the various areas (Stremke, Sven ; Dobbelsteen, 2013). This information is valuable when it comes to looking into harnessing energy to meet the energy demands of NCR.

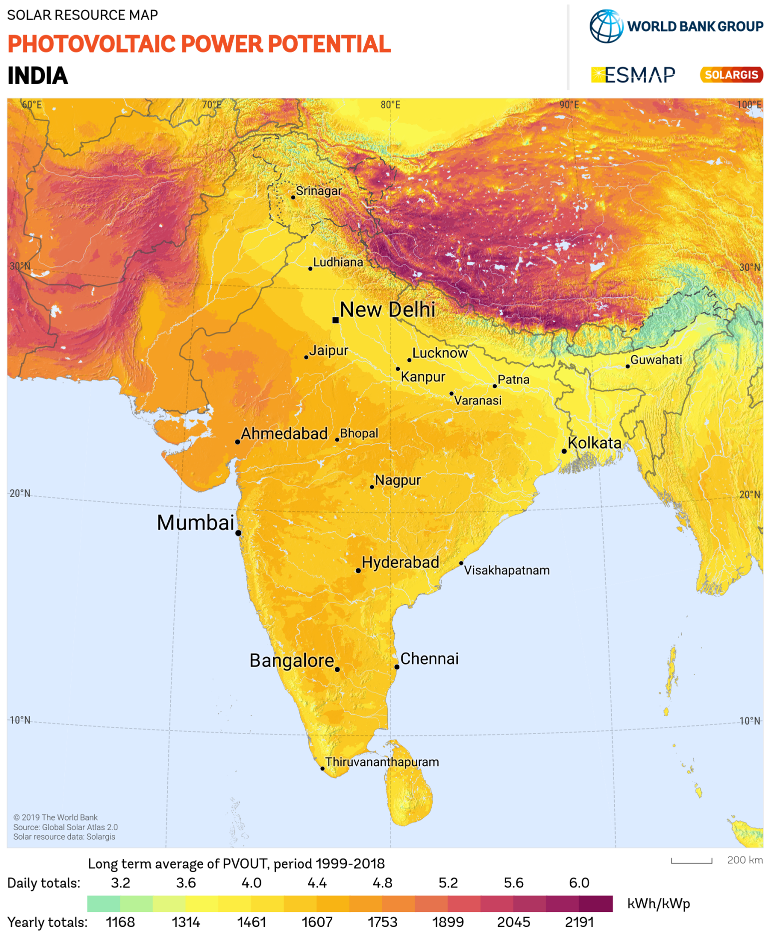


Fig 4.4: Map showing the PV potential power of India.
Source: Global Solar Atlas

| Energy calculations

Looking at the time frame in the future, the energy demands for that time period is to be calculated. To be more specific on the implication of energy on space, energy to area calculations are done. These calculations take into account energy potential of the area, the growth in energy demand and the various energy sources like solar or biomass. These calculations (see appendix)support in the development of scenario planning in the local scale.

4.5 | Scenario planning

The method of scenario planning is used to imagine plausible ways of implementing different energy systems to meet the energy demands and alleviating energy poverty. This strategic planning method is useful in this project to imagine ways in which the energy system can be implemented in a just manner. Every scenario is based on a time frame and here, the projections are made for the year 2051. This is based on census years in India, as the last census year was 2011, next in 2021 and so on.

The determinants for scenarios are based on the various energy systems seen implemented in India and organisation of the energy systems. The first path way for the scenario is the energy mix (non-renewable or renewable). And the second pathway is for the organisation (centralised or decentralised). The NCR region has plans to add more thermal power plants based on coal, at the same time there are projects in southern India like the Kamuthi Solar Power Project which is a centralised solar power station spanning over $10km^2$ of area. Small scale projects involving decentralised renewable energy systems are being set up in rural areas for rural electrification. Combining these conditions, 3 scenarios are set to be explored.

1. 100% Centralised Non-renewable energy system
2. 100% Centralised Renewable energy system
3. 100% Decentralised Renewable energy system

Outcomes of the spatial implications of the scenarios are visualised in maps. Since the project has a research by design approach, the scenarios are mapped out and through impact assessment (explained in the next section) of all scenarios, a comparitive analysis is done. It is based on this analysis that a conclusion that drives the formulation of vision and strategies are made.

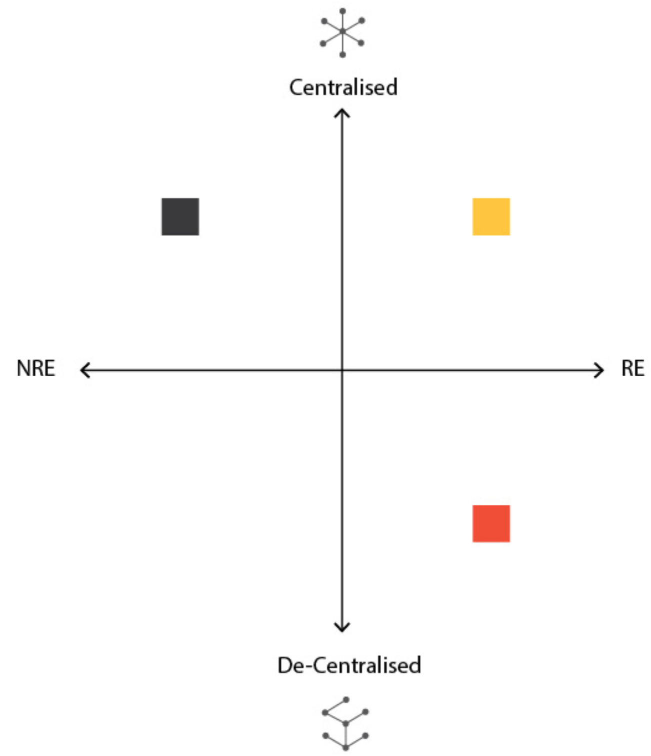


Fig 4.5: Diagram showing the 3 scenarios.
Source:Author

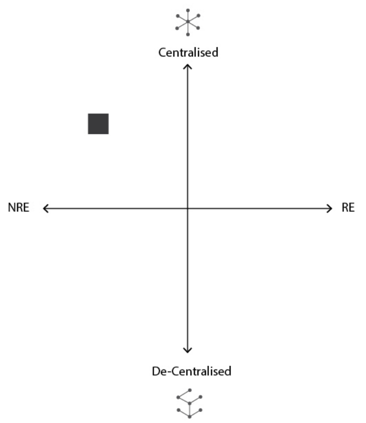


Fig 4.6 : Thermal power plant
Source: www.theweek.in

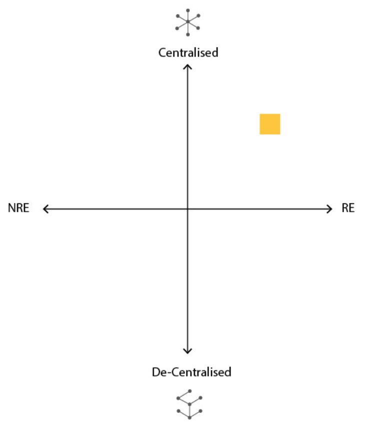


Fig 4.7 : Centralised Solar farm, Tamil Nadu
Source: www. opusmagnagroup. com

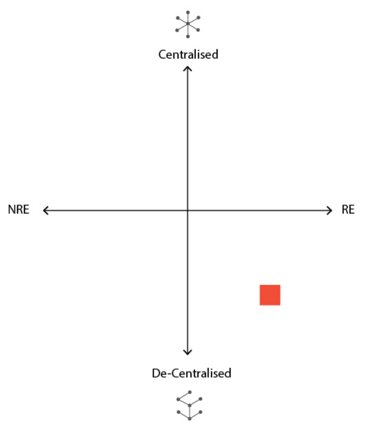


Fig 4.8 : An example of a Decentralised energy system
Source: : www.metabolic.nl

| Impact Assessment

The parameters revolve around linking the 3 components of energy poverty and thinking from a sustainability and circular economy point of view. These aspects are derived from combining the theoretical and conceptual framework. Linking the resource component with spatial component brings the ecological impacts. The spatial component and policy component bring together people living in space and the ways of addressing policies which culminates to form the social impacts. And resource component and policy component brings together addressing the use of energy in an economic perspective and thus forming the economic impacts.

The parameters under each of the impacts are based on the research questions and the analysis made through transcalar analysis, literature review and field work. These impacts are graded to the scenario based on the positive and negative changes it brings to the existing scenario and if they embody aspects of sustainability or circular economy.

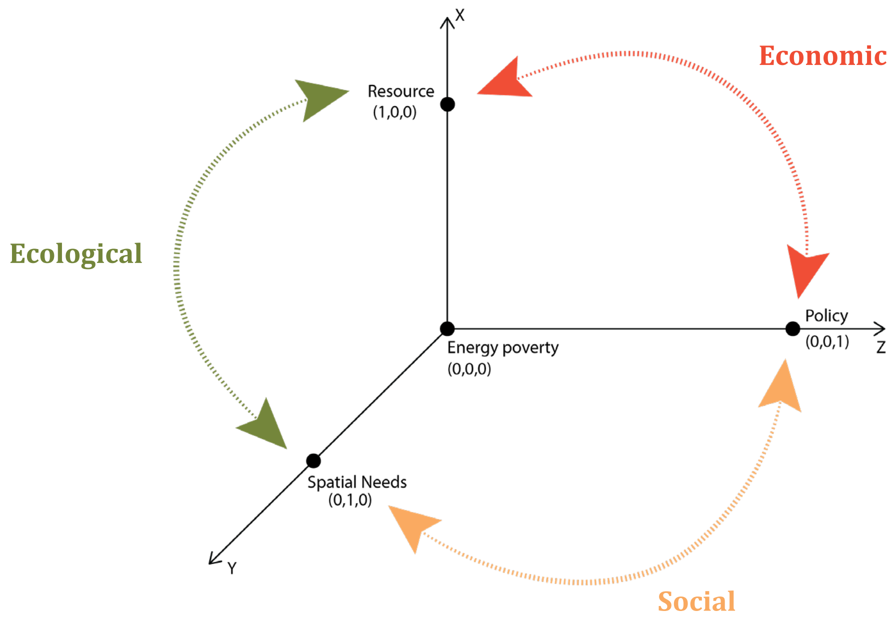


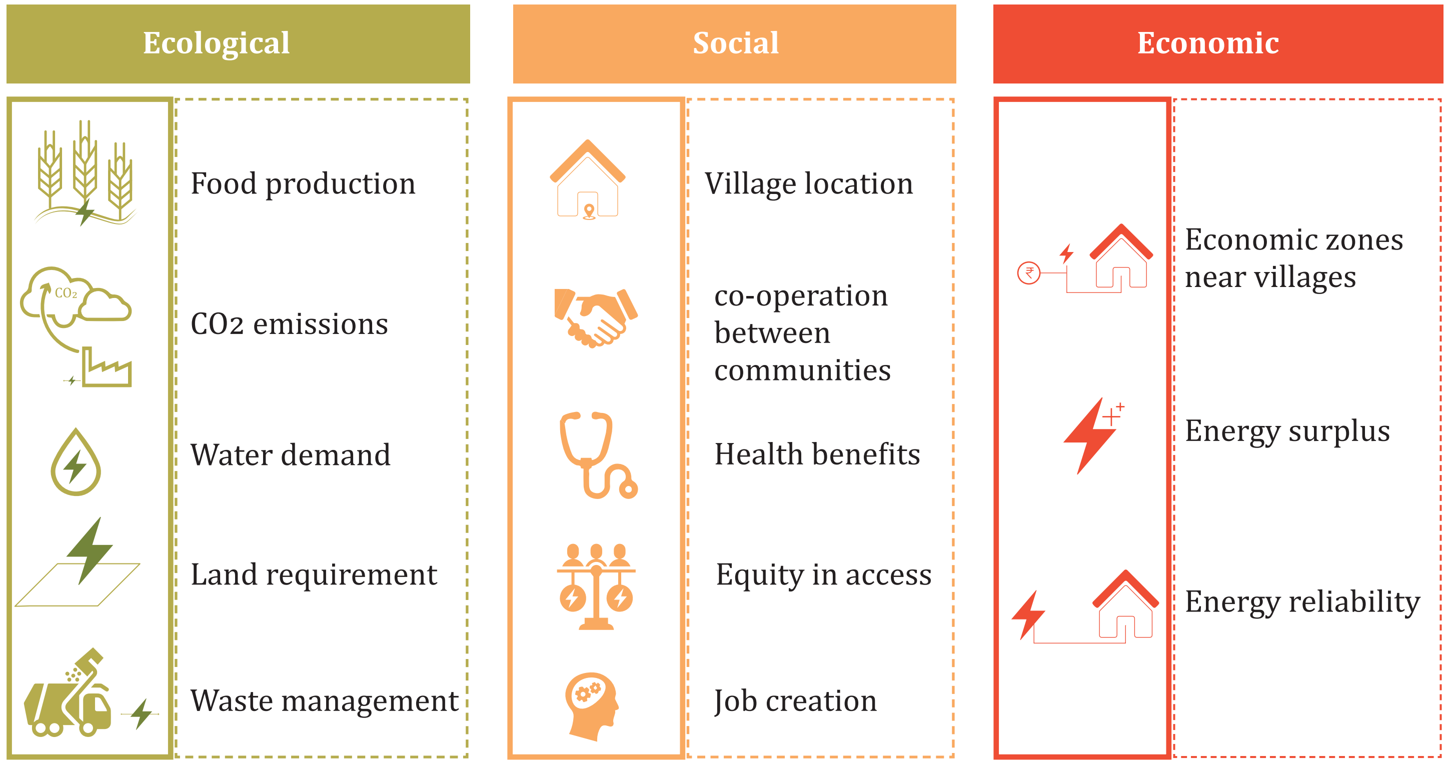
Fig 4.9: Linking the three components of energy poverty.
Source: : Author

The ecological impacts will have focus on the aspects of circular economy like: (a) Preserve and reuse the resources that exist. (b) Resources used as materials and energy are renewable and reusable with non-toxic properties (c) Waste from production and consumption are sources that are either recycled for same resource production or reused for generating secondary resources.

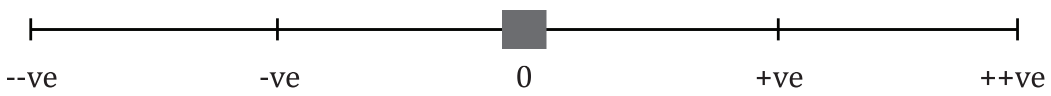
The social impacts will focus on aspects of social sustainability like: (a) Actions are based on the social well-being of the community at large (b) Lifestyle changes in the societies are made to promote responsible consumption of resources and promote better well-being (c) Resources are shared amongst the society in a fair and equal manner as it promotes to better standard of living, reducing social inequality and poverty.

The economic impacts will focus on aspects of economic sustainability like
(a) Economic growth and development are pursued with the need to create jobs, contribute to country's GDP b) Resources used to develop the economy are clean and have the capability of developing the society.

Parameters for impact assessment



Impact assessment grading



Legend

***--ve** : A very negative change and embodies no values of sustainability or circular economy, creating a long-lasting chain of negative events*
***-ve** : A negative change to the existing status quo but embodies one aspect of sustainability or circular economy*
***0** : Has no impact on the existing status quo*
***+ve** : A positive change to the existing status quo and embodies one aspect of circular economy or sustainability*
***++ve** : A very positive change and embodies multiple aspects of sustainability or circular economy.*

4.6| Scientific and Societal Relevance

Scientific relevance

The incentive of the project is to address the problem of energy poverty. This project looks at it from an ecological, social and economic point of view. The social aspect involves the need to study energy flows to ensure access to energy, as this helps provide a better livelihood, possibility of jobs and more. It is also necessary to also think about this from an ecological standpoint. Moving from conventional sources of energy that dominate the energy grids of the world to renewable sources is to reduce the environmental impact.

Hence, this project takes into consideration the spatial needs for an energy transition, and the resilience and efficiency in energy flows. Much of the knowledge has been based on energy transition in cities and often the rural areas are not in the picture. Understanding the flow of energy and designing a means to effectively create strong urban-rural energy networks is missing. Assessing the impacts on other flows like food and water is also critical in adding to the knowledge gap of energy systems and renewable energy transition. Creating strategies that work well with the design will shed light on the socio-technical transition methods. The project will add to the knowledge base of dealing with energy poverty in rural areas, and in areas with similar context and ways of living, like in other urban-rural contexts of the Global South.

Societal relevance

"Energy poverty is both a cause and consequence of poverty" (González-Eguino, 2015). Energy poverty stands in the way of better health, better education, and better jobs. Development experts increasingly agree that there is no way to end extreme poverty without making energy access universal. Alleviating energy poverty also promotes better human and economic development. Additionally, the contribution of energy transition to the UN Sustainability Development Goals (UN SDGs) and the goal of supplying energy for all is an important marker of the societal relevance of this project.

Fig 4.10: Sustainable development goals that are addressed in the project. Source: www.sustainabledevelopment.un.org

05

Regional Exploration

5.1 | The region

The region comprises the National Capital Territory (NCT) Delhi along with 9 districts of Haryana, 6 districts of Uttar Pradesh and 1 district of Rajasthan. The total area of the region is 34,144 km^2 (NCRPB, 2013). The Netherlands is just 1.2 times larger in area than this region.

NCT Delhi has the lowest area percentage at 4.4% of the total region in comparison to the other sub-regions. Haryana sub-region is the highest at 39.3%, Uttar Pradesh at 31.8% and Rajasthan at 24.5% of the total area of the region.

The districts under Haryana include sub-region Faridabad, Jhajjar, Gurgaon, Rewari, Rohtak, Mewat, Sonepat, Palwal and Panipat. The districts under Uttar Pradesh sub-region include Meerut, Gautam Budh Nagar, Baghpat, Ghaziabad, Bulandshahr, Hapur. The district under Rajasthan sub-region include Alwar.

The districts that are closer to the NCT Delhi is seen to have more urbanisation levels, population density and higher human development index and lower multi-poverty index. More details on this insight are explained in the next sections.

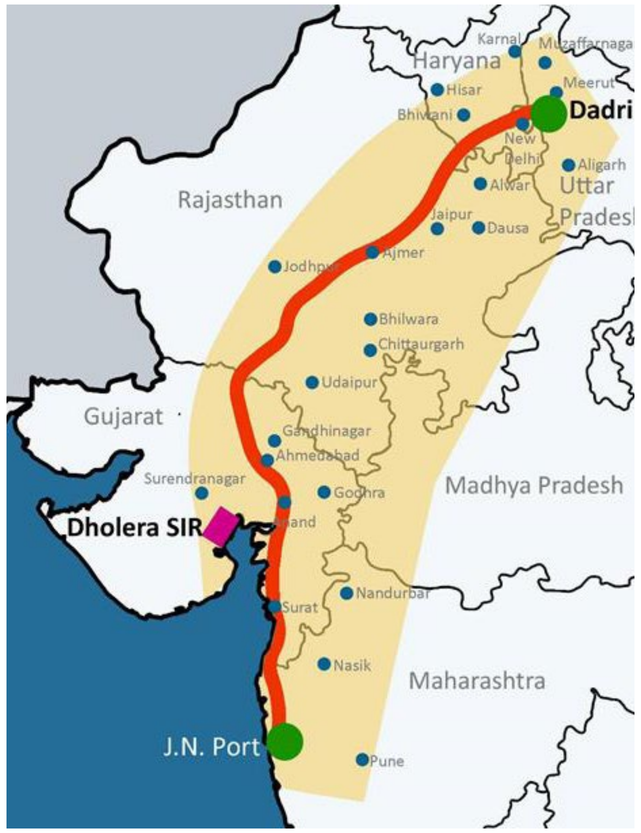


Fig 5.1 : Delhi-Mumbai corridor
Source: : www.dipp.gov.in

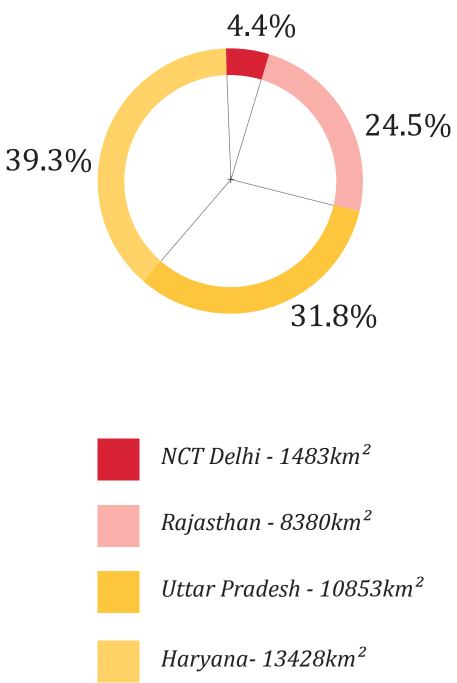


Fig 5.2 : Percentage of land area for each sub-regions in NCR.
Source: : (NCRPB, 2013)

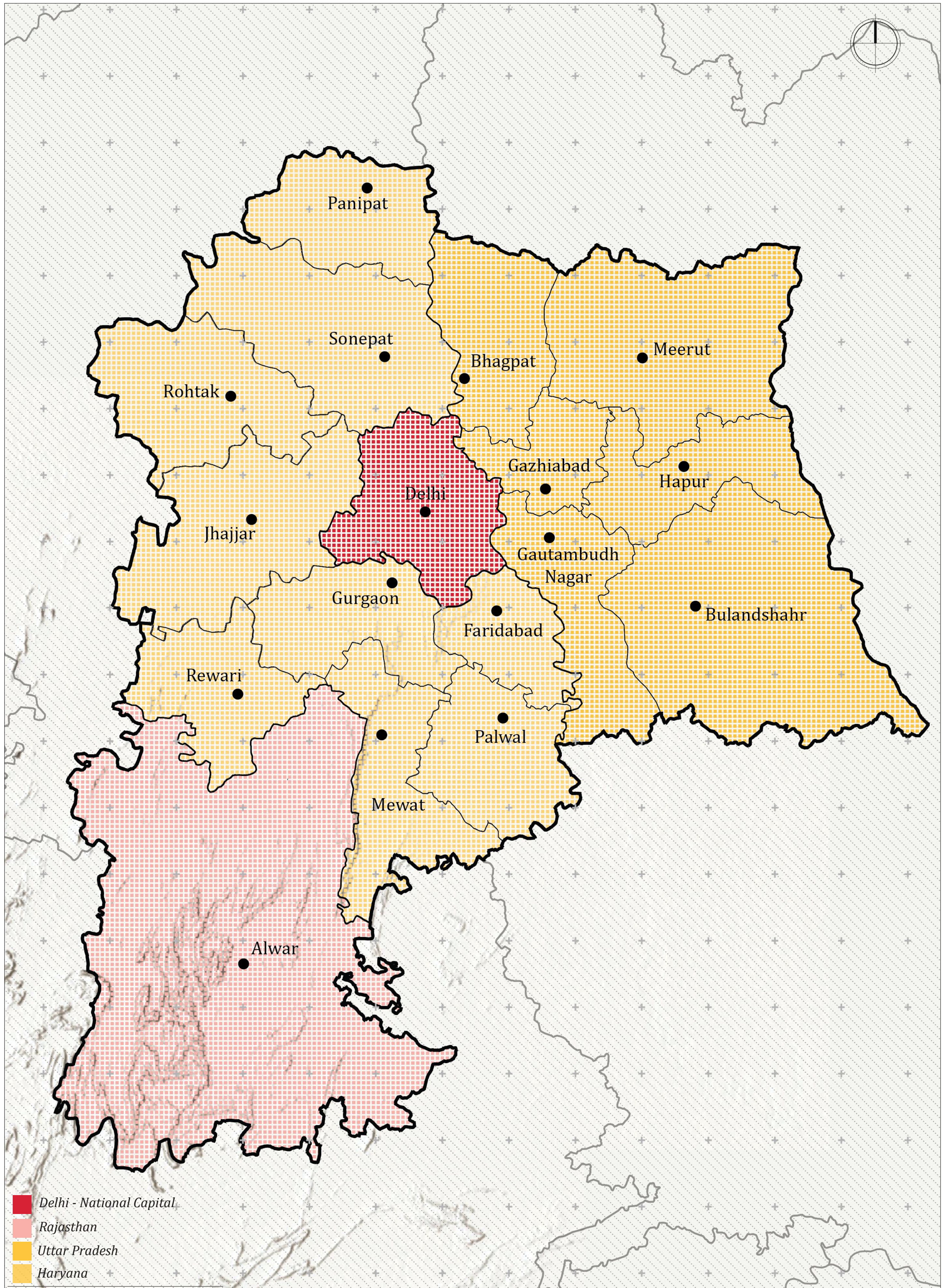


Fig 5.3 : Districts within NC region ; Source: Author; Adapted from NCR regional plan.

5.2 | Energy Vulnerability

The Human Development Index (HDI) is a measure that summarizes the achievements in fundamental dimensions of human development: longevity, education and living standards. Multiple deprivations at the household and individual level in health, education and living standards are recognized by the Multidimensional Poverty Index (MPI). Every individual in a household is classified into two: poor and non-poor. This classification is based on a weighted number that reflects the deprivations in the individual's household (UNDP, 2018).

Combining these two quantities will give rise to the district that is most vulnerable. State wise data on the households with access to electricity, will help to find areas that could to susceptible to energy poverty. It can be concluded that the sub-region of Rajasthan and Uttar Pradesh are more likely to be vulnerable to energy poverty and have low standards of living. The number of households electrified in these regions also confirm the injustice in access to energy.

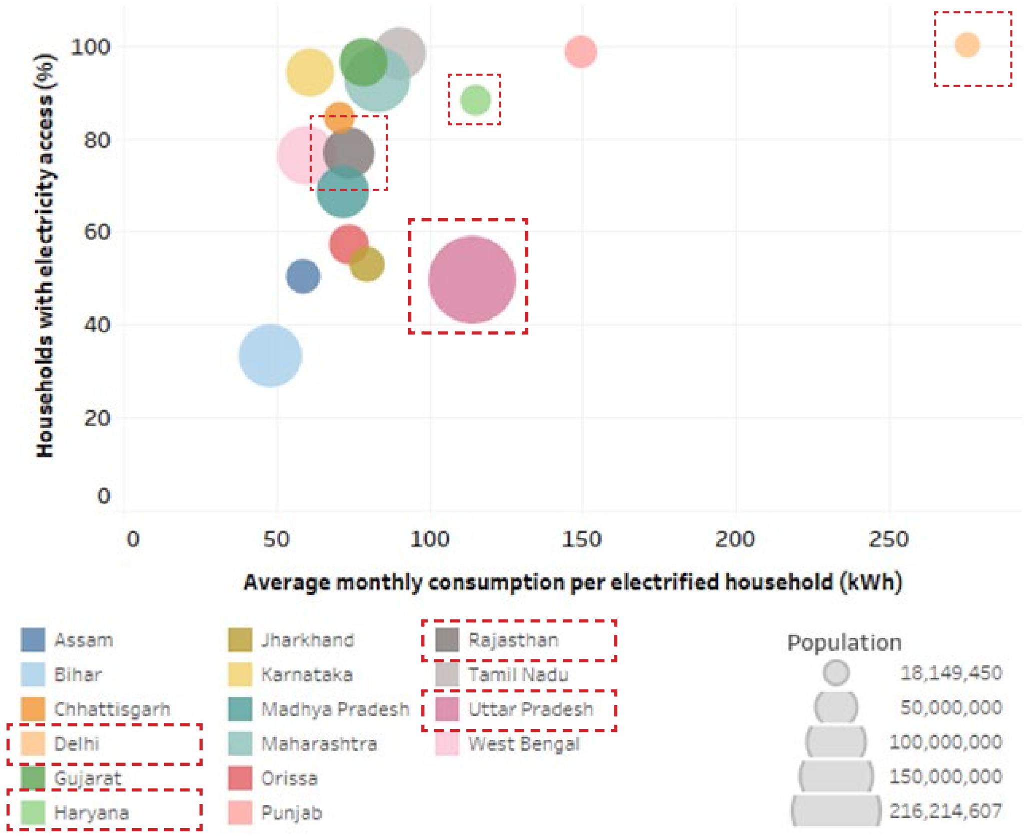


Fig 5.4 : Household access and average monthly consumption per electrified households, 2017. Source: https://www.cprindia.org

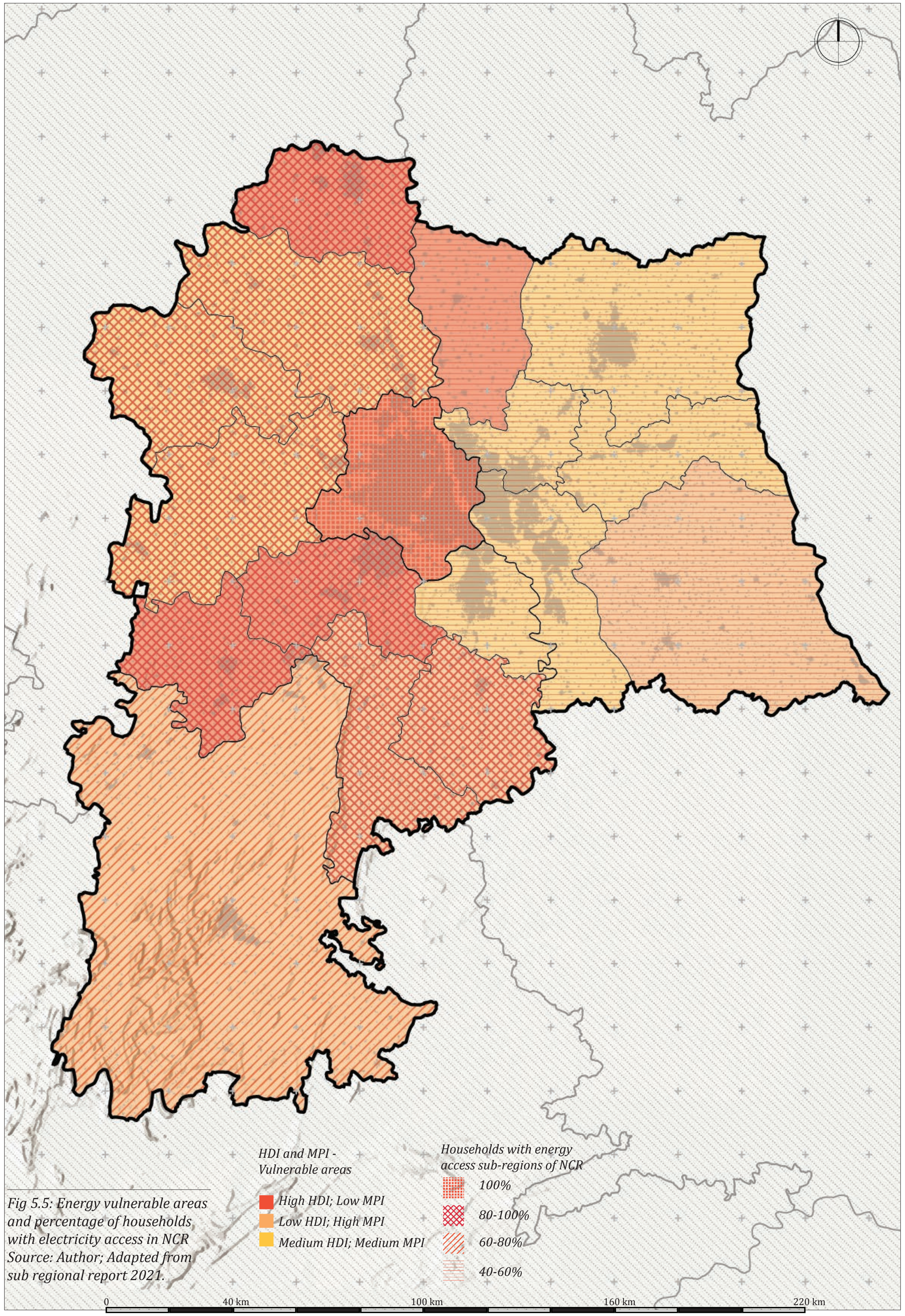
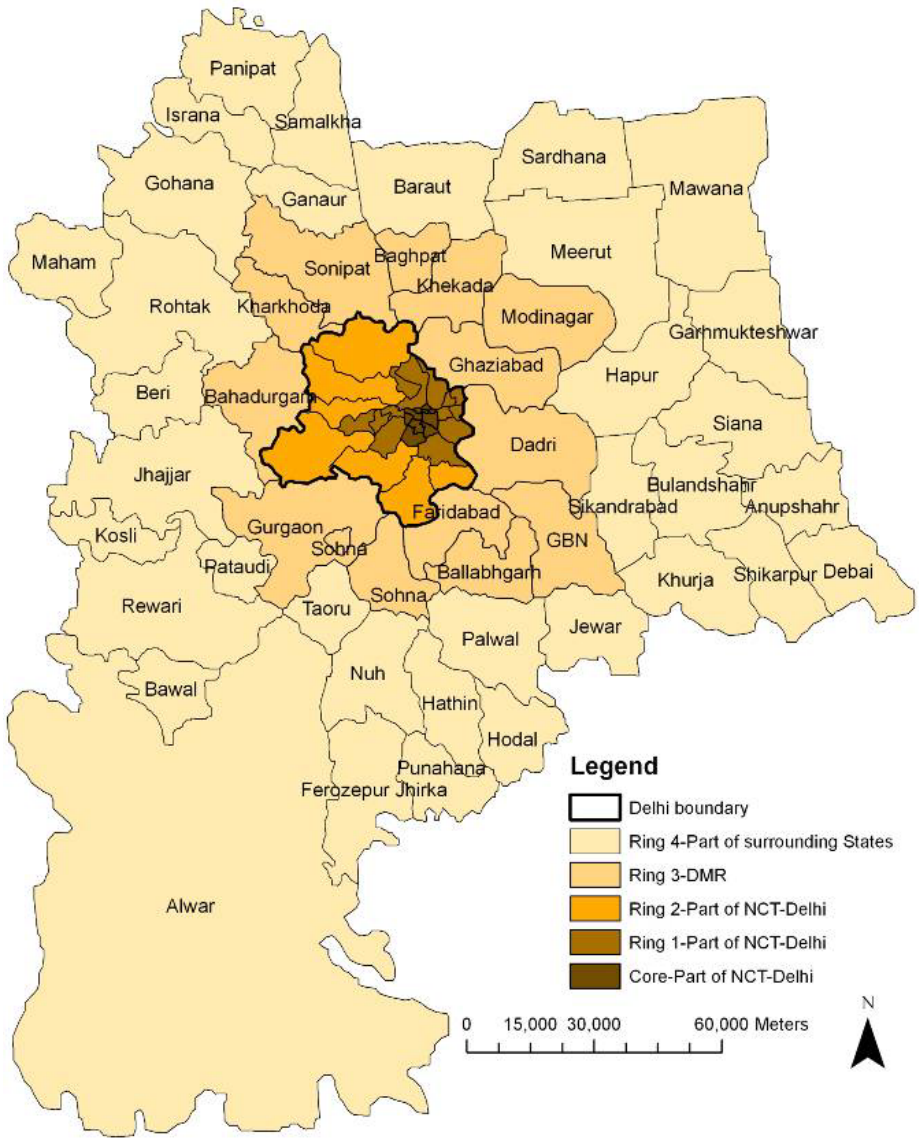


Fig 5.5: Energy vulnerable areas and percentage of households with electricity access in NCR Source: Author; Adapted from sub regional report 2021.

5.3 | Spatial analysis

Urban amenities are mostly always available at the higher-tier centres. Hence, to utilize the amenities to the maximum, the population concentrates in urban centres. The hindrance of growth in the lower-tier settlement is caused by the reduced access to urban service and decrease in agglomeration of economies (Jain, Knieling, & Taubenböck, 2015).

This map indicates that towards the southern part of NCR is prone to have lesser access to services due to its distance from Delhi. The areas also experience lower economic development and suffer from energy poverty or frequent energy shortage.



	Core	Ring 1	Ring 2	Ring 3	Agglomeration	Ring 4
1971-81	+	++	++	+++	++	+
1981-91	-	+	++	++	++	+
1991-2001	--	++	++	++	++	+

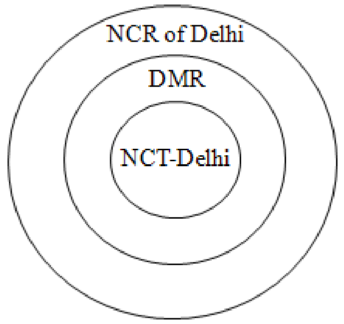


Figure 5.6: Map indicating that the development is weaker and slower in the areas situated away from the urban centre.

(Source: Census of India and German Remote Sensing Data Center)

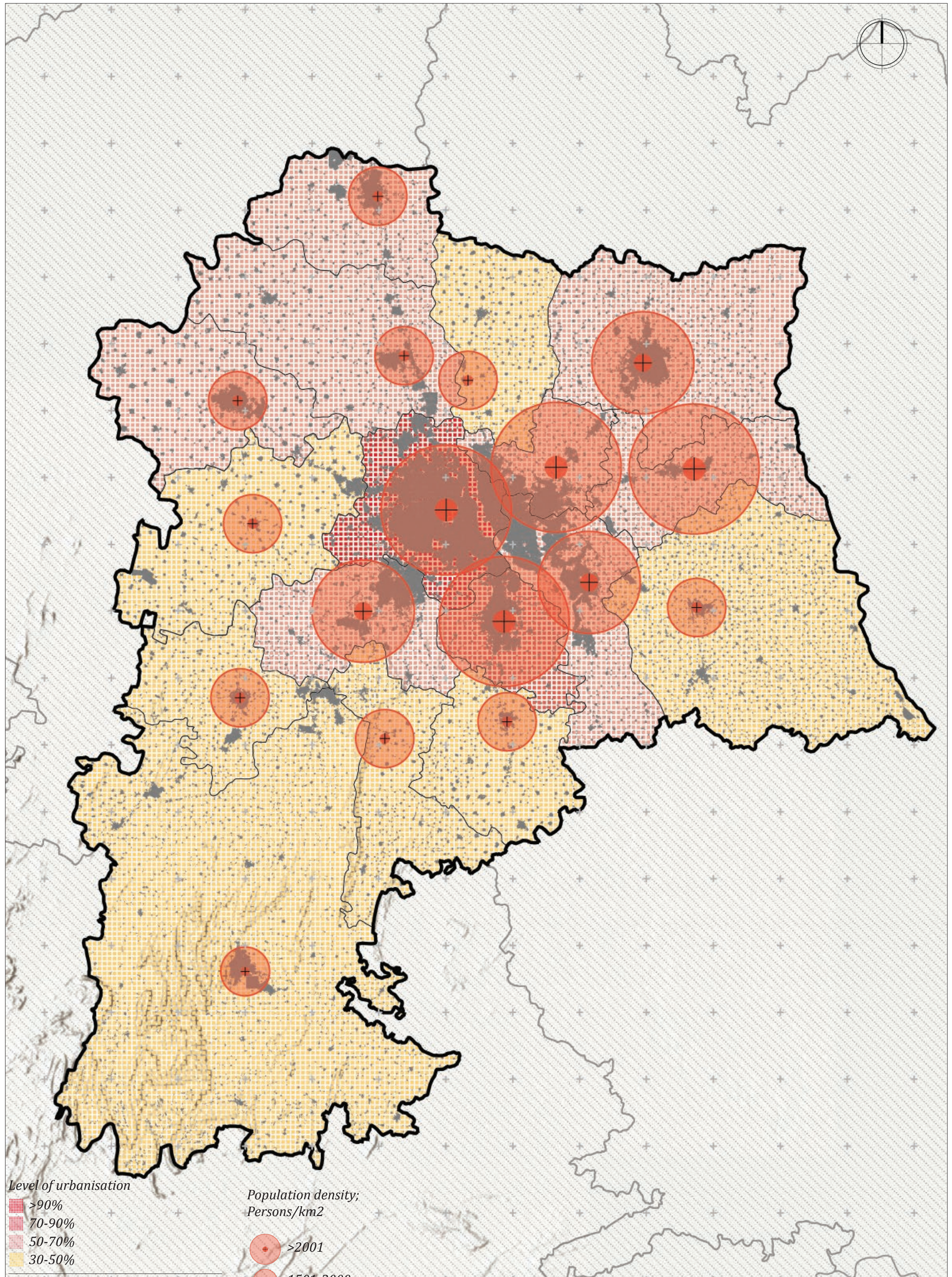


Fig 5.7 : Population density and urbanisation levels in NCR
Source: Author; Adapted from NCR regional plan.

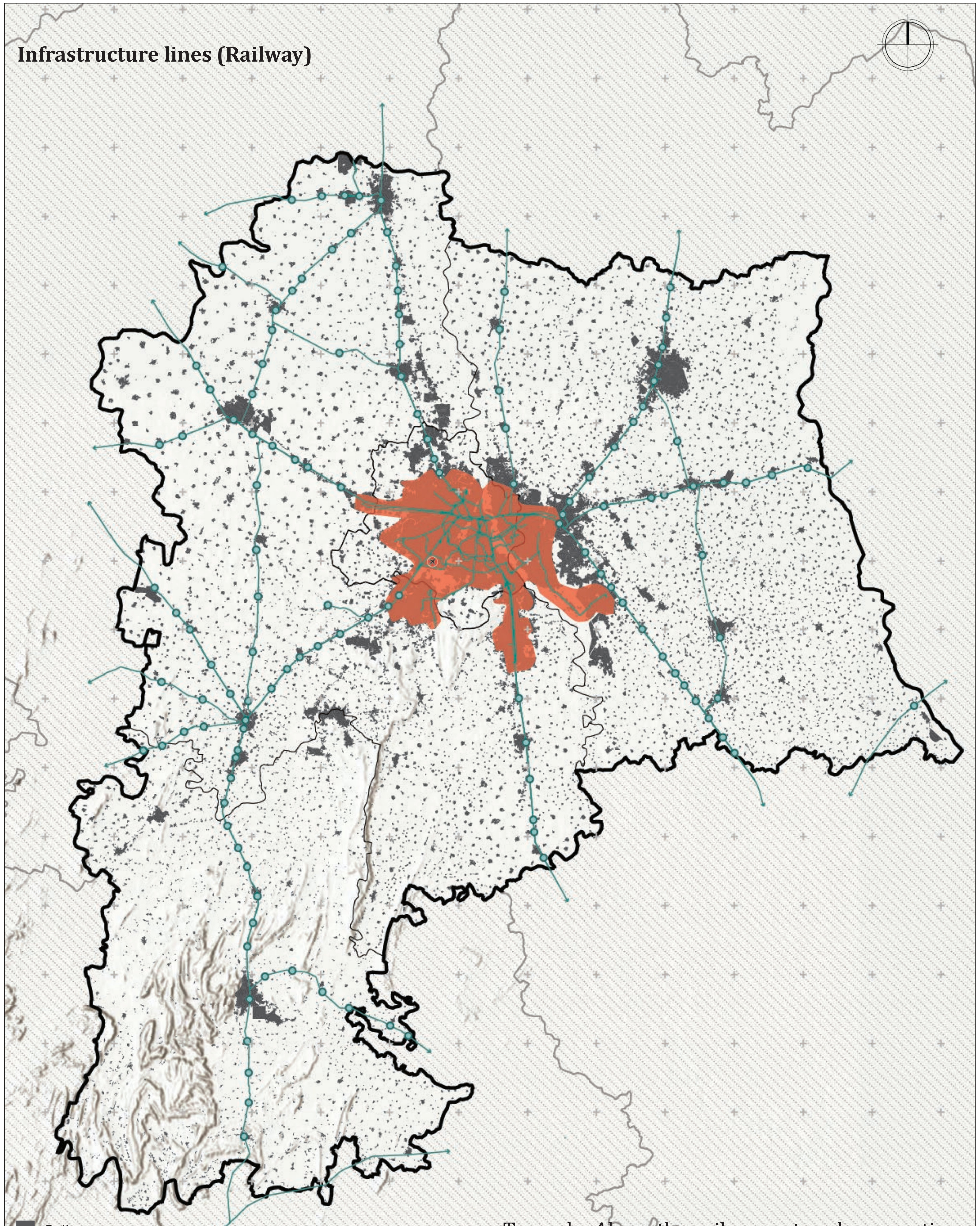


Fig 5.8 : Primary roadways
Source: Open source GIS

Towards, Alwar the railway network connections are less dense. Railway infrastructure is one of the primary modes of transport for people in rural areas to go to cities. Lesser infrastructure developments can also indicate the lower levels of development.

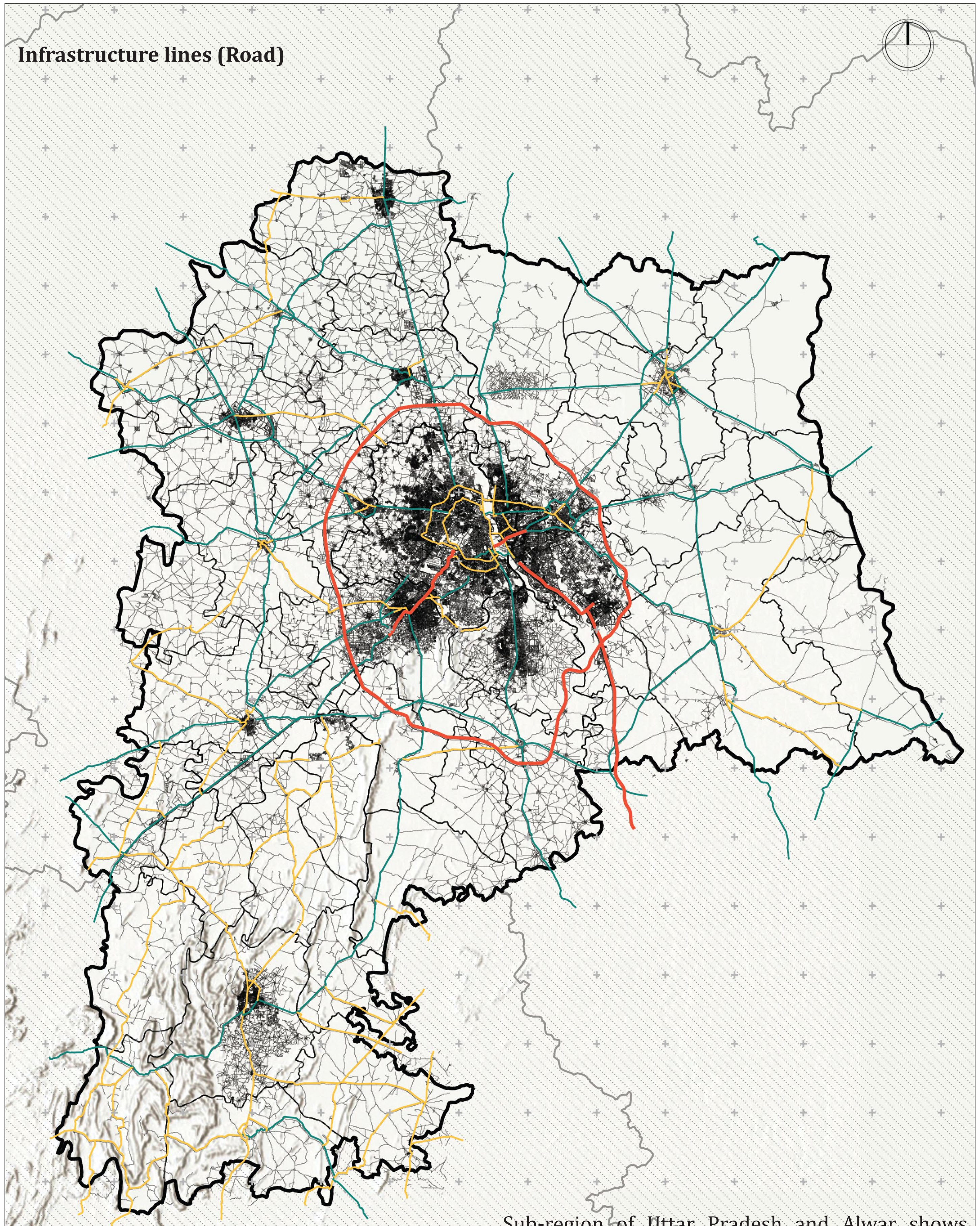
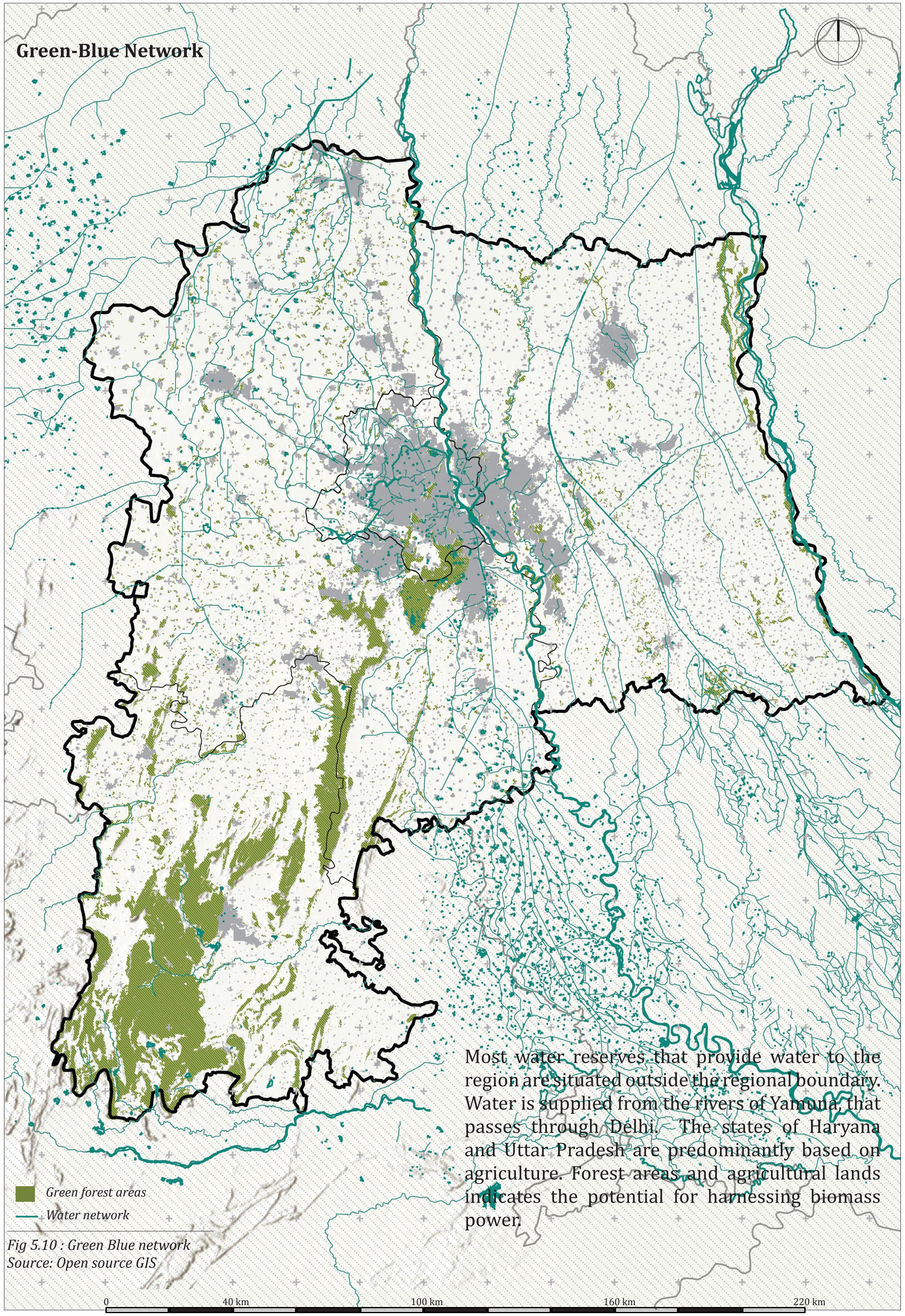


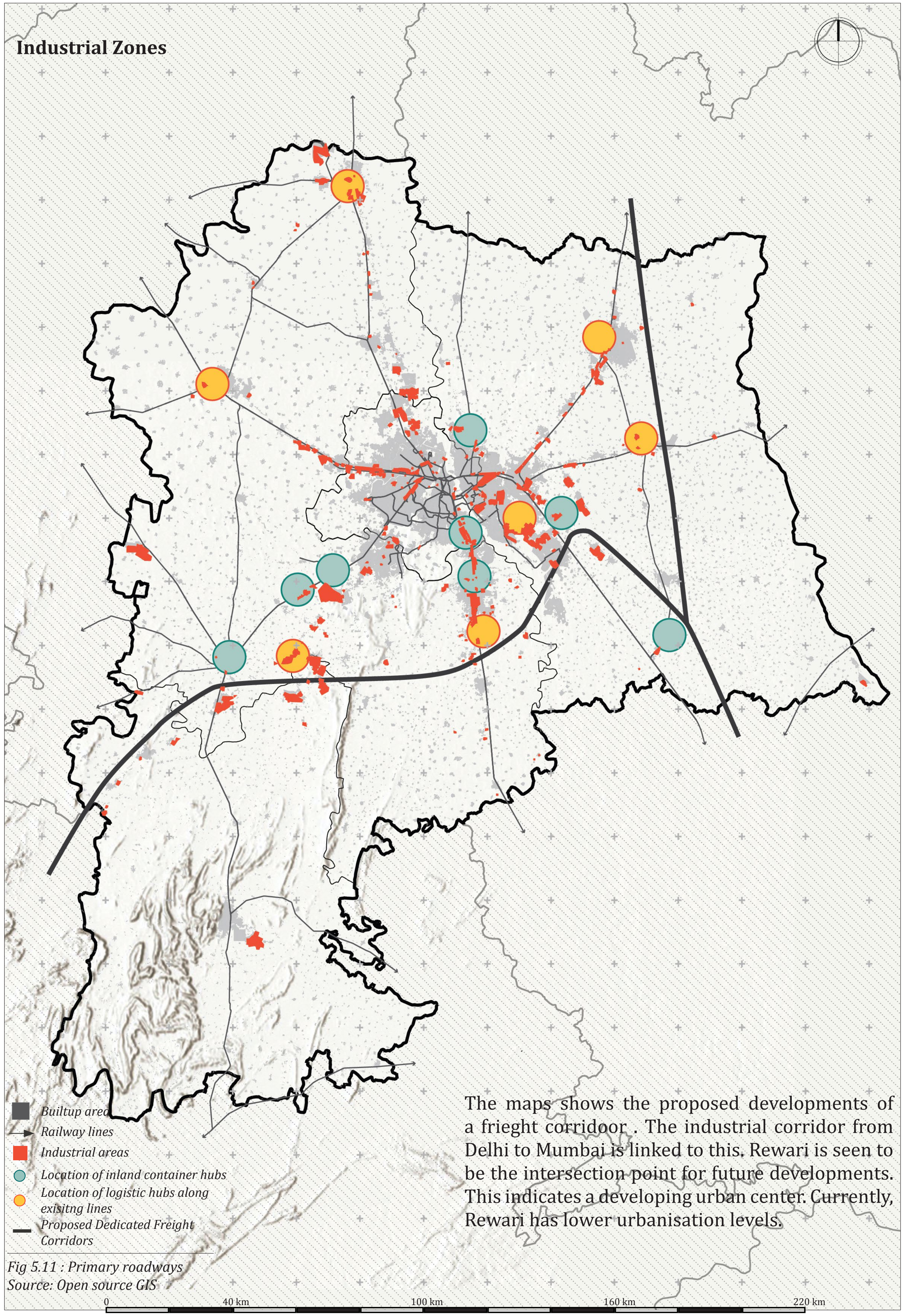
Fig5.9 : Primary roadways
Source: Open source GIS

Sub-region of Uttar Pradesh and Alwar shows relatively lesser number of road links through the rural village areas. This is seen more towards the region of Uttar Pradesh. Lack of proper infrastructure lines towards rural areas is an indication of urban-rural divide.



Most water reserves that provide water to the region are situated outside the regional boundary. Water is supplied from the rivers of Yamuna, that passes through Delhi. The states of Haryana and Uttar Pradesh are predominantly based on agriculture. Forest areas and agricultural lands indicates the potential for harnessing biomass power.

Fig 5.10 : Green Blue network
Source: Open source GIS



The maps shows the proposed developments of a frieght corridoor . The industrial corridor from Delhi to Mumbai is linked to this. Rewari is seen to be the intersection point for future developments. This indicates a developing urban center. Currently, Rewari has lower urbanisation levels.

Fig 5.11 : Primary roadways
Source: Open source GIS

5.4 | Conclusions

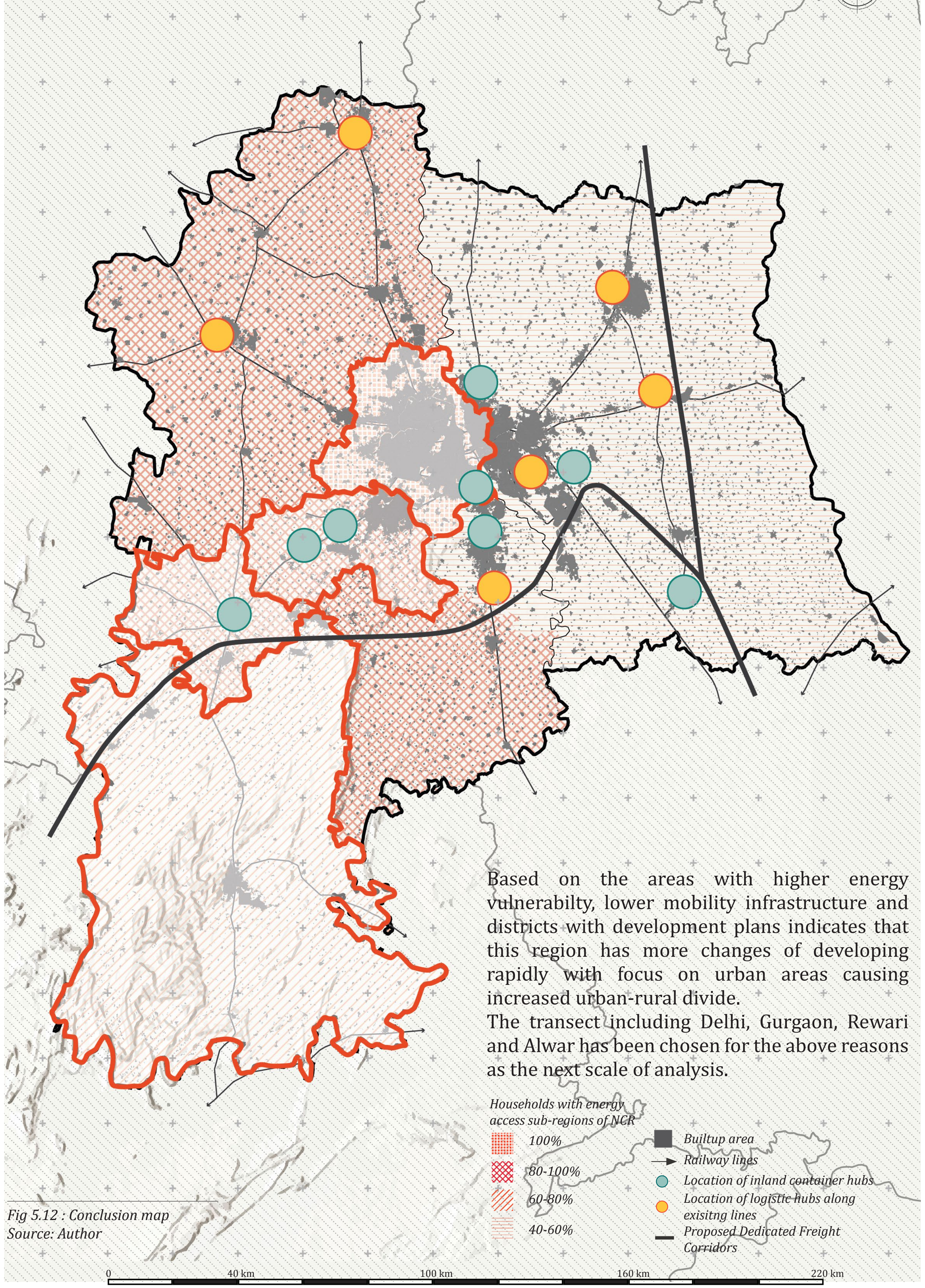


Fig 5.12 : Conclusion map
Source: Author

Based on the areas with higher energy vulnerabilty, lower mobility infrastructure and districts with development plans indicates that this region has more changes of developing rapidly with focus on urban areas causing increased urban-rural divide.

The transect including Delhi, Gurgaon, Rewari and Alwar has been chosen for the above reasons as the next scale of analysis.

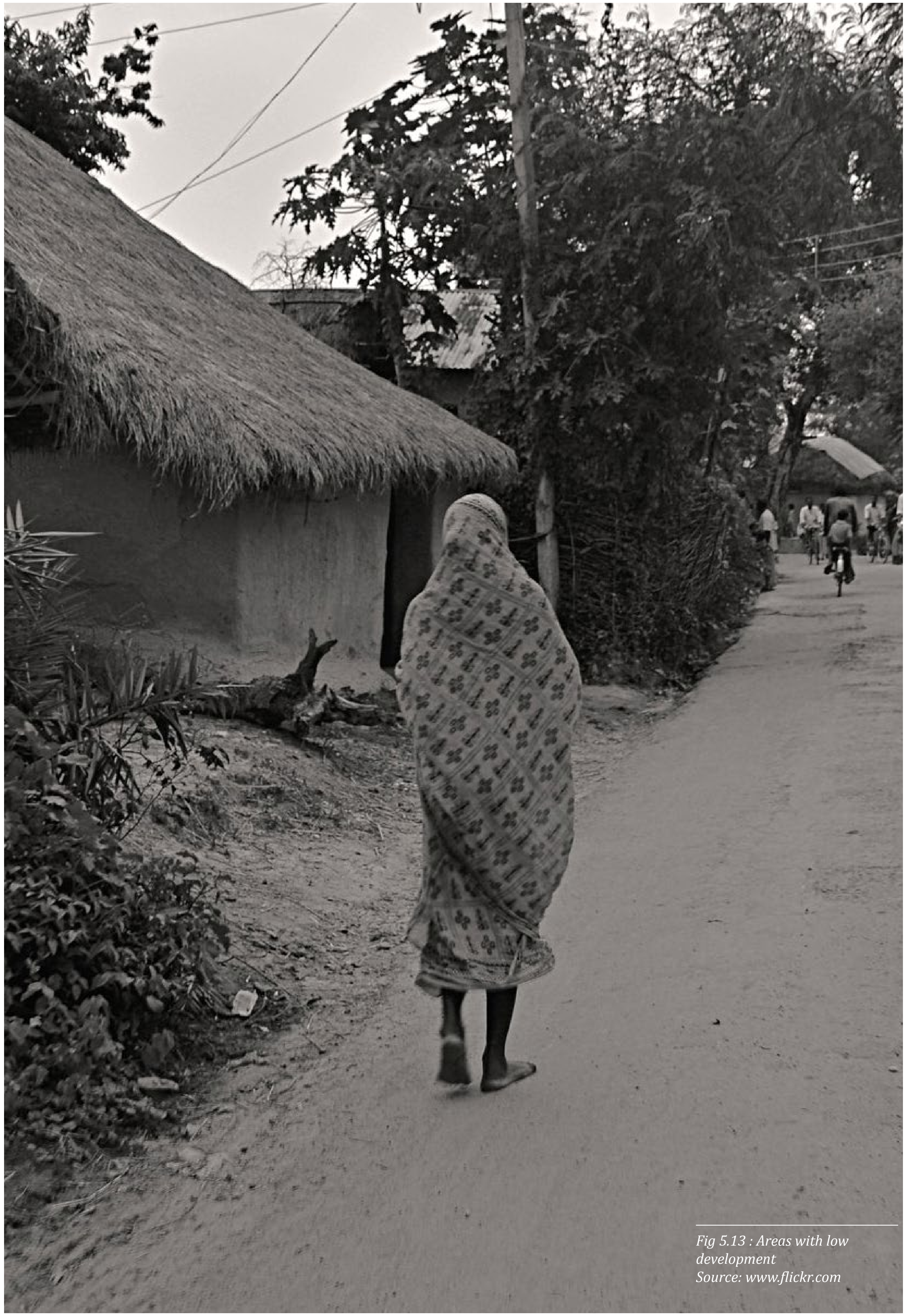


Fig 5.13 : Areas with low development
Source: www.flickr.com

06

Regional energy potential mapping

6.1 | Energy demands

India's ambitious energy goal is to around 40% non-fossil based energy in the energy mix by 2030's conditional targets (Climate action tracker, 2020) . However, electricity has become a necessary commodity in our lives and access to affordable, reliable and quality electricity for all households should be ensured while considering the inclusive growth. The NCR experiences frequent power cuts due to an overall shortage in the northern power grid from where the region draws its power, which severely disturbs daily life as well as affects the economic productivity in the region. Alleviating energy poverty also means more electricity demand (NCRB, 2013).

Around 13 power projects are planned for meeting the demands of the region, these are state and private sector projects are under discussion for commisioning to start power generation. This chapter looks into the energy potentials in the region and generate an understanding on the relation between energy and space. The regional map has been overlayed with a 10km x 10km grid to have more precise analysis when it comes to application at the local scale.

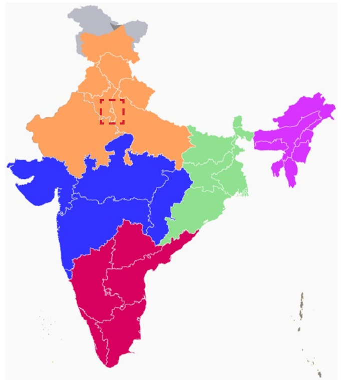


Fig 6.1: Map showing the different power grid zones. NCR is powered by the northen grid. Source: www.wikipedia.org

Year	National Consumption (GWh)	Delhi Consumption (GWh)	Delhi Population (millions)	Delhi Per-Capita Consumption (in kWh)
1947	4,182	125		
1950	5,610	168	13,69,000	123
1956	10,150	305	18,72,000	163
1961	16,804	504	23,94,000	211
1966	30,455	914	29,71,000	308
1974	55,557	1,667	42,36,000	393
1979	84,005	2,520	53,35,000	472
1985	1,24,569	3,737	72,26,000	517
1990	1,95,098	5,853	93,84,000	624
1997	3,15,294	9,459	134,51,000	703
2002	3,74,670	11,240	169,56,000	663
2007	5,25,672	15,770	199,46,000	791
2012	7,85,194	23,556	234,64,000	1,004
2013	8,24,301	24,729	242,39,000	1,020
2014	8,81,562	26,447	250,39,000	1,056
2015	9,38,823	28,165	258,66,000	1,089
2016	10,01,191	30,036	267,20,000	1,124
2017	10,66,268	31,988	276,02,000	1,159
2018	11,30,244	33,907	285,14,000	1,189
2019	11,96,309	35,889	293,99,000	1,221

Fig 6.2: Increase in consumption rate in Delhi. Source: https://populationstat.com and energy statistics report, 2018

Fig 6.3: Transmission lines across fields. Source: Public domain

6.2 | Energy and space

The space required for non-renewable energy production is 100-1000 times less than renewable energy production. The reason being fossil fuels has higher power density than RE. W/m^2 is the amount of power produced per meter square of land, also called the power density (Smil, 2015) (Fig 6.4). By looking at various forms of power generation, an idea can be formed on how much space will be utilised. This is essential when it comes to spatially locating RE production zones in the NCR. This also means that transitioning into RE systems will be more spatially demanding, hence integrating this in a spatially just manner is necessary (Fig 6.6).

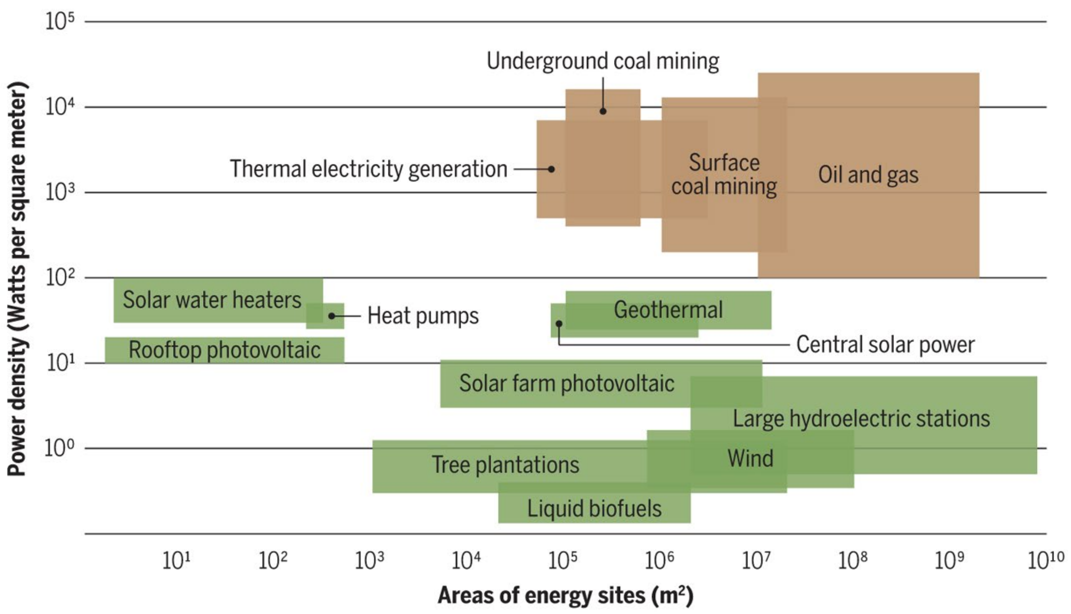


Fig 6.4: Power density vs area of energy sites
Source: (Smil, 2015)

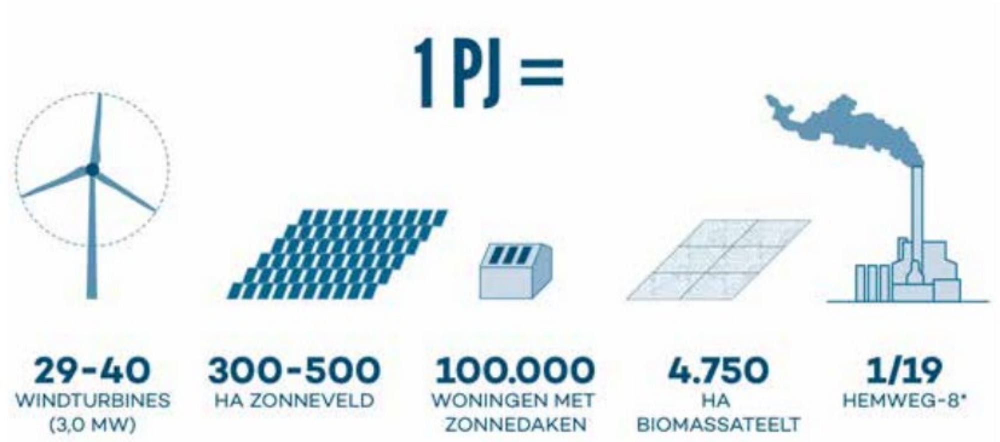


Fig 6.5: Spatial footprint left by energy sources
Source: Posad report, 2018

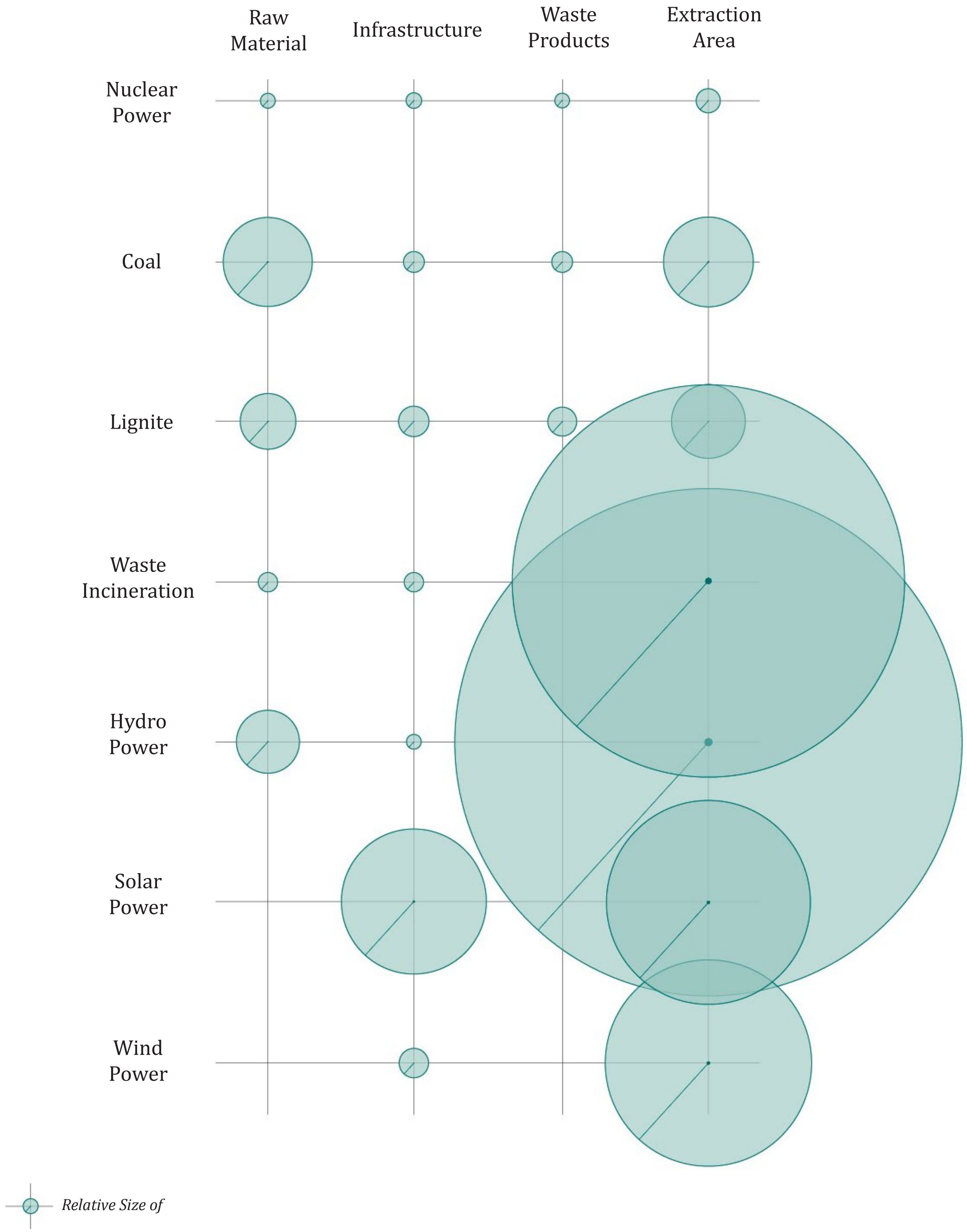
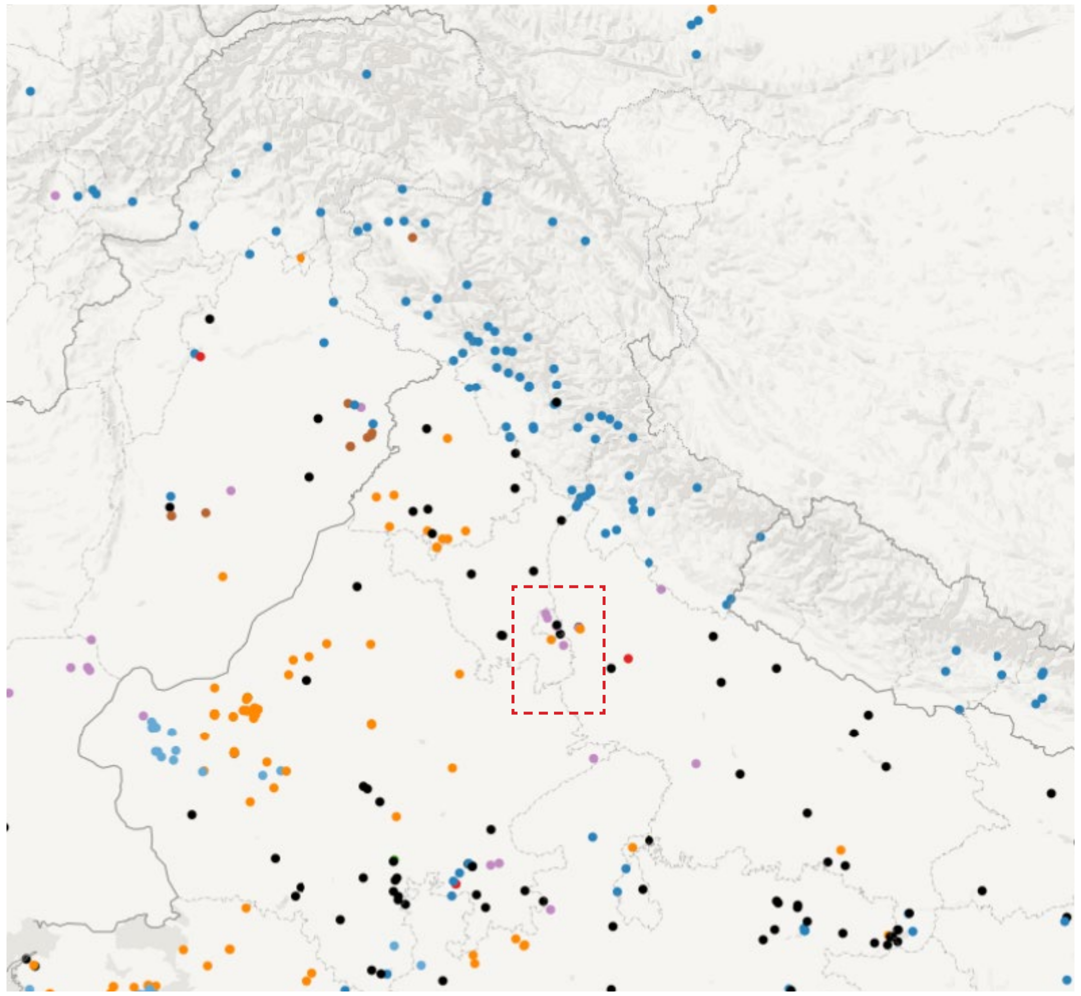


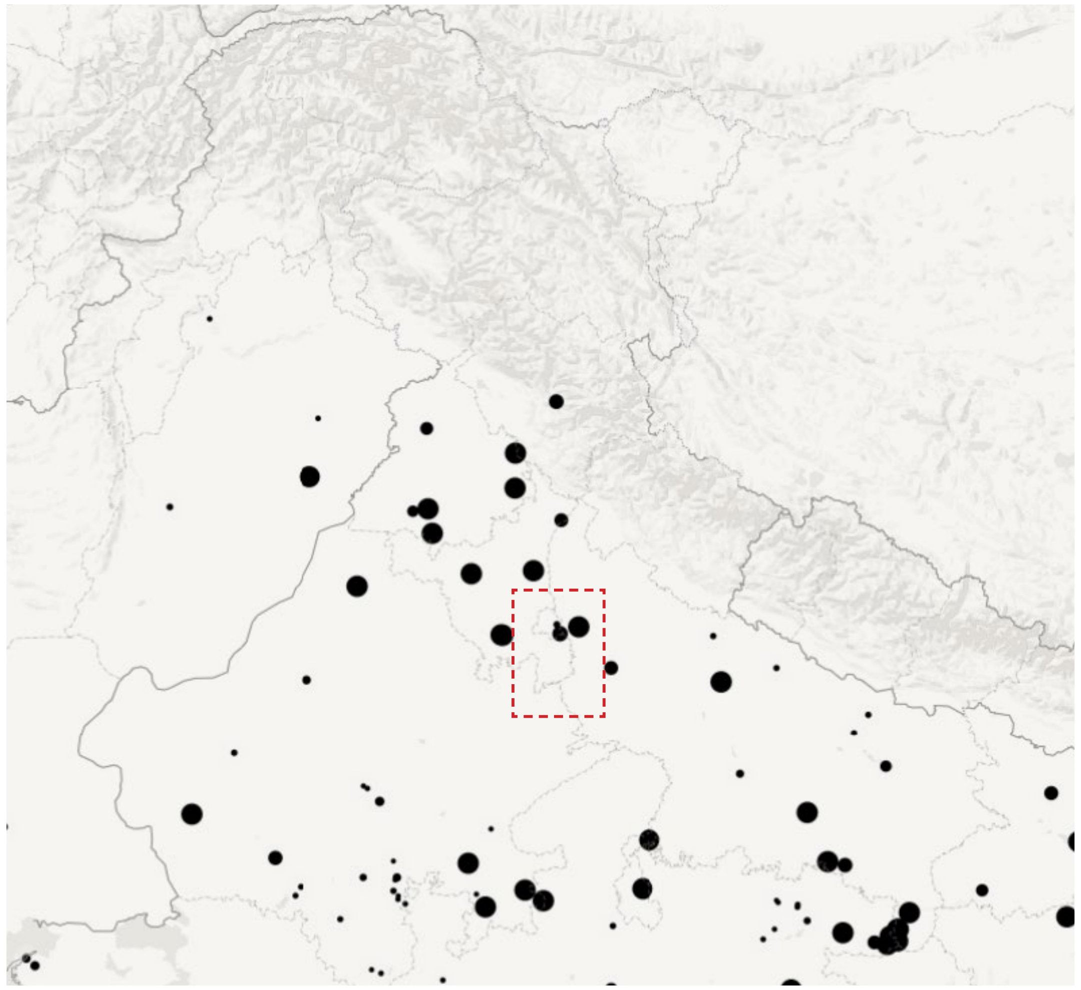
Fig 6.6: Spatial Footprint of energy sources; their extraction and generation areas to produce energy for meeting targetted demands.
Source: Adapted from Sijmons,2014

As seen area required for growing biomass crops is much larger than the biomass plant infrastructure. The infrastructure space required is lesser than a coal plant. Laying out solar farms also take up a lot of area. This can cause the problems like energy vs food production or cause relocation of rural villages to set up these such solar fields.



Coal
Oil
Gas
Hydro
Nuclear
Solar
Waste
Wind
Geothermal
Biomass

Fig 6.7: Map showing types of power plants in the northern region.
The red box marks the NCR region
Source: https://resourcewatch.org/



Coal Power Plants by Capacity (MW)

Capacity (1MW-740MW)

Fig 6.8: Map showing the coal power plants in the northern region
The red box marks the NCR region
Source: https://resourcewatch.org/

Fig 6.9: Map showing the solar power plants in the northern region
The red box marks the NCR region
Source: https://resourcewatch.org/

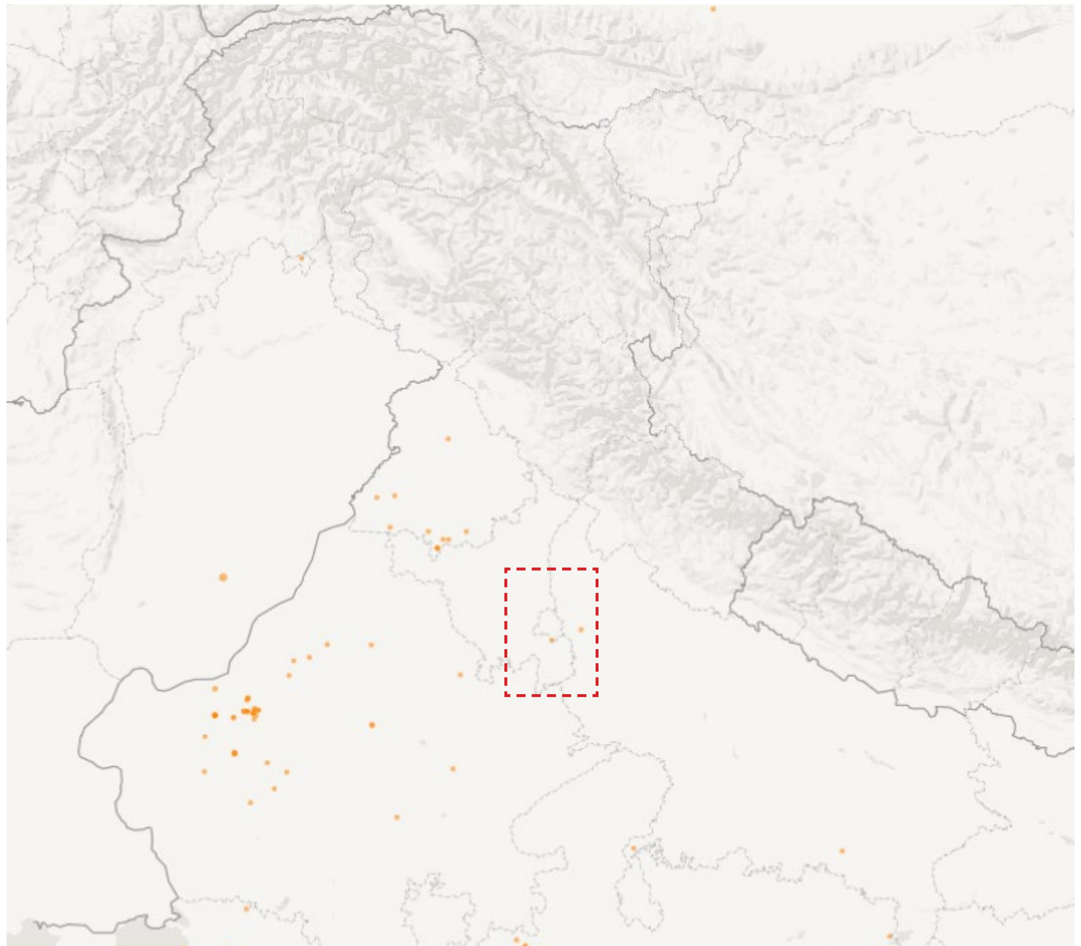
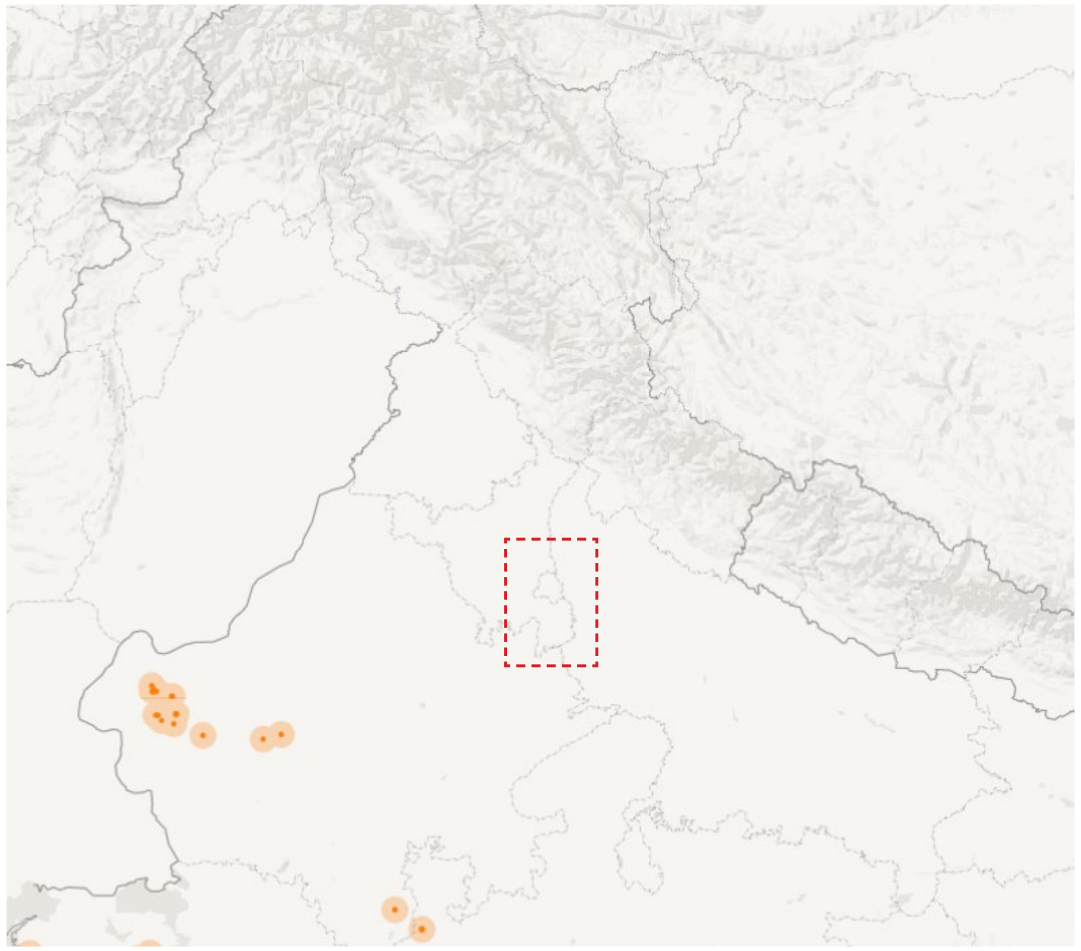


Fig 6.10: Map showing wind power areas
The red box marks the NCR region.
Source: https://resourcewatch.org/



6.3 | Renewable energy potential

| Solar potential

The region receives over 300 days of sun and the NCR has a huge potential for setting up PV panels on roofs or as solar farms or as micro-grids (Fig 6.11). The map shows a range of annual solar power potential from 4-5 kWh/m^2/day (Fig 6.12). The solar potential can be harnessed to help meet the energy demands and also promotes to the development of renewable power. Using storage facilities, the month's were surplus energy is generated can be stored and used when production is low.

Solar technology is no longer in its infant stage. Leapfrogging of technologies can allow for more efficient use of solar power potential.

Fig 6.11: Images showing examples of differences in the scales of solar projects

Roof top solar panels
Source: www.pv-magazine.com

Micro-grids set up in india
Source: www.jakson.com

Solar farm in China
Source: www.qz.com

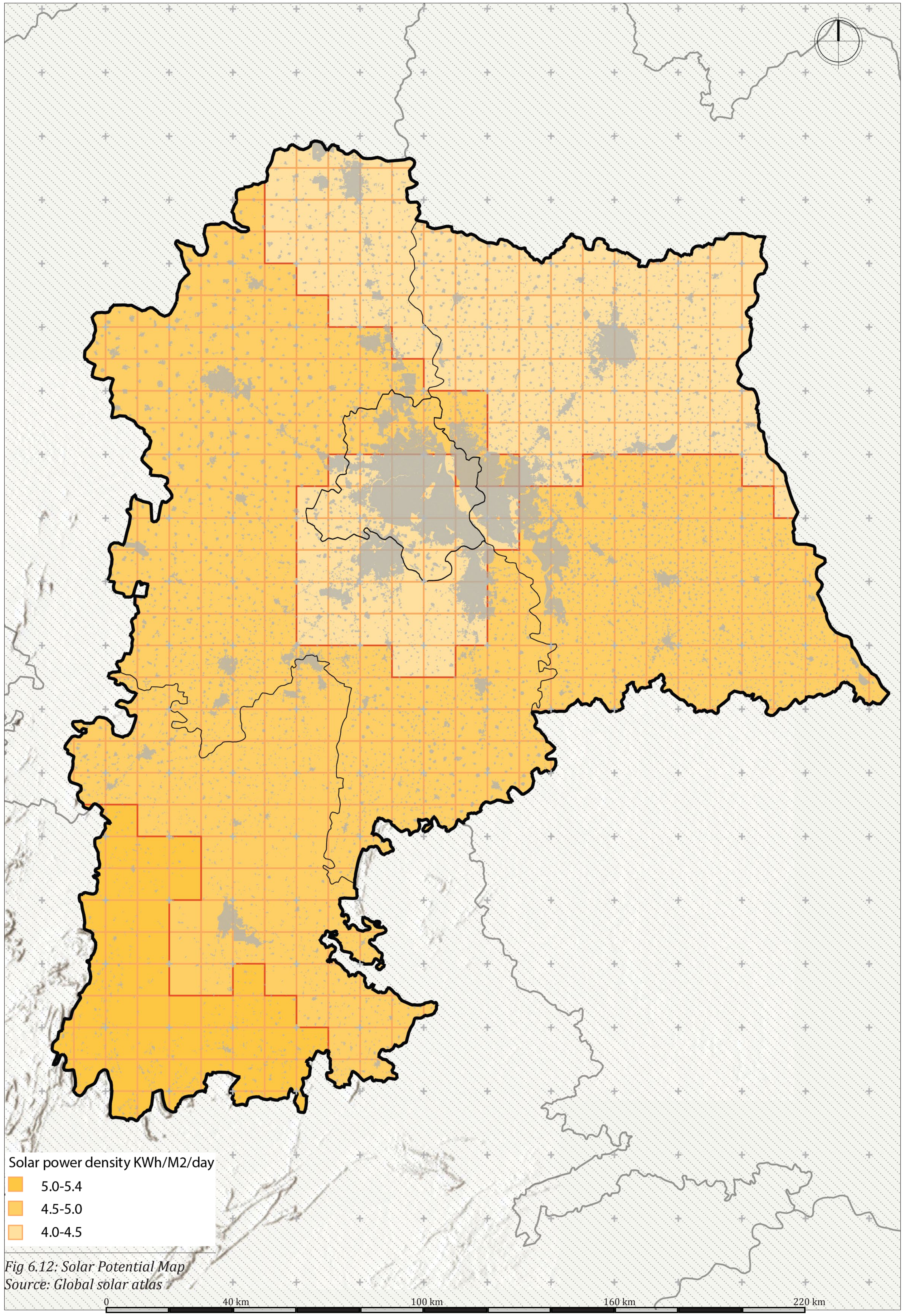


Fig 6.12: Solar Potential Map
Source: Global solar atlas

| Wind potential

Comparing the maps on the national and regional scale shows that the region has low wind power potential. Higher wind potentials are seen to the southern part of India (Fig 6.13). India has identified the coastal areas of Gujarat and Tamil Nadu to generate around 70,000MW of power. However, for the region of NCR, the wind speeds are low (Fig 6.14), making it not so promising to harness the wind based renewable power generation.

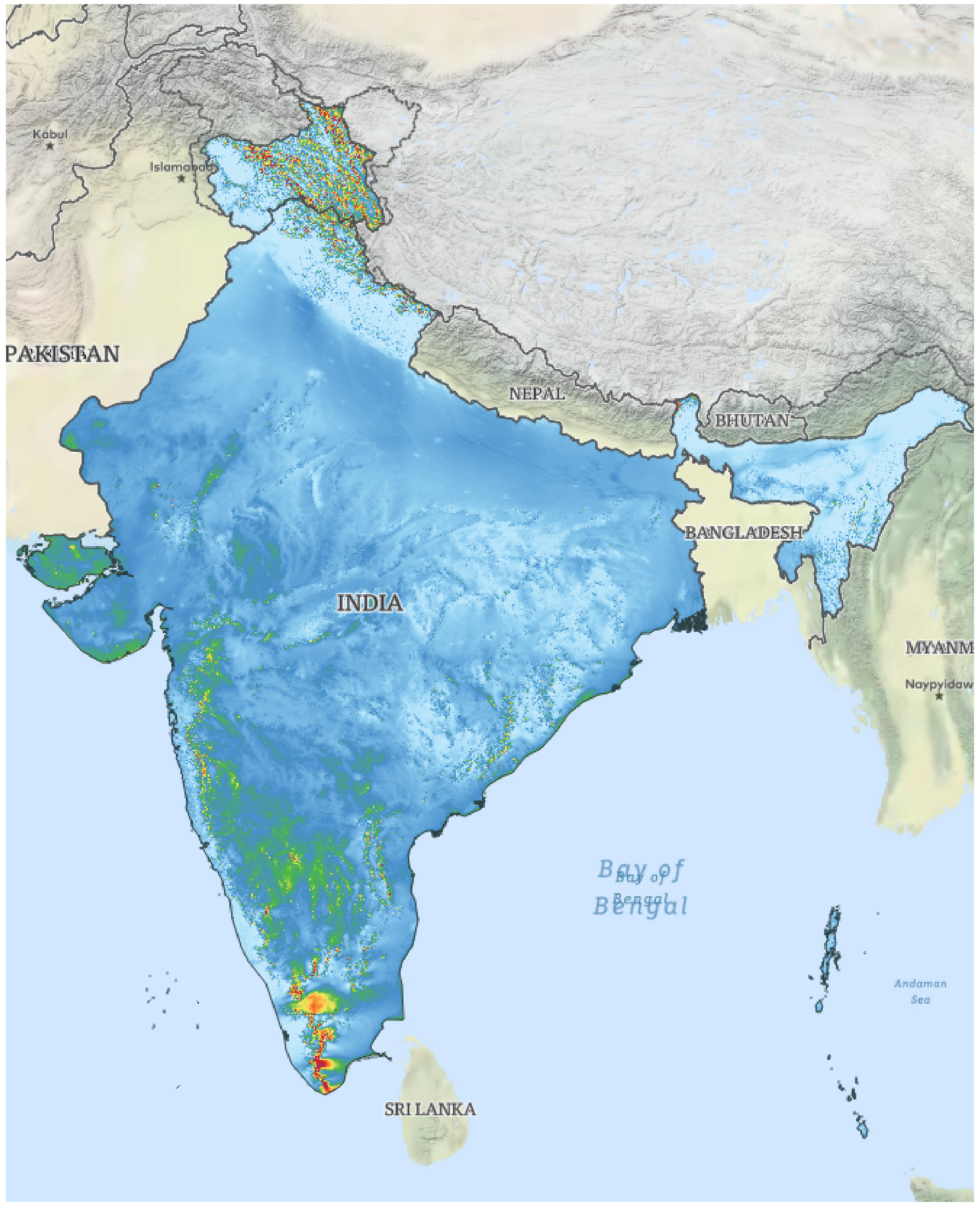


Fig 6.13: Wind power density of India
Source: World wind atlas

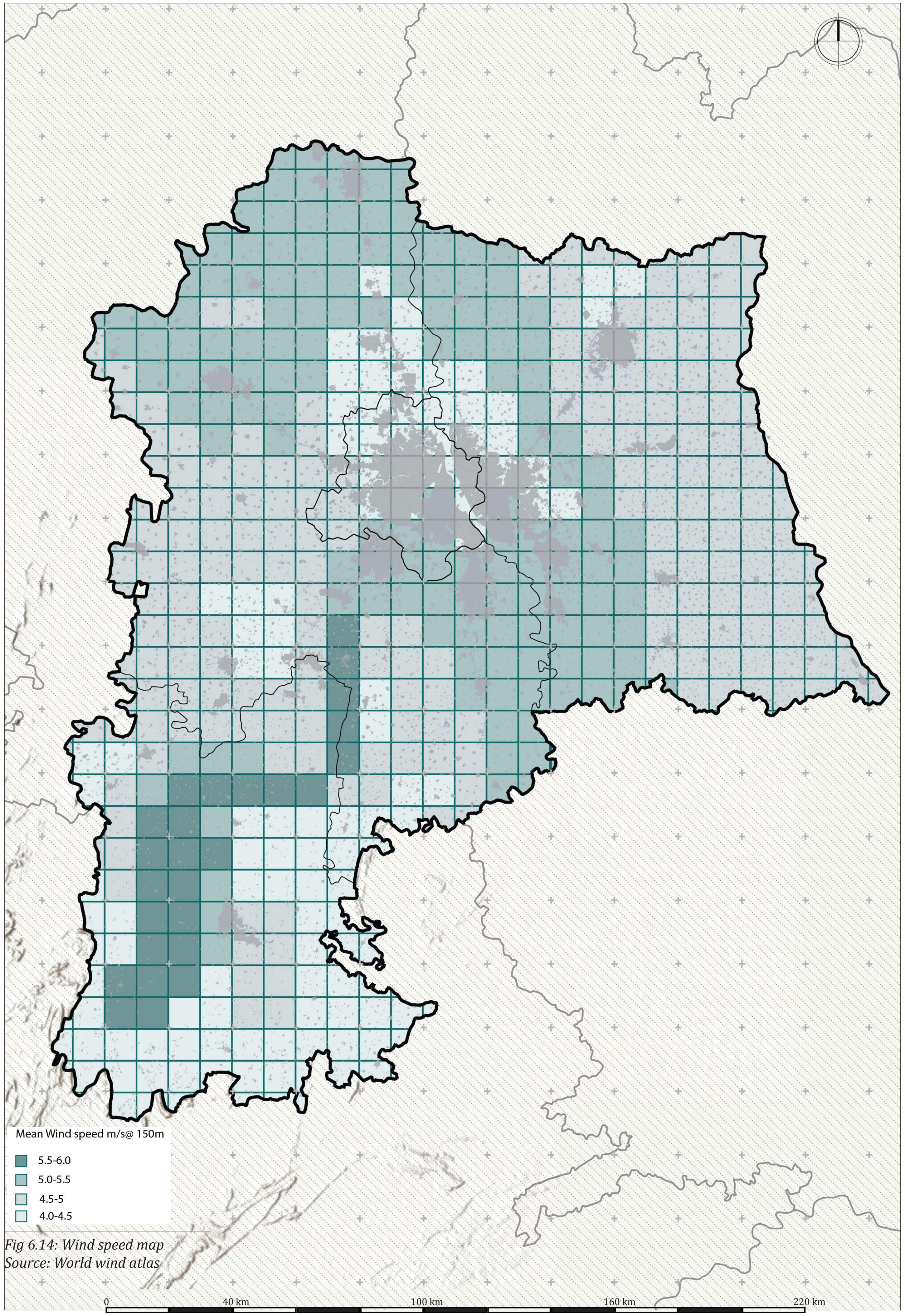


Fig 6.14: Wind speed map
Source: World wind atlas

| Biomass potential

According to (NCRB, 2013), 77.46% of the region's land use is agriculture. The region also has open forest towards the region of Alwar that has forest residues. (Fig 6.19) shows a higher cumilative biomass potential in the district of Alwar. Utlising the agriculture and forests residues to generate power is of high potential in the region. This can also alleviate the process of 'stubble burning' (Fig 6.15) where fields are cleared by setting them on fire. This leads to increased air pollution making NCR region one of the most polluted areas in the nation.

Harnessing biomass potential will also indicate the alternative use to the agricultural waste produced.

Fig 6.15: Remains of stubble burning seen in the region Source: www.engineered. thyssenkrupp.com

| Other energy potentials

The region of NCR falls in the seismic zone IV with earthquakes of magnitudes 5.5 to 6.5. This makes it dangerous to set up nucleus power plants. The region doesnot fall under the geo-thermal zone which negates that for energy potential in the region.

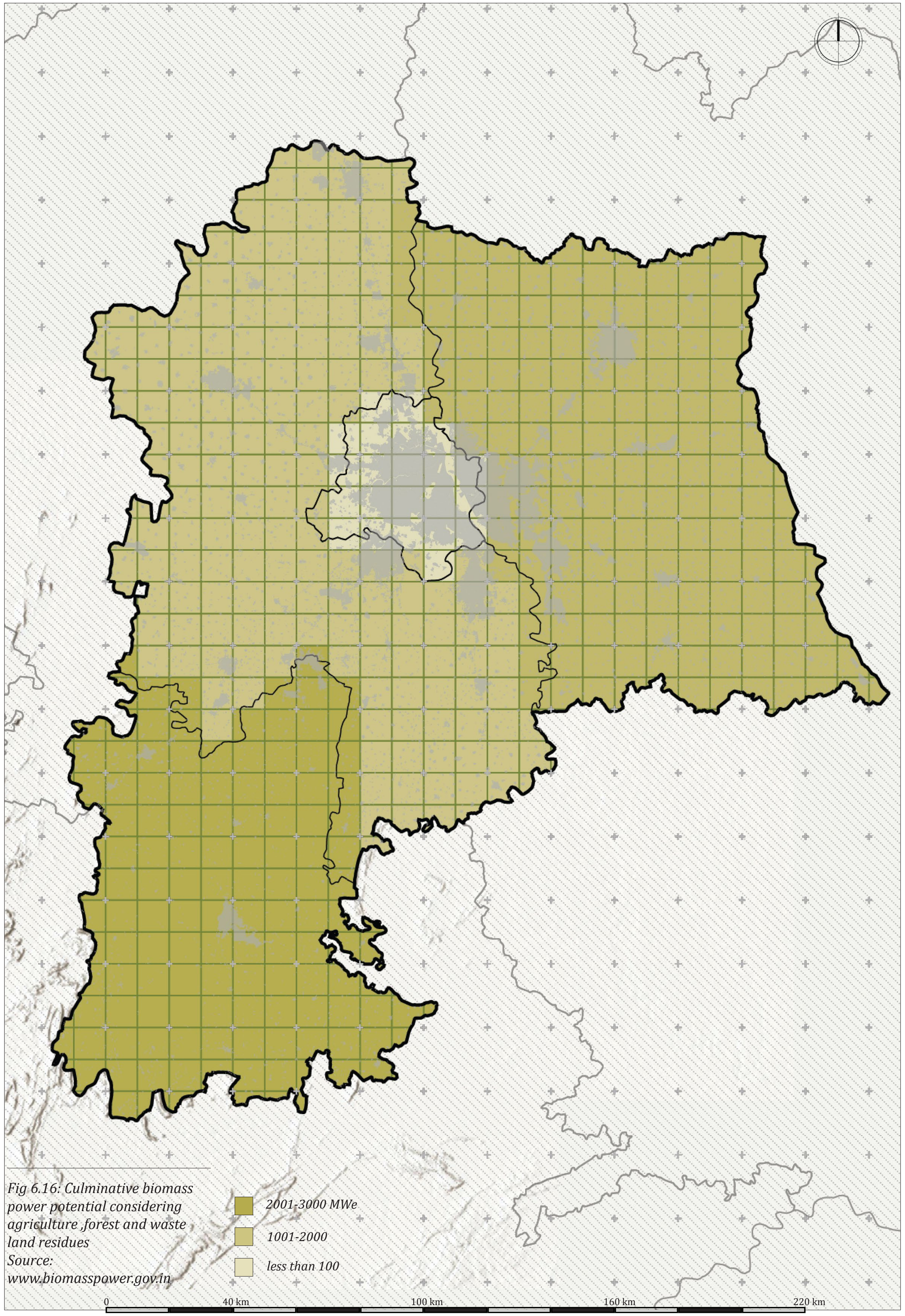
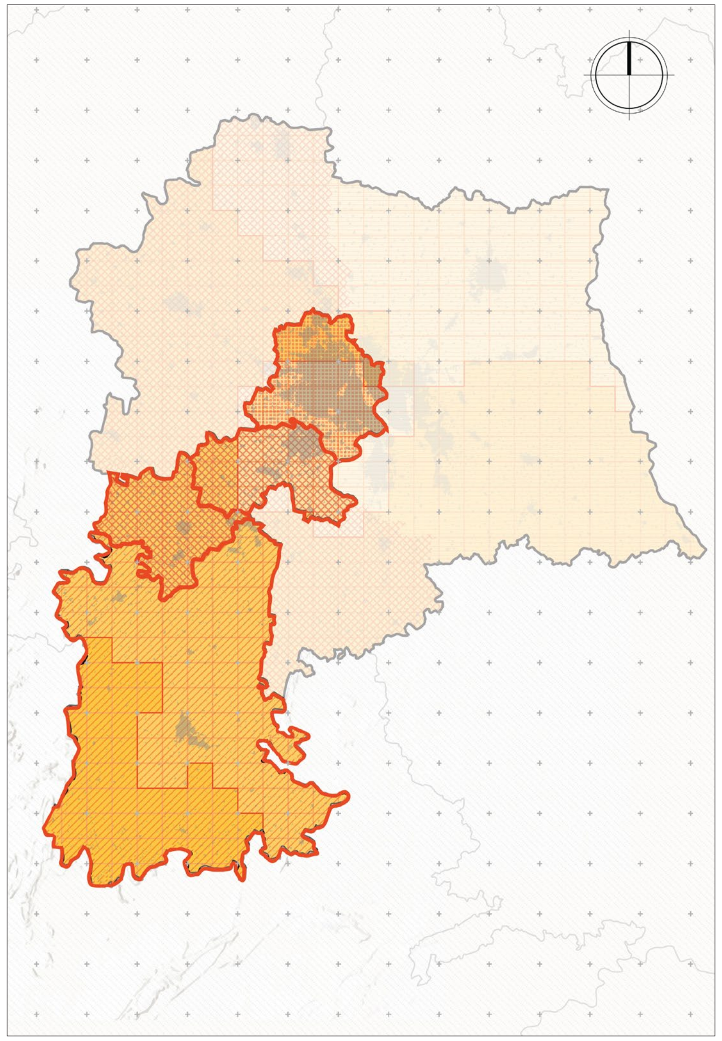
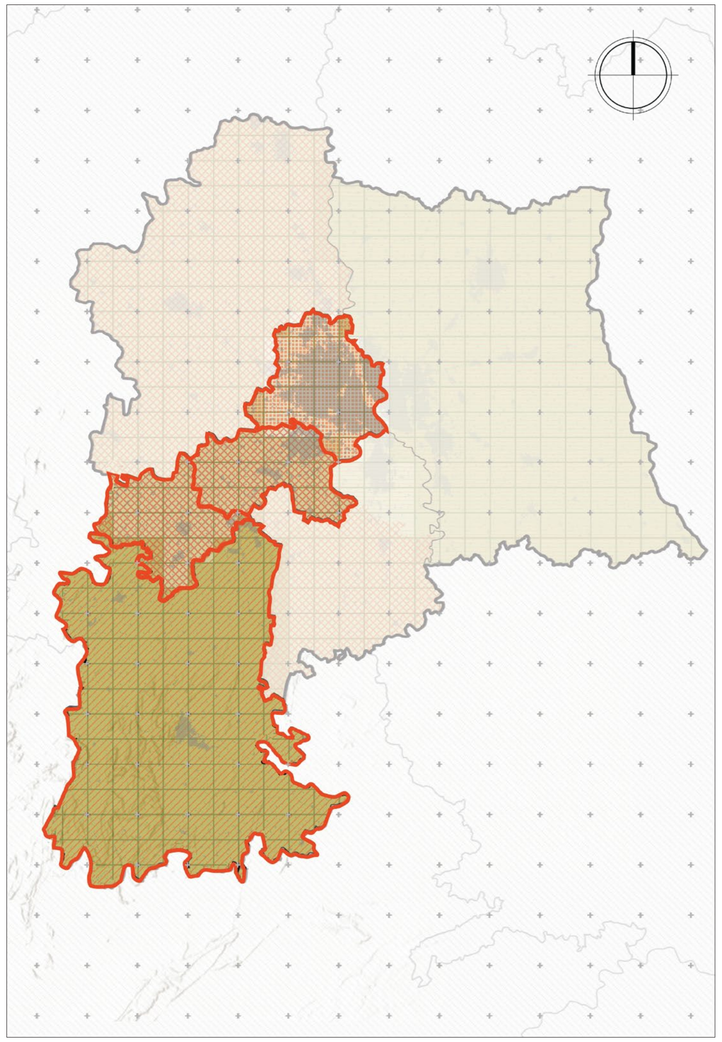


Fig 6.16: Culminative biomass power potential considering agriculture ,forest and waste land residues Source: www.biomasspower.gov.in

6.4 | Conclusions





Solar power density KWh/M2/day
- 5.0-5.4
- 4.5-5.0
- 4.0-4.5

Fig 6.17: Solar Potential Map, with the energy access imposed on the transect
Source: Author

- *2001-3000 MWe*
- *1001-2000 MWe*
- *less than 100 MWe*

Households with energy access sub-regions of NCR
- *100%*
- *80-100%*
- *60-80%*
- *40-60%*

Fig 6.18: Biomass Potential Map, with the energy access imposed on the transect
Source: Author

In this chapter, the renewable energy potentials in the region are analysed and the overlays of the potential maps show that solar and biomass potentials are higher in this region. This analysis combined with the transect selected in the previous section shows the potential values with the transect scale. These values can be used during the energy calculations for the local scale that is derived from the further analysis of the selected transect scale.

Fig 6.19: Farmlands in Rajasthan
Source: Public domain

07

Transect Study

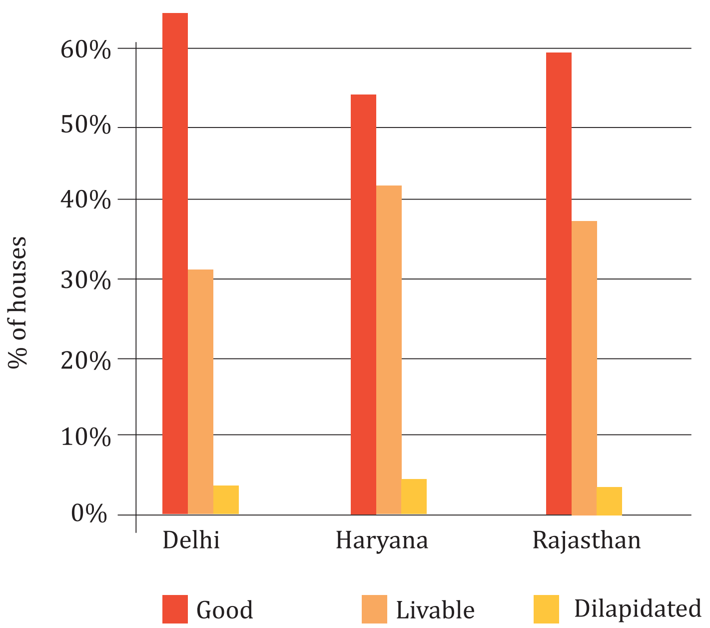
| The southern transect

The transect study shows looks into the Delhi, the district of Gurgaon, Rewari and Alwar. The study is done to have an more insight into development of the districts. The settlement pattern, agricultural production, water conditions and future developments are analysed.

7.1 | Settlement Pattern

The settlement pattern shows Delhi as a strong urban center, followed by Gurgoan (Fig 7.2). Rewari has been marked a regional center in the proposed settlement plan for the future (Fig 7.6) . The district is located in the second ring of the NCR settlement ring. Being in this zone, the proposed policies are to develop the area into a zone that attracts secodary and tertiary activities, providing increased job opportunities for the people, and promote to more economic development (NCRB, 2013). Alwar is also proposed to develop as a regional centre. These two districts have higher levels of rural population. However, these proposals do not discuss the development of the rural areas in the vision of making Rewari and Alwar regional centres.

| Building Conditions



The percentage of dilapidated houses is more in rural areas (4.2%) as compared to urban areas (2.6%) in NCR. The quality of housing in NCR is relatively better than India's average. About 54% houses in Haryana and U.P sub-regions have been classified as good quality housing, remaining is marked as livable. This could mean that the houses might not have the structural capability of holding rooftop solar panels. This is to be noted while looking into renewable energy transition in the rural areas (NCRB, 2013).

Fig 7.1: Graph showing the building conditions of the houses in the transect
Source: Adapted from NCRB, 2013

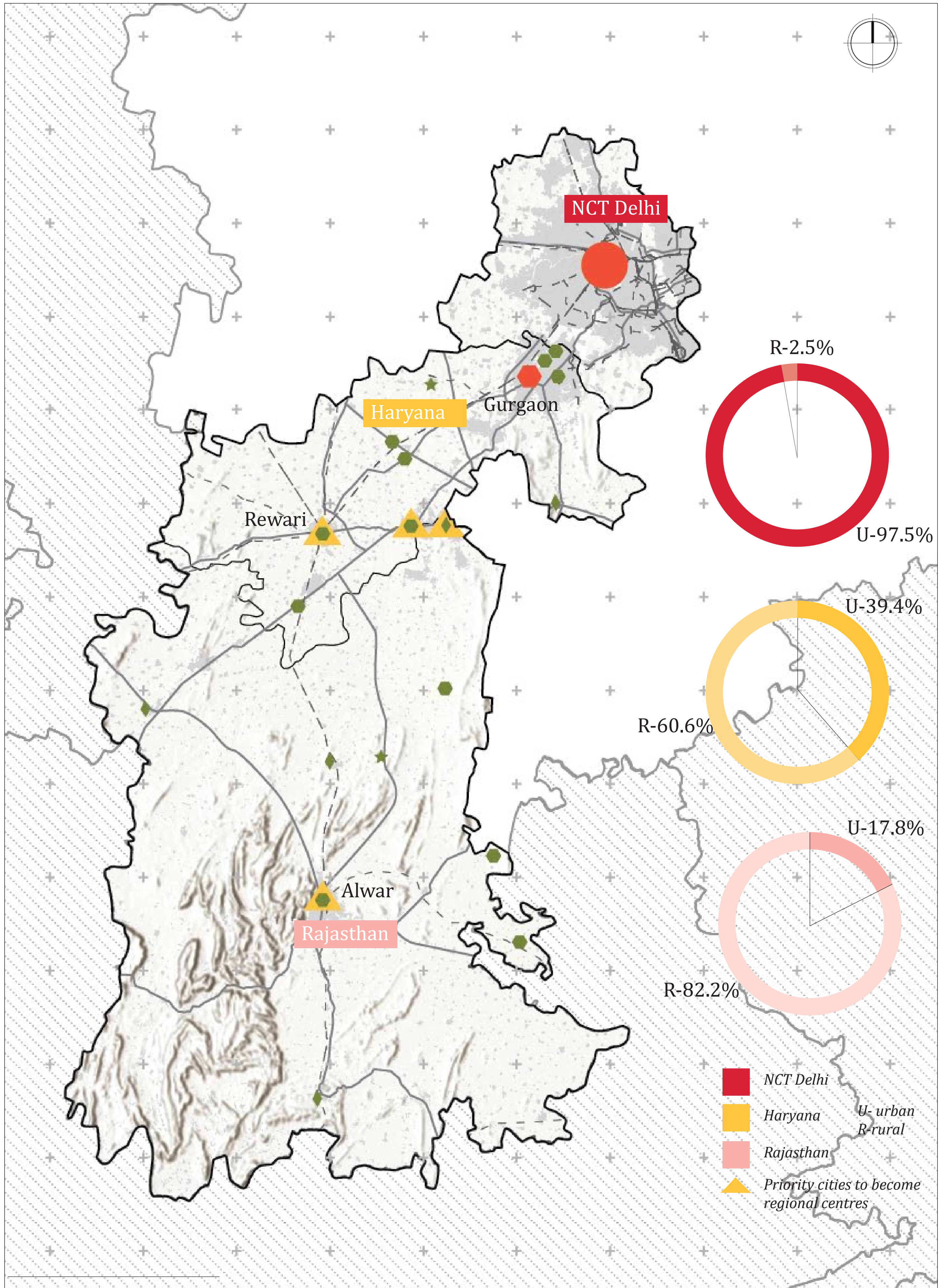


Fig 7.2: Existing settlement pattern 2010
Source: Adapted from NCRB, 2013

7.2 | Food production

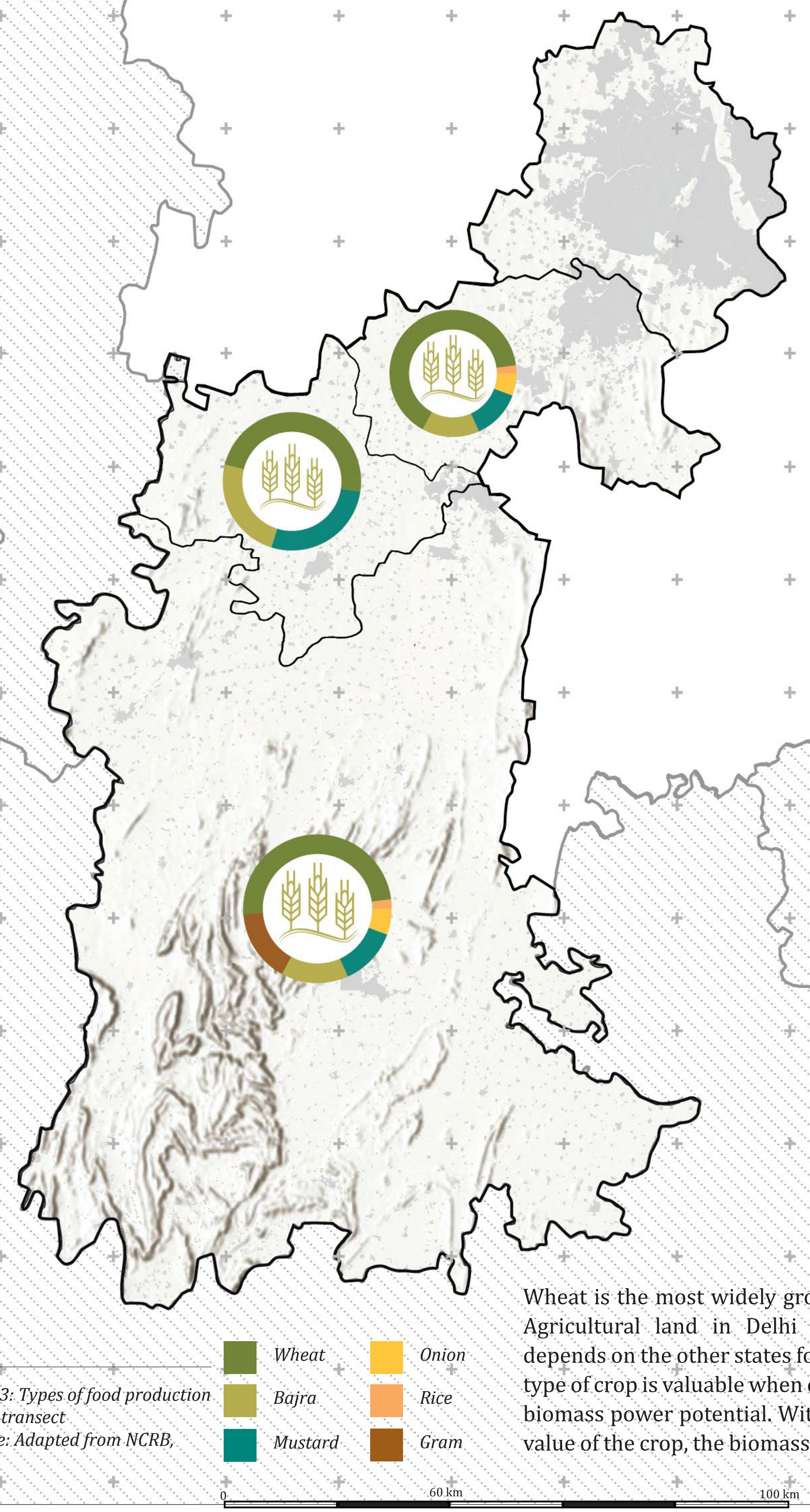


Fig 7.3: Types of food production in the transect
Source: Adapted from NCRB, 2013

Wheat is the most widely grown crop the the region. Agricultural land in Delhi is very limited and it depends on the other states for the supply of food. The type of crop is valuable when coming to calculating the biomass power potential. With change in the calorific value of the crop, the biomass power generated varies.

7.3 | Water conditions

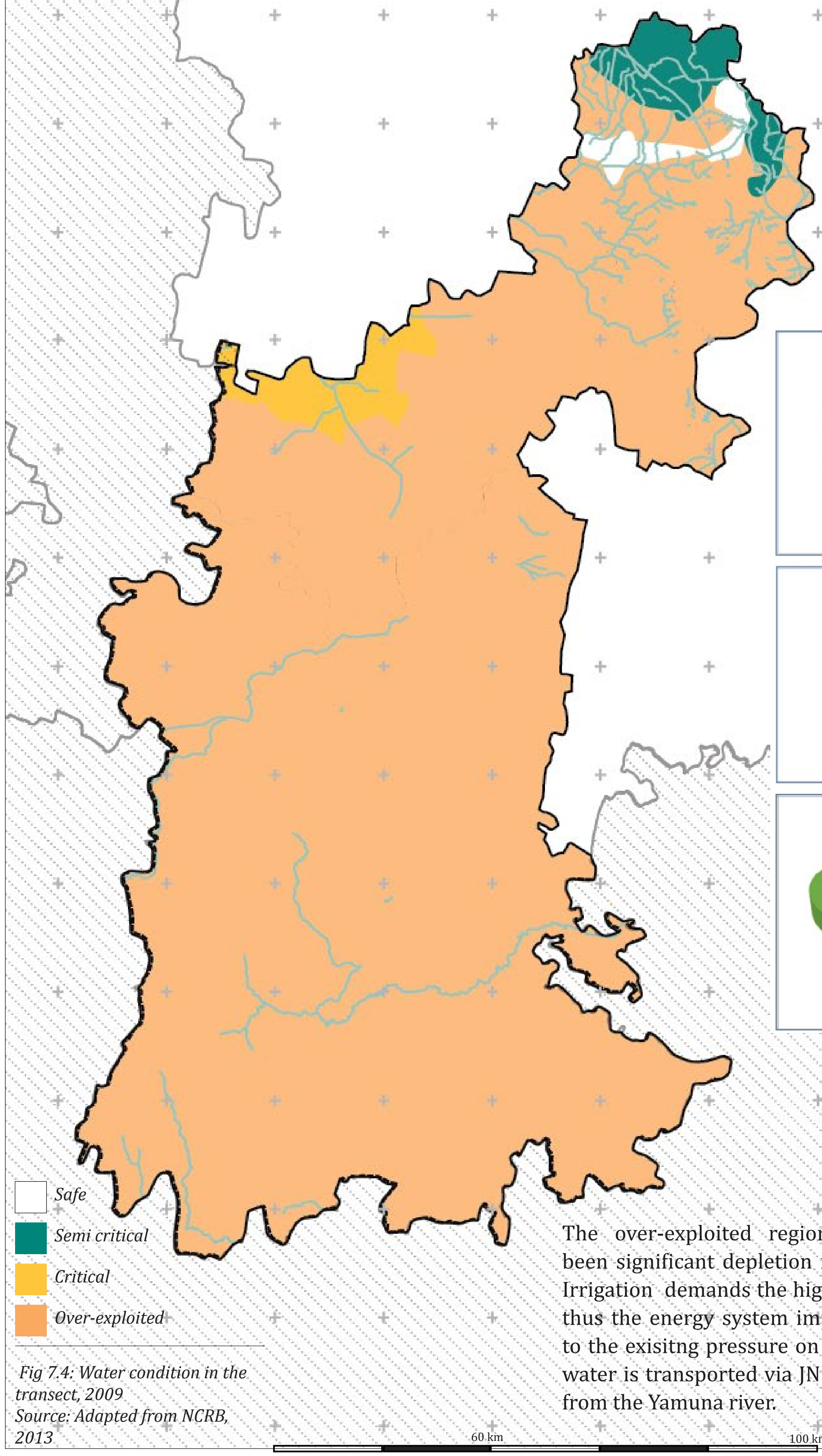


Fig 7.4: Water condition in the transect, 2009
Source: Adapted from NCRB, 2013

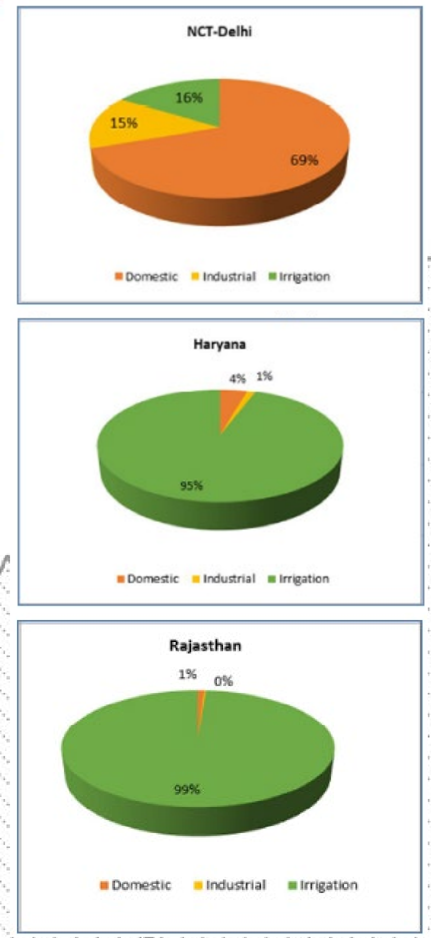


Fig X : Sectoral water demand
Source: NCRB, 2013

The over-exploited region shows that there has been significant depletion in the ground water table. Irrigation demands the highest quantity of water, and thus the energy system implemented should not add to the exisitng pressure on the water table. Currently, water is transported via JNL canal that conveys water from the Yamuna river.

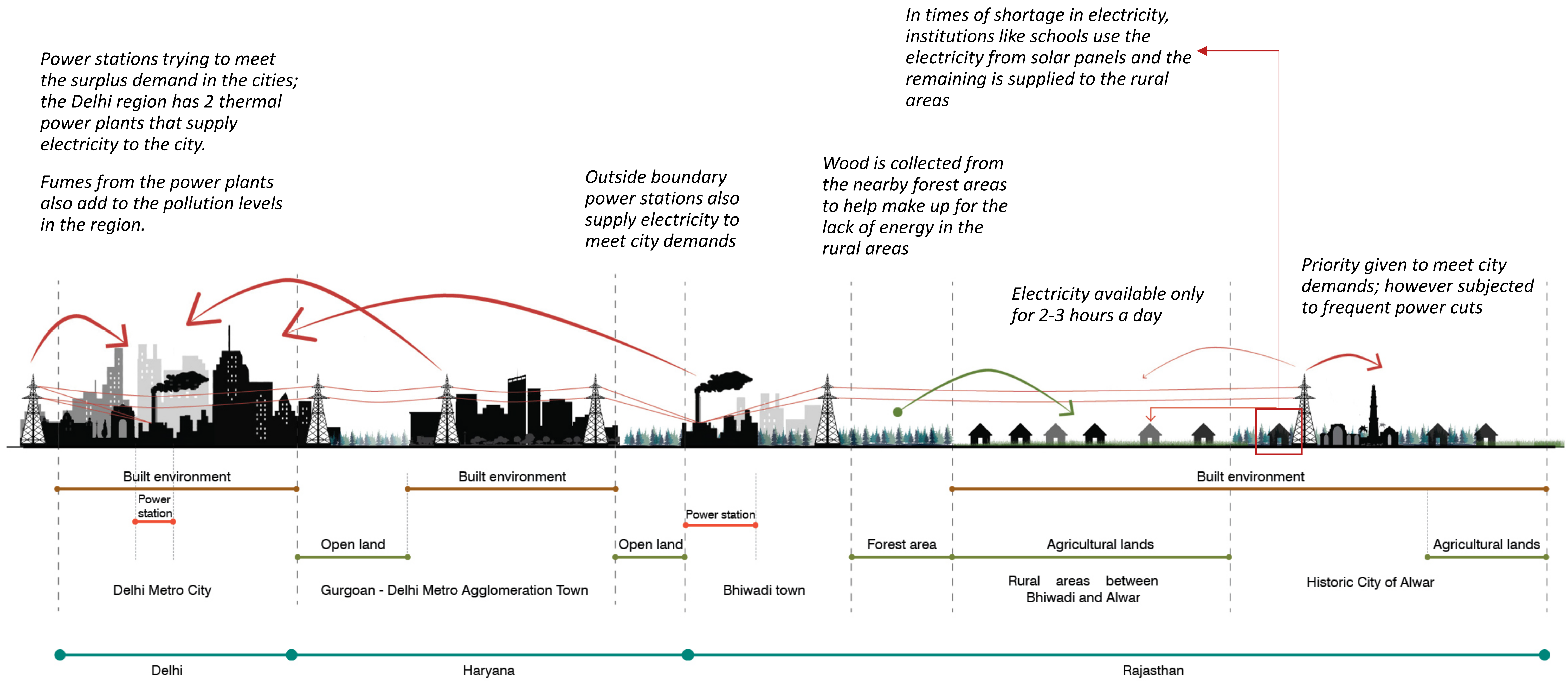
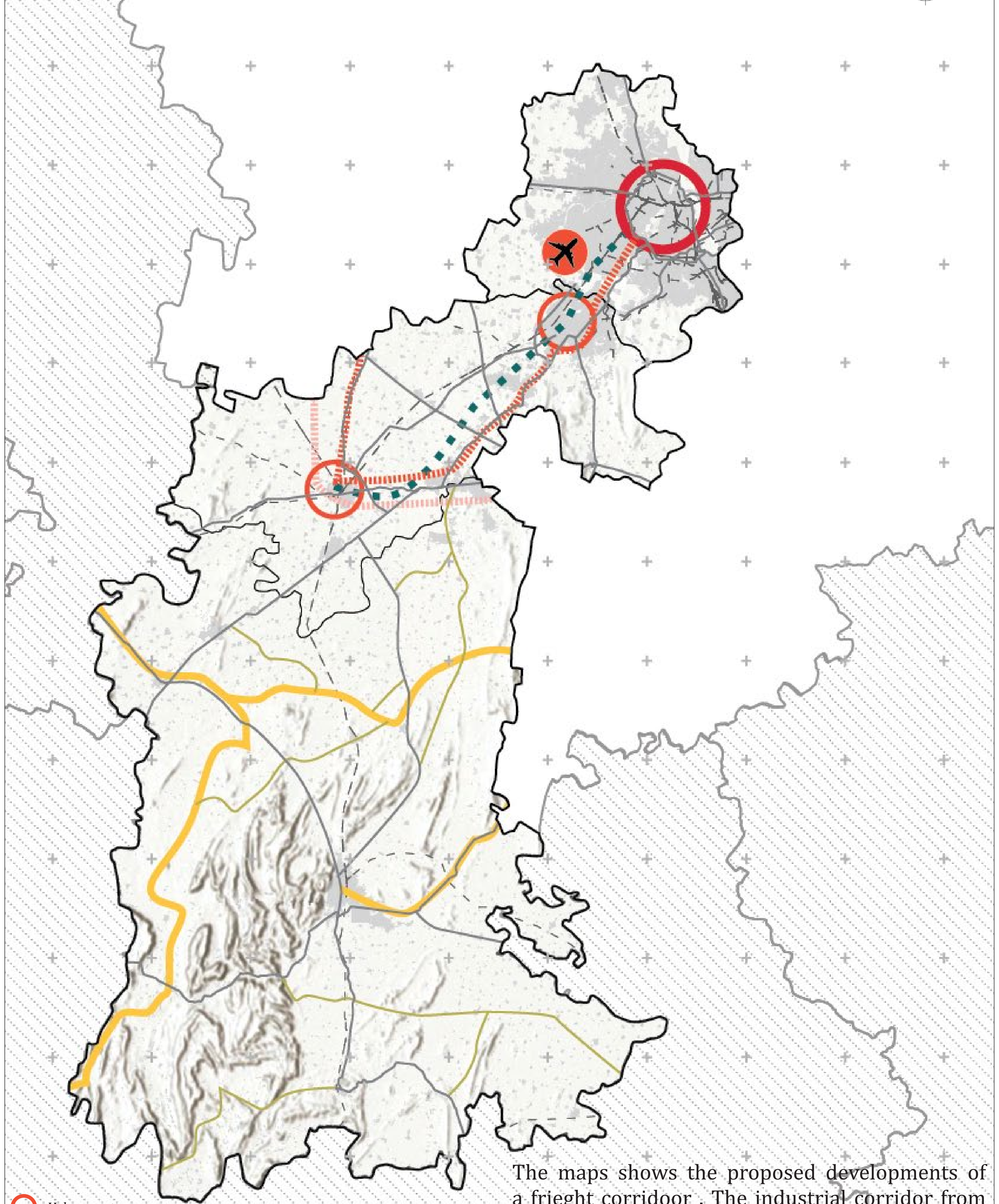


Fig 7.5: Section explaining energy flows in the transect
Source: Author

7.5 | Proposed future developments



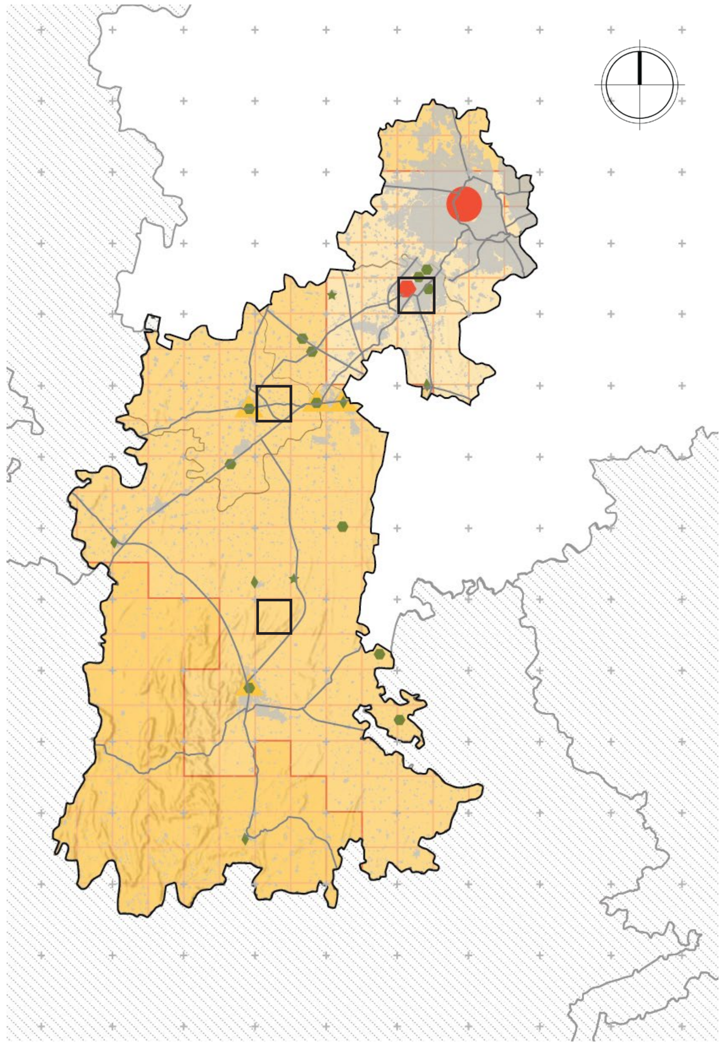
The maps shows the proposed developments of a frieght corridoor . The industrial corridor from Delhi to Mumbai is linked to this. Rewari is seen to be the intersection point for future developments. This indicates a developing urban center with vast amounts of rural villages around. This can lead to further disparities.

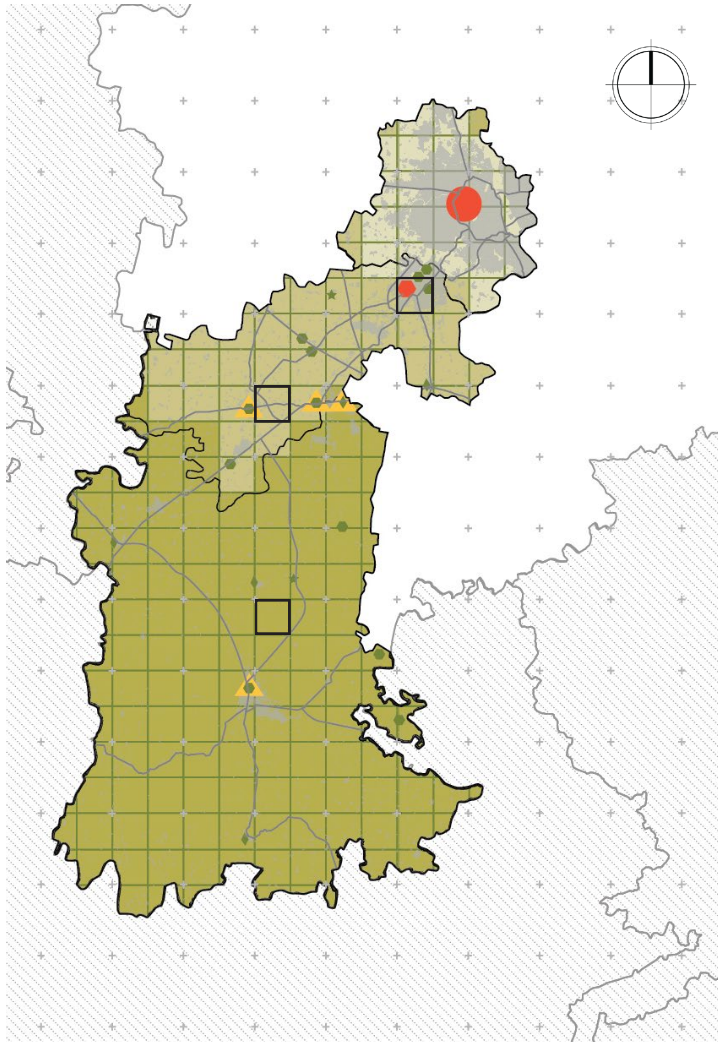
Fig 7.6: Map showing proposed developments.
Source: Adapted from NCRB, 2013

7.6 | Conclusions

Through the process of transcalar analysis and energy potential mapping, three zoom in locations were identified. These are based on the different types of urban-rural systems seen. The zoom in location for scenario planning is based on the urban-rural relation. A location that is transitioning into an urban center with its rural surroundings is chosen as the zoom in location.

These aspects will be detailed out in chapter 9.





The two maps indicate different energy potentials for the locations both with solar and biomass. Based on the compilation of all this data, scenario planning and impact assement will be done.

Solar power density KWh/M2/day
- 5.0-5.4
- 4.5-5.0
- 4.0-4.5

Biomass power potential
- *2001-3000 MWe*
- *1001-2000 MWe*
- *less than 100 MWe*

Fig 7.7: Overlap of solar potential and biomass potential onto the settlement pattern
Source: Author

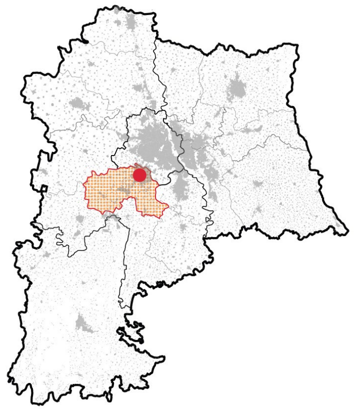


Fig 7.8: Location in between Delhi and Gurgaon borders.
Source: Google earth, 2019

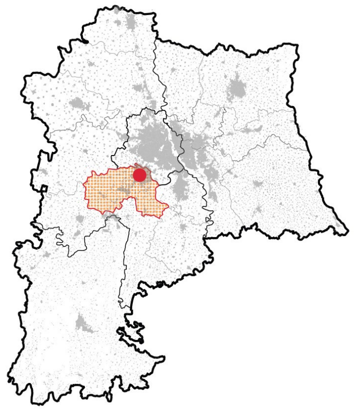
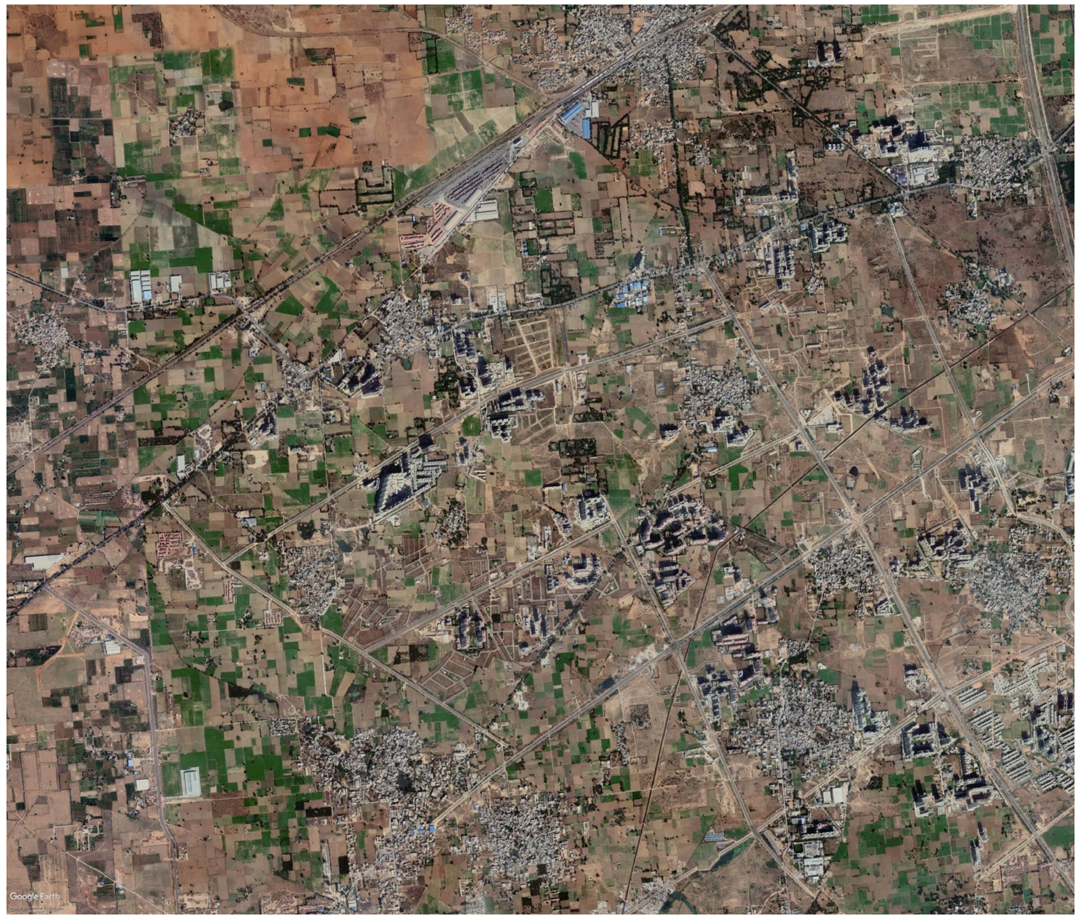


Fig 7.10: Location on the outskirts of Gurgaon
Source: Google earth,2019



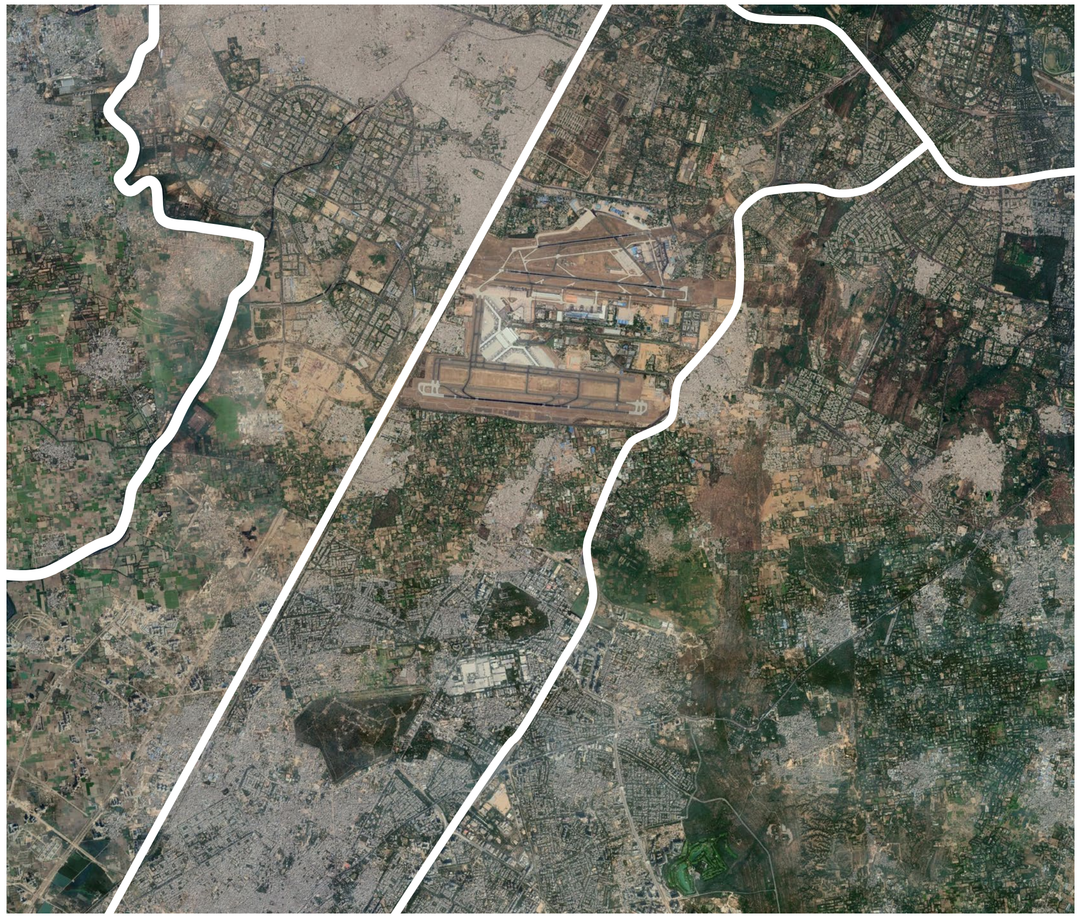
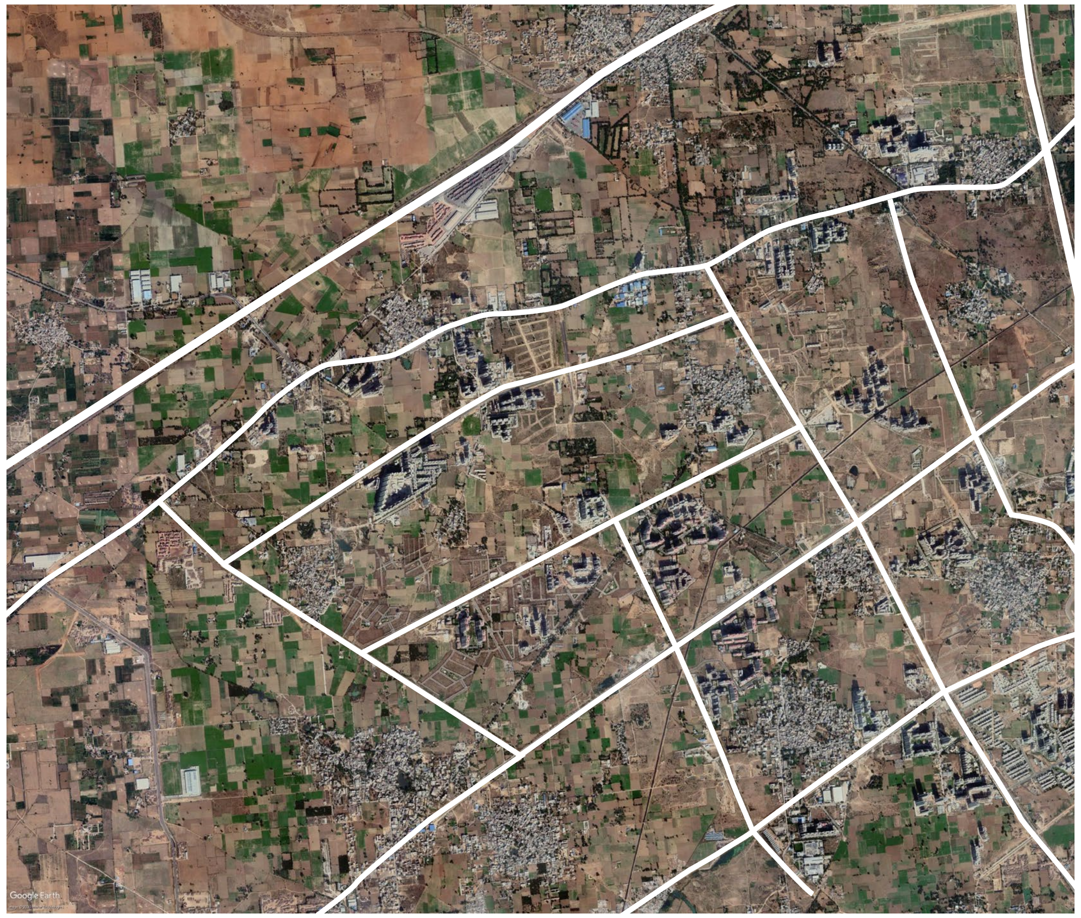


Fig 7.9: Map showing infrastructure lines creating a separation between the urban and rural areas.
Source: Google earth, 2019

Fig 7.11: Map showing rural area cleared for new town developments.
Source: Google earth,2019



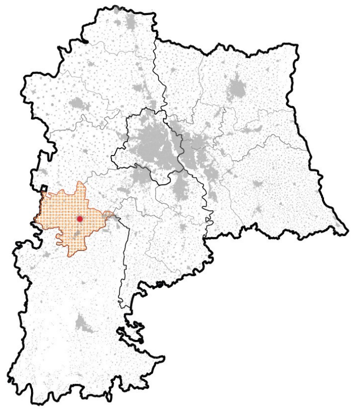


Fig 7.12 : Location of Rewari city
Source: Google earth,2019

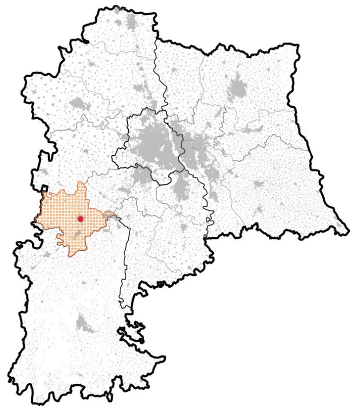


Fig 7.14: Rural villages outside Rewari city
Source: Google earth,2019

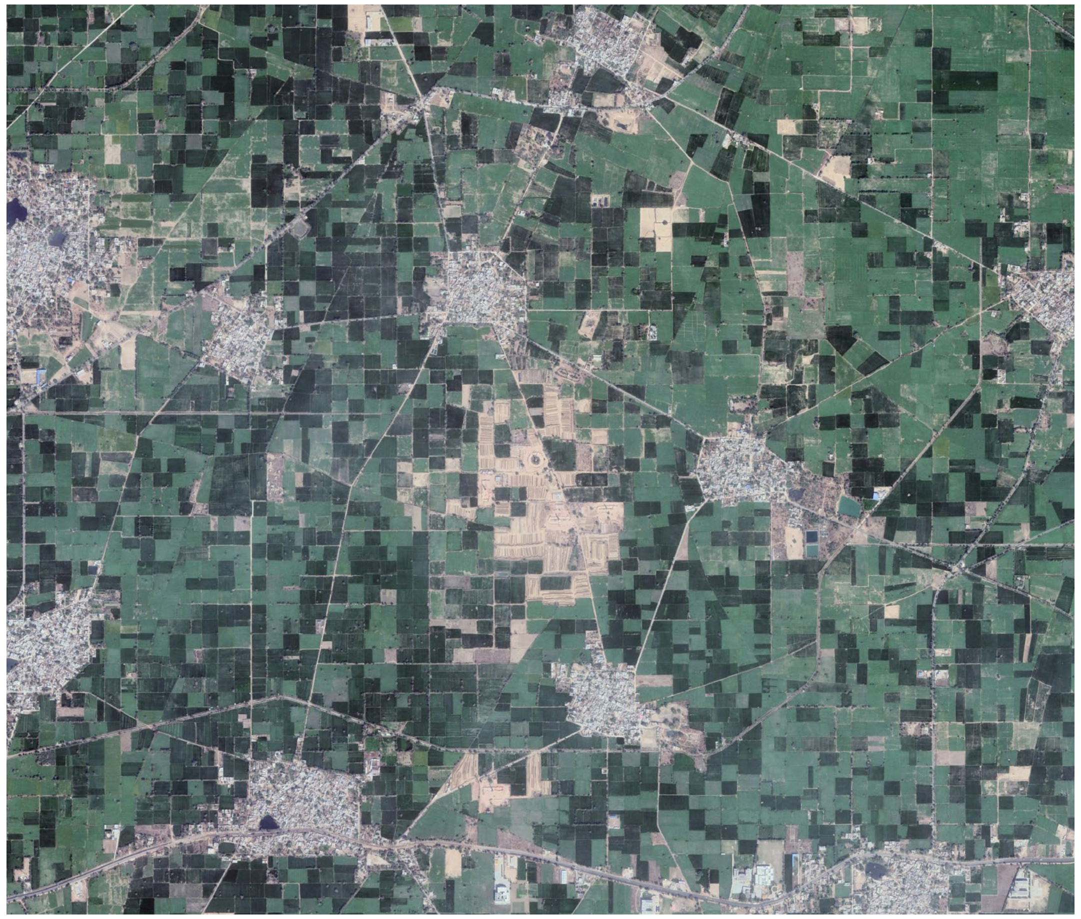
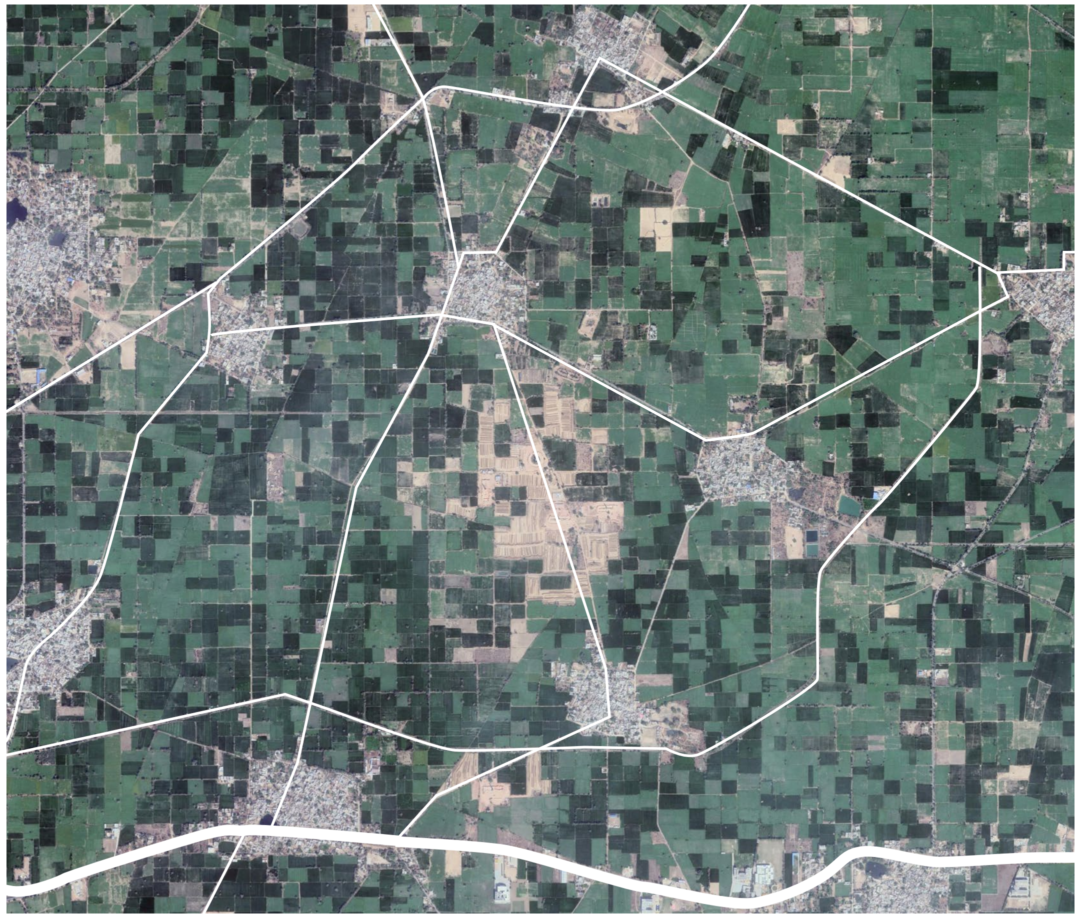


Fig 7.13: Ring road around the urban area and an outward road cutting through towards the rural areas. The urban area is seen expanding along the lines.
Source: Google earth, 2019

Fig 7.15: Small roads that cut through agricultural fields linking the rural villages of Rewari
Source: Author



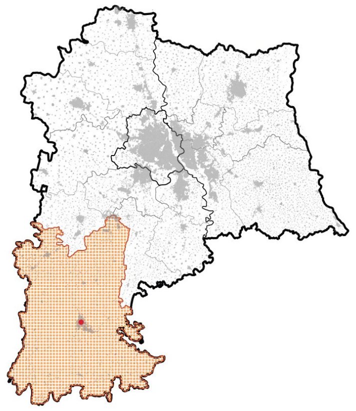


Fig 7.16: Alwar city orginating from Alwar hills
Source: Google earth, 2019

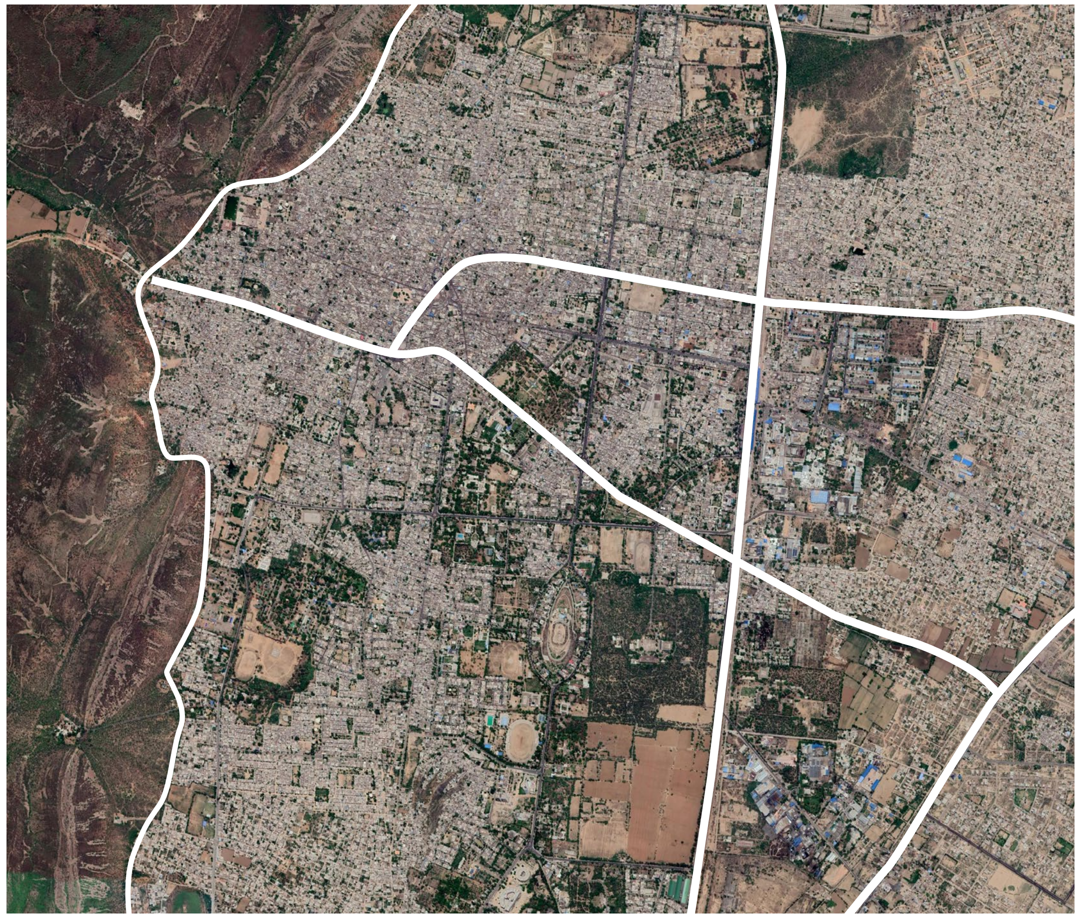


Fig 7.17: Alwar city is nested between the Alwar hills keeping the city away from the rural areas.
Source: Google earth, 2019

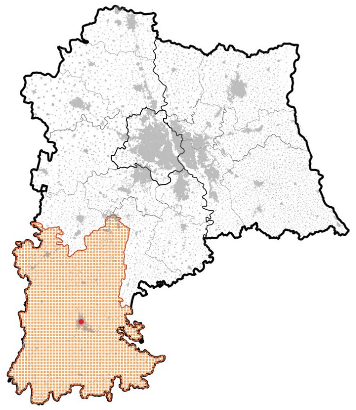


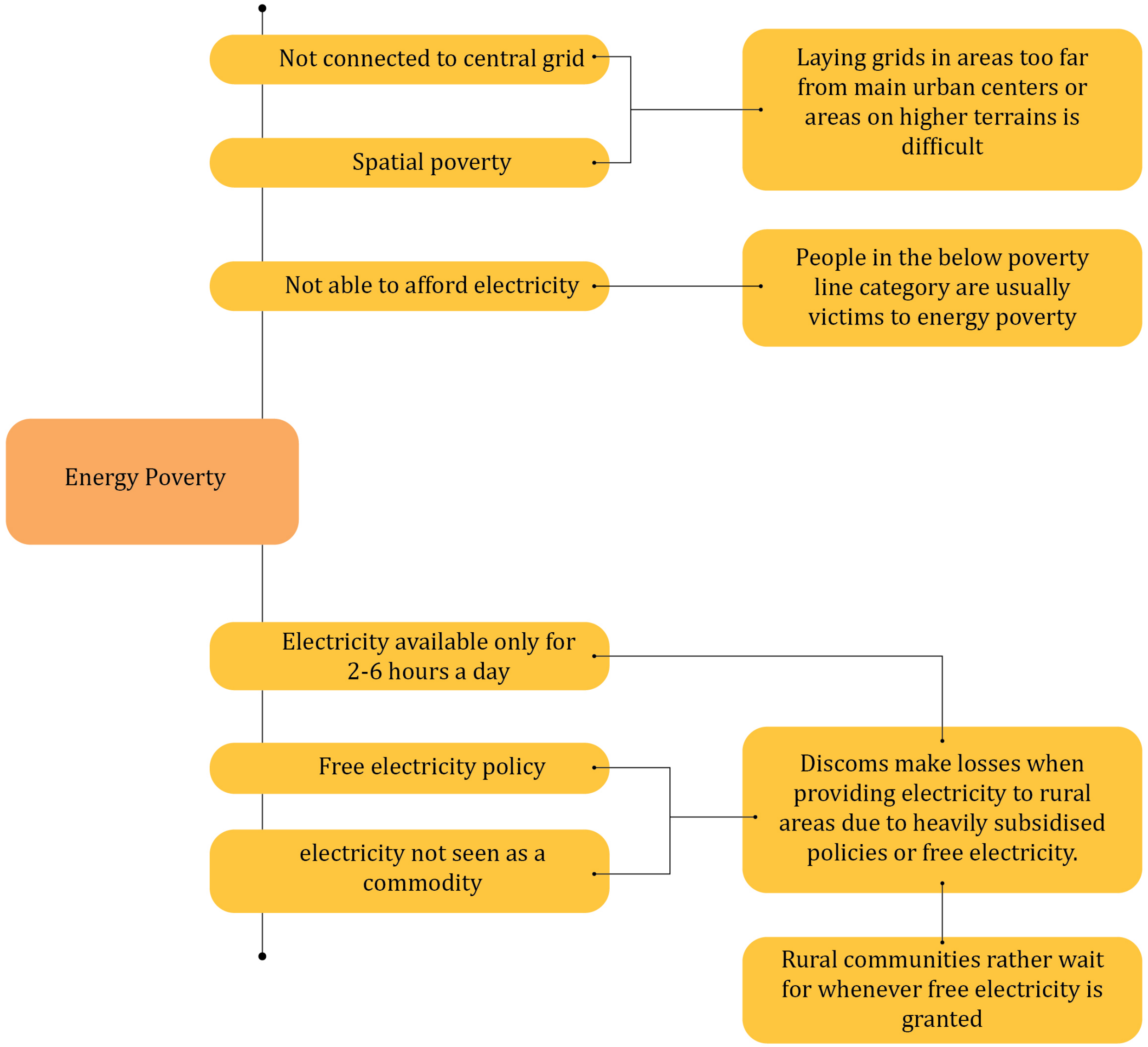
Fig 7.18: Scattered rural areas of the Alwar district
Source: Google earth

Fig 7.19: Rural villages in Alwar district are scattered along the small roads the seem to originate from the hills.
Source: Google earth, 2019

08

Energy poverty, transition and governance

8.1 | Reasons for energy poverty



“

One of the main problems faced is that, the village communities do not see electricity as a commodity. The government has continuously given them false hopes of free electricity that they prefer to keep the free electricity (available for 2 hours) and use wood, coal or kerosene for the remaining hours.

- Mr. Shubashis Dey (Shakti Energy Foundation)

”

Fig 8.1 : Rural household in darkness
Source: www.tes.com

“

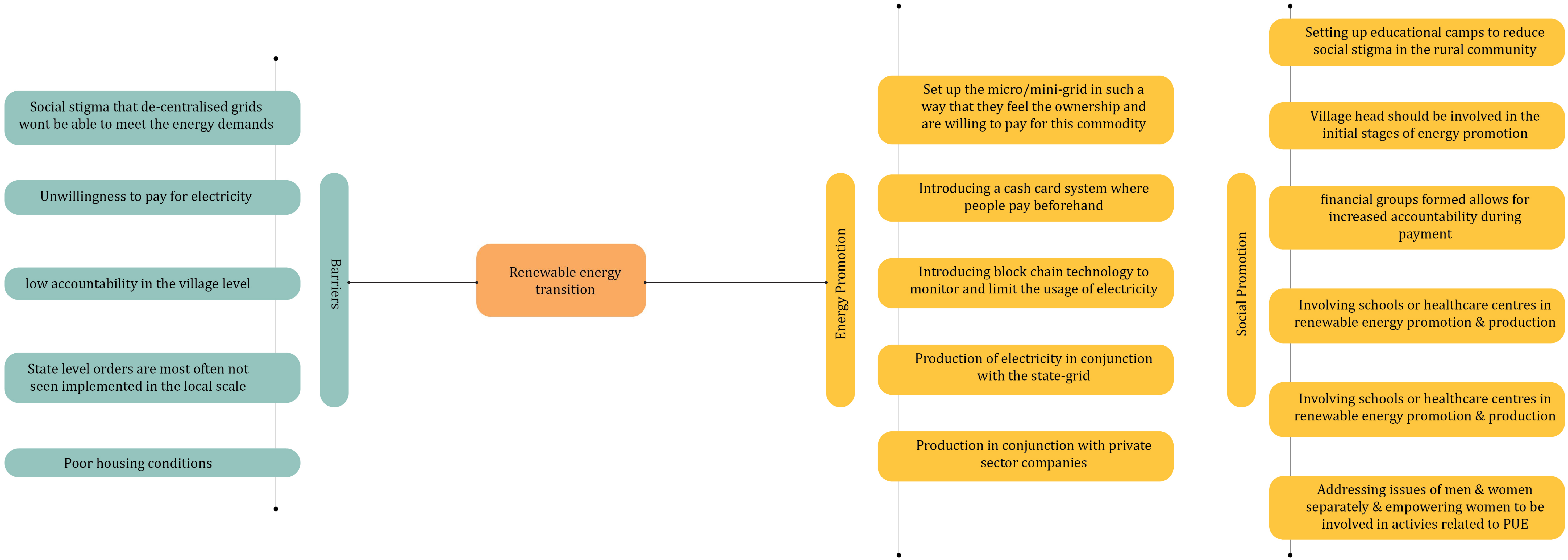
Rural electrification or energy access is about providing more or better-quality electricity to the villages that are away from the grids.

The main concern is the quality of electricity provided. Even though the villages might have electricity connections, the state-grid is able to provide electricity to the villages for only around 2-6 hours a day, instead of 24x7. The government will have to bear huge losses if electricity is supplied 24x7 as the electricity to villages are subsidised. Also, the state-grid supplies electricity at random hours during a day, thus making the system unpredictable and unreliable. Whereas, in the case of local mini-grids, electricity is available during certain fixed hours every day, making it more reliable (better quality electricity).

- Mr. Kunal Amitabh (Boond Solar)

”

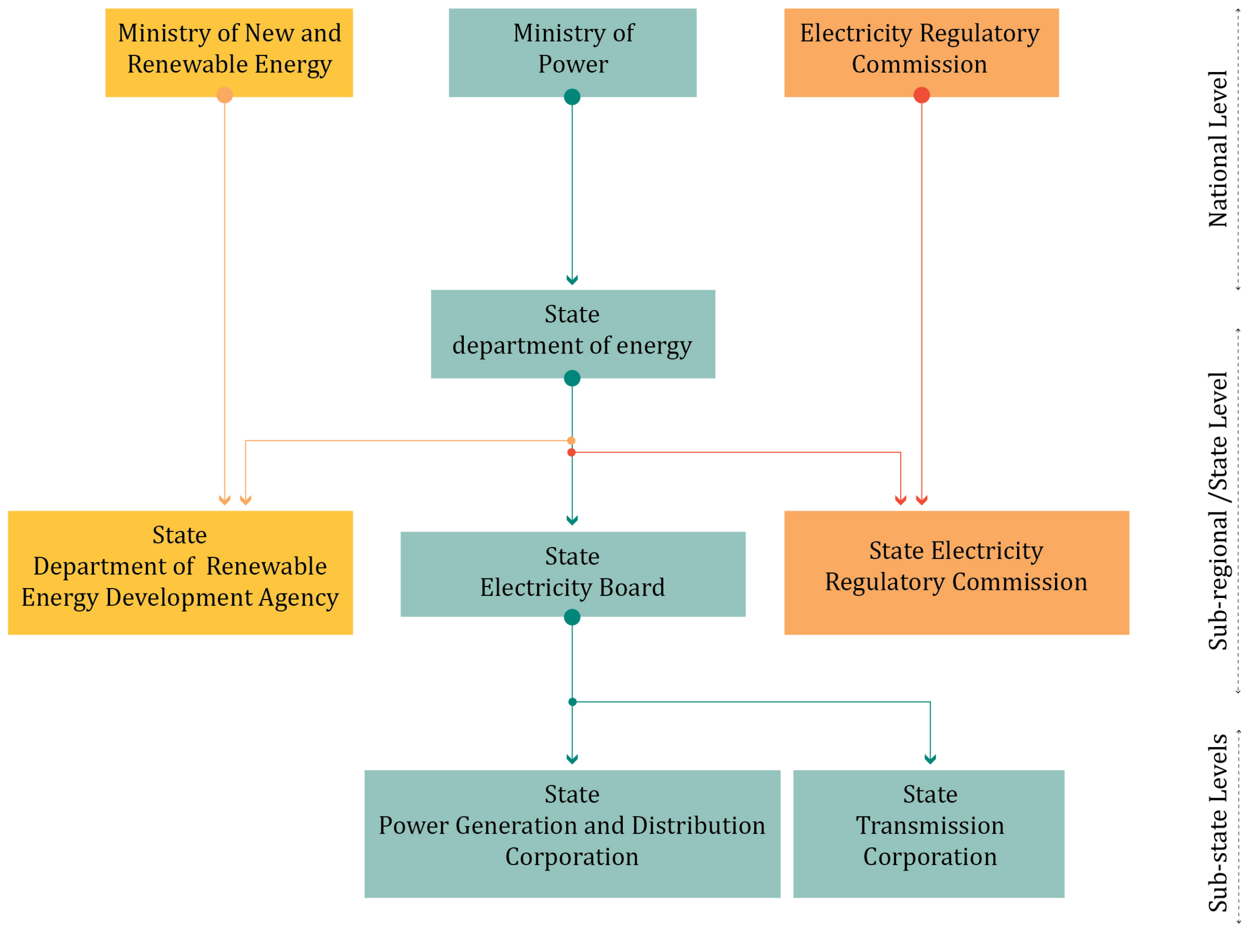
8.2 | Renewable energy transition : Barriers & Promotion



> A method of electricity bill collection involves re-routing the electricity through primary institutions such as health centres or schools, which are necessary in a village. These primary institutions will use electricity as much as they require and give the remaining electricity to the community. The person running these institutions would be of high social capital and can exert pressure on people who are supposed to pay
>
> - Mr. Pustav Joshi (Shakti Energy Foundation)

> Village women are seen to be more involved in activities that involve energy or running small businesses etc. Camps are organised to mobilise the women where they are educated and trained for a particular sector. It is best to address the issues of men and women separately as this creates more active dialogue during community meetings.
>
> - Mrs. Lakshmi Krishnan (Society For The Promotion Of Women And Child Welfare)

8.3 | Governance structure for energy



The northern grid is a congregation of power systems of NCT-Delhi and three NCR sub-regions: Haryana, Rajasthan and Uttar Pradesh. The State Load Dispatch Centres (SLDCs) in the constituent states of NCR oversee the real-time grid operation, scheduling and dispatching of generators in their own states.

The state governments are responsible for generation, procurement and supply of electricity within their region of governance. They avail the services of different corporations/IPPs for these tasks. In addition to the state government's efforts, central government facilitates addition of generation capacity through CPSUs and appropriate firm/unallocated power from their own power stations to the states. The states in turn redistribute these additional resources to different DISCOMs within the states. Thus, the NCR states hold all the cards when it comes to power management in their respective sub-regions (NCRB, 2013).

| Conclusions

Through the interviews, it is clear that there is a need for empowerment of the rural areas. However, empowering the communities on local area planning and initiating financial aid groups among community co-operatives are the initiatives that need to be considered while designing a just energy transition for the urban-rural areas.

Emphasis has also been given towards the need for creating educational camps regarding renewable energy transition, energy production and local area planning to all levels of governance to improve the relations between the public, private and civil society. The next chapter puts together all the analysis and conclusions derived so far into the scenario planning of the locations.

09

Application of Scenario Planning

9.1 | Gurgaon, DMA-Haryana Sub-region

The following areas are the selected locations based on the analysis conclusions as metioned previously (refer chapter 7).

Gurgaon is one of the districts in the Haryana sub-region. Over the years, this area has urbanised along with the capital city of Delhi. Now, Gurgaon is a strong urban centre along with Delhi and attracts a lot of people for economic activities. The city of Gurgaon has one of the highest human development index in the country. With the developments and the increase of population in the NCR region, the urban centre has expanded and spread rapidly to its rural areas.

This is the first type of urban-rural system in this region, where the strong urban centre is more dominant and has almost taken up the rural areas for more urban development. Issues of village displacement and slum formation due to this can be seen.

Fig 9.1 : Urban area is prominant
Source: Author

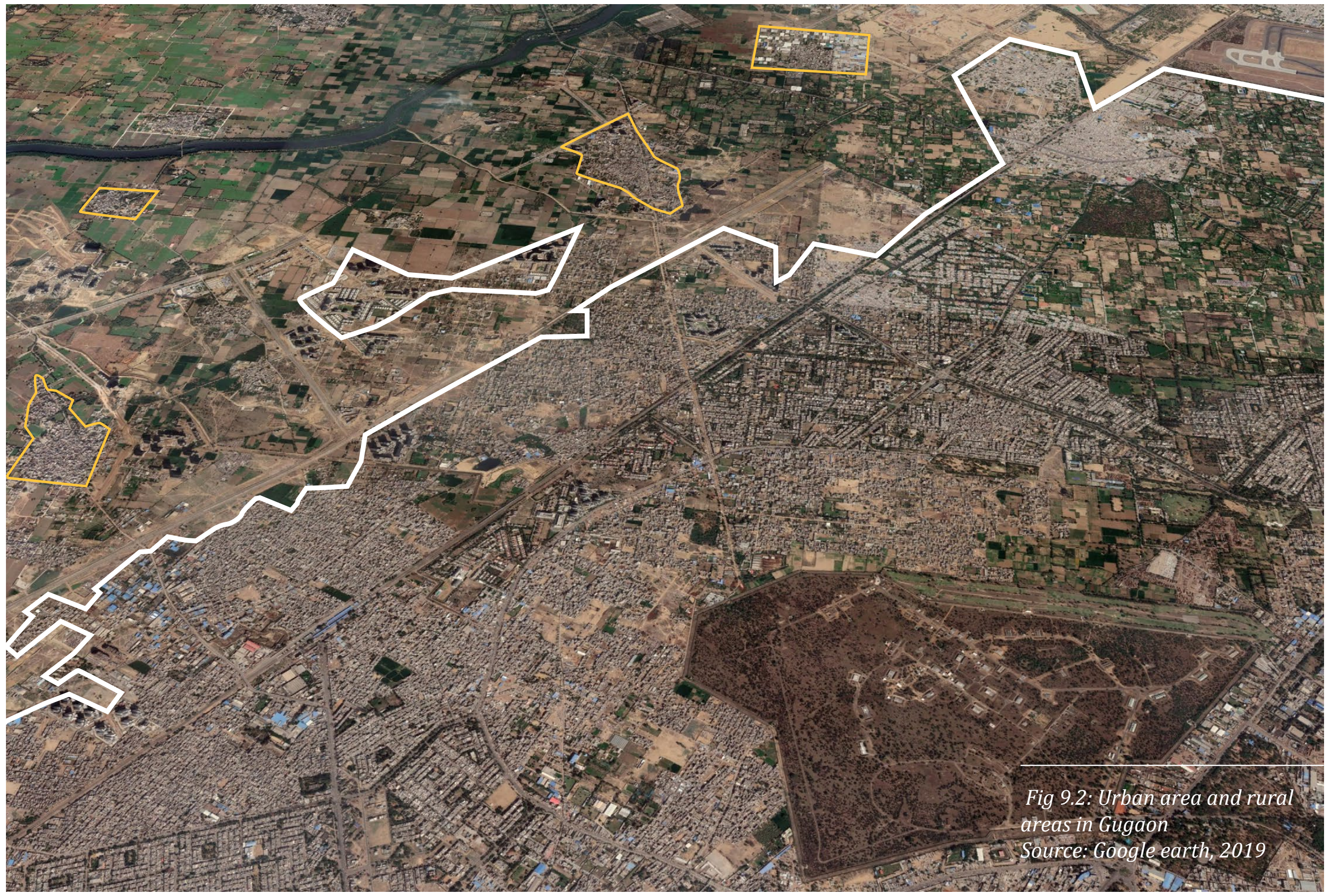


Fig 9.2: Urban area and rural areas in Gugaon
Source: Google earth, 2019

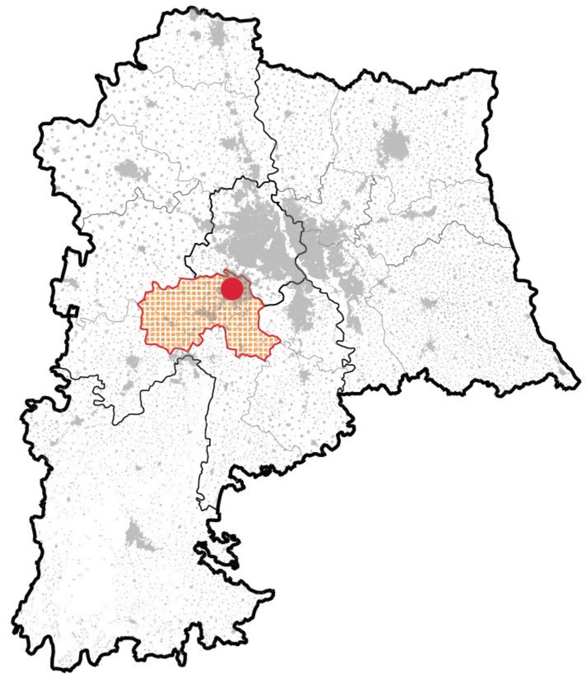


Fig 9.3: Gurgaon outskirts
Source: SEL projects

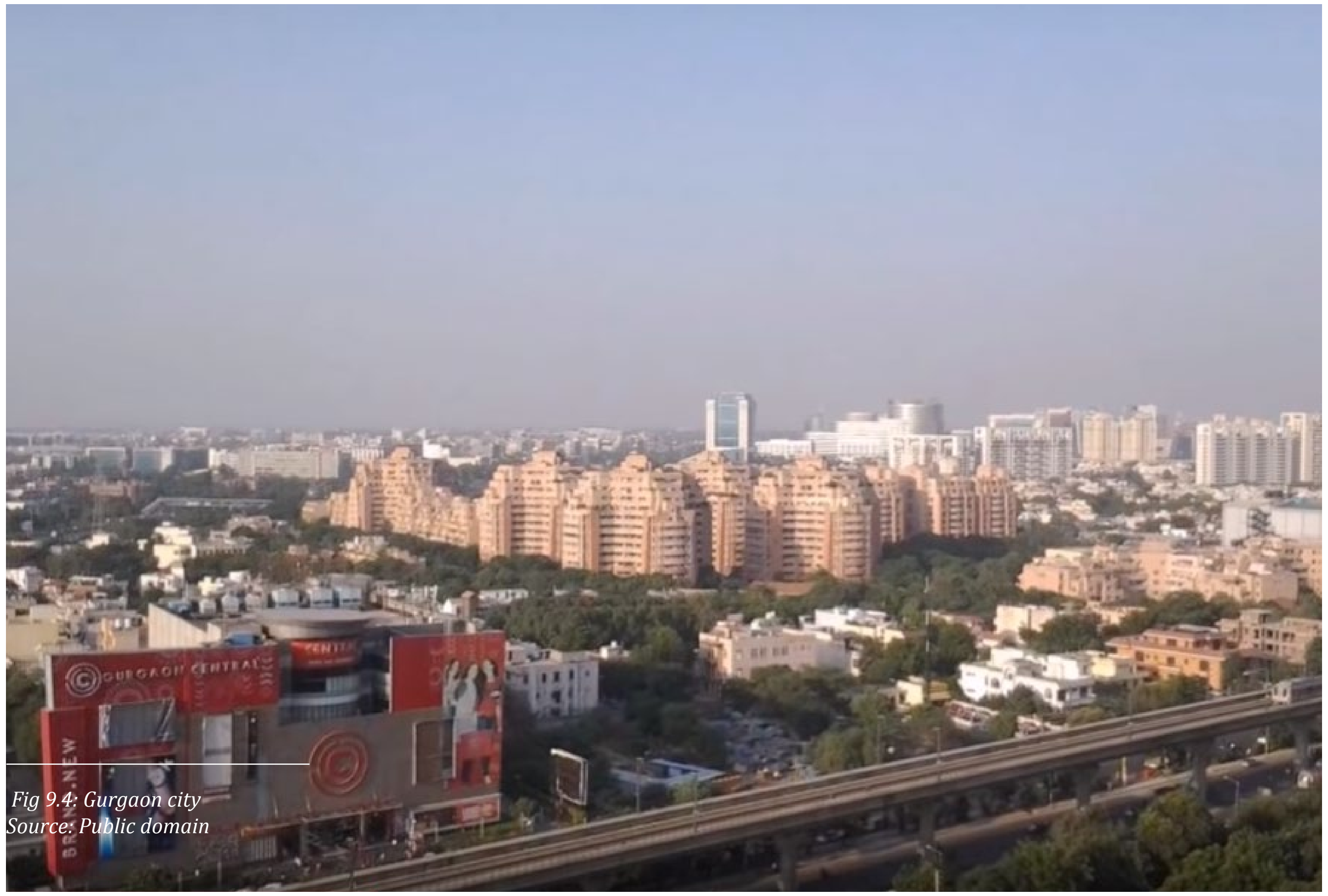


Fig 9.4: Gurgaon city
Source: Public domain

9.2 | Location 2 : Alwar, Rajasthan sub-region

Alwar is the district in the Rajasthan sub-region of the study transect. This region has very low levels of urbanisation and has a historic city that is linked to tourism activities. The remaining entire area are rural areas with villages.

This is the second type of urban-rural system, where the area is predominately rural with high levels of agricultural activities.

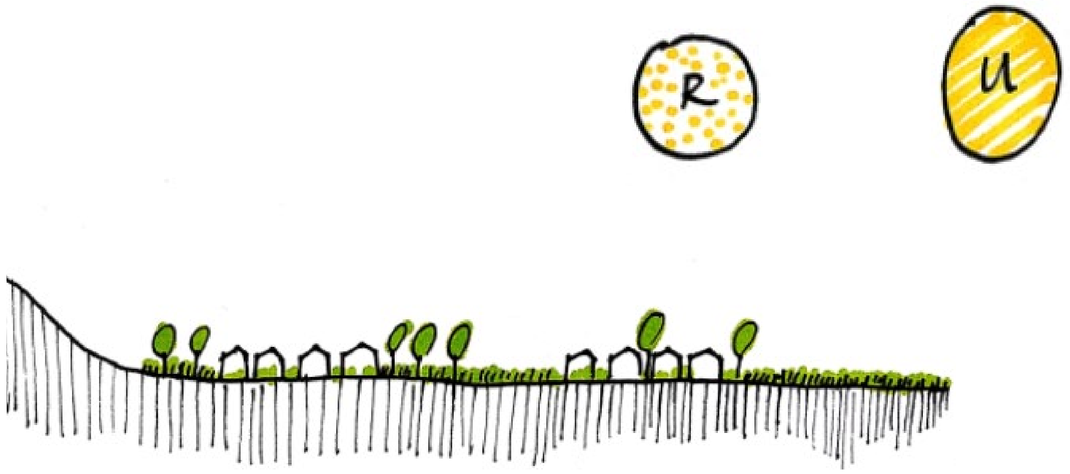


Fig 9.5: Predominantly rural area
Source: Author

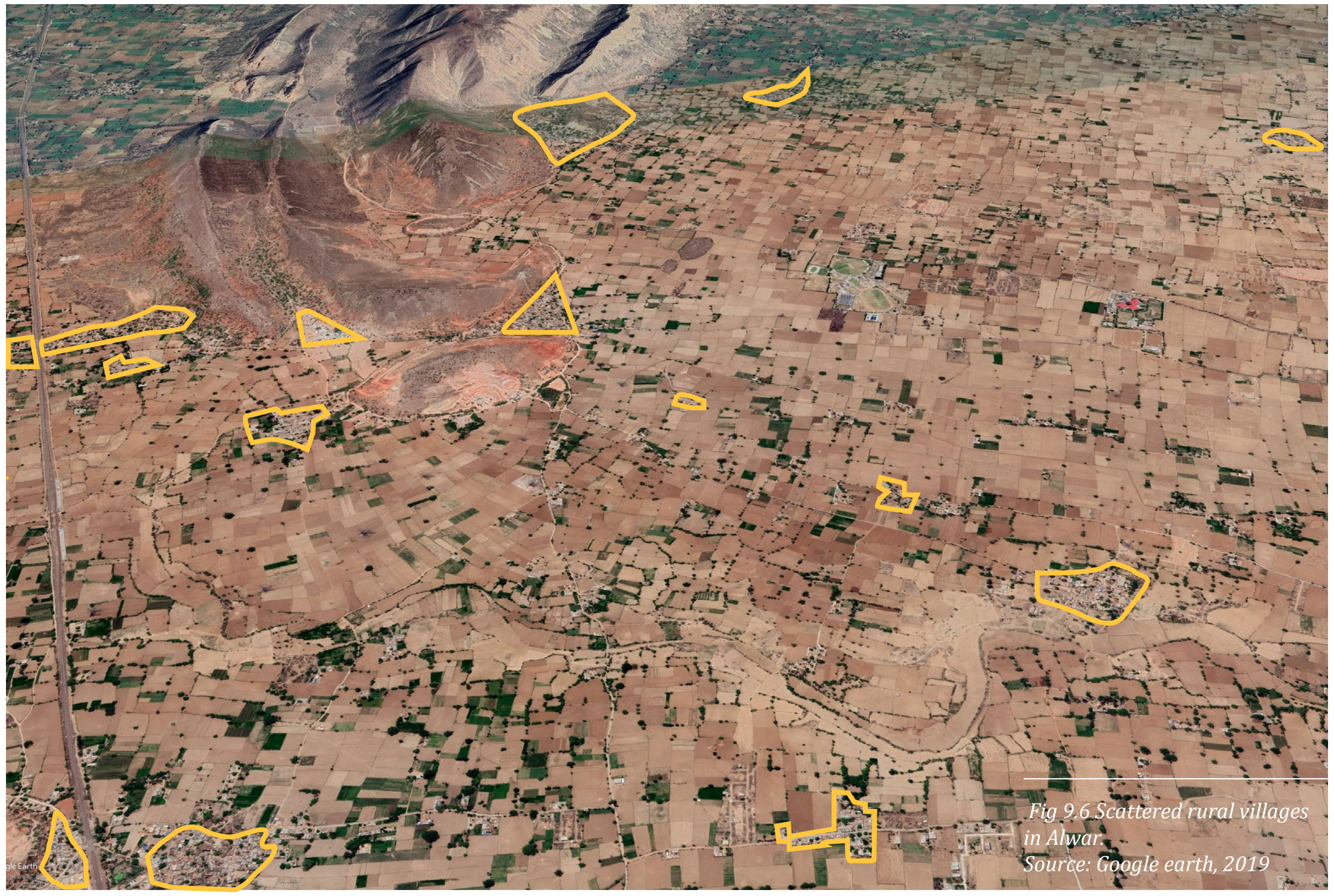
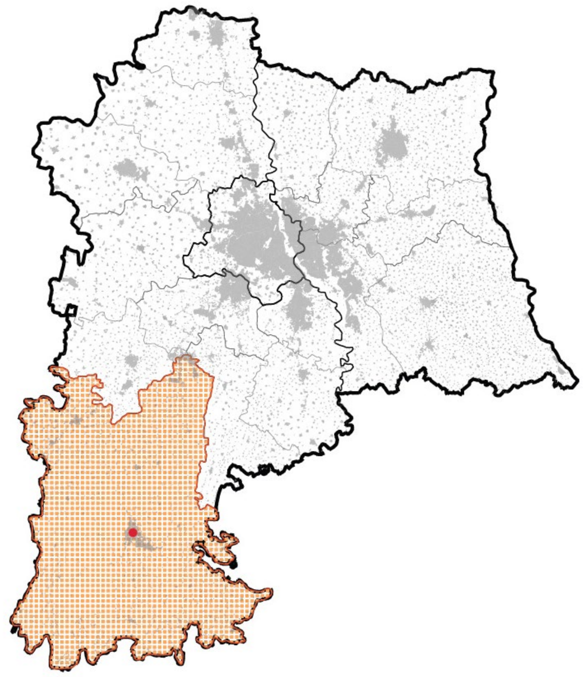


Fig 9.6 Scattered rural villages in Alwar
Source: Google earth, 2019



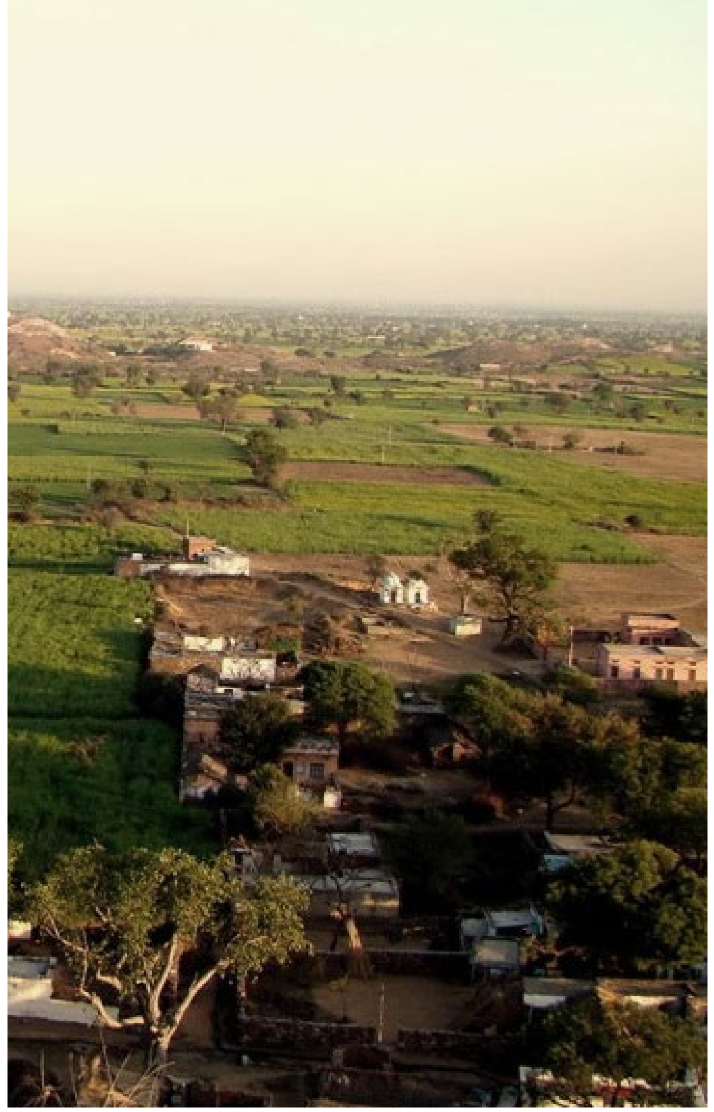


Fig 9.7: View of a village in Alwar
Source: www.mapio.net

Fig 9.8: Village in Alwar situated in between agricultural fields.
Source: www.mapio.net

9.3 | Location 3 : Rewari, Haryana sub-region

Rewari is one of the 9 districts in the Haryana sub-region. The city of Rewari is developing as an extension of the growth from Delhi to Gurgaon to Rewari. Currently, the city is developing but is still in close link with the rural areas. The villages are situated outside the city boundaries. The city is also part of many planned development projects in the near future. This means more development and chances of increased urban-rural divide, if not developed in a just manner.

This is the third type of urban-rural system seen in the transect scale. And for the study of local scale, it is this type of urban-rural system (the case of Rewari) that is used. Application of scenario planning will be tested on this particular location. This is further explained in the next section.

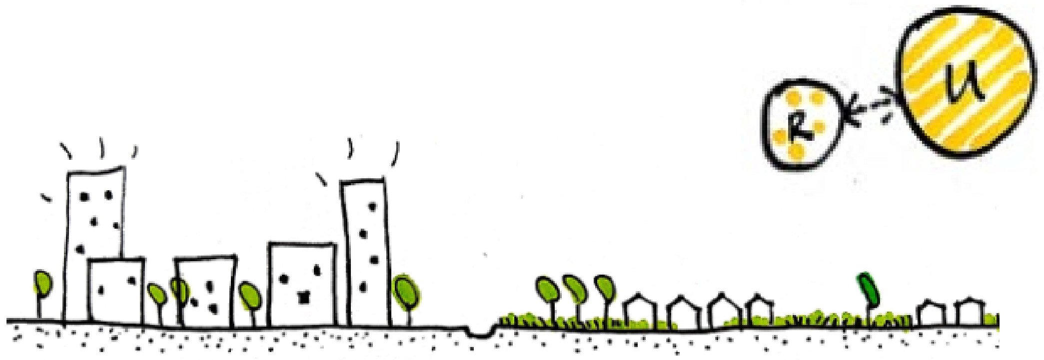


Fig 9.9: Urban area transitioning into regional center. The link to rural area is still visible
Source: Author

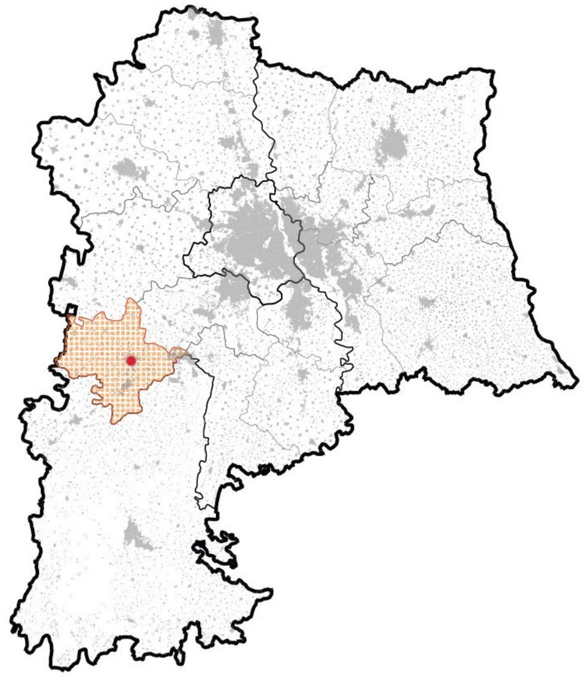


Fig 9.11 : Streets in the outskirts of Rewari
Source: SEL Projects

Fig 9.10: Urban area transitioning into regional center. The link to rural area is still visible
Source: Google earth, 2019

Fig 9.12 : Bird's eye view of Rewari
Source: Google earth, 2019

9.4 | Scenarios of Rewari

This section covers the details regarding the exisiting status quo, population and energy projections for 2051, scenarios studied, ecological, social and economic impact assessment and conclusions of each of the scenarios.

| Existing Status quo

The study area is a 100km² (10km x 10km) area of the Rewari district. This area includes a part of the urban area and the rural villages. The calcualtions in the coming sections are based on the details from the census 2011 and these details have been used to map out the scenarios on to the zoom-in location.

***Demographics**

900,300 people live in the district of Rewari

live in 72.4% rural areas

Based on census 2011

Population Density

565 pp/km²

Based on census 2011

Landuse Pattern

1594 km² area of district of Rewari

65 km² of urban area

1442 km² of rural area

1208 km² of net sown area

**Net area sown in the district is 83.79 percent of total area*

Gender vs jobs

36.8% WPR

49.8%

22.1%

Shelter

46% houses in Haryana sub region are not in good condition

4.2% rural

2.6% urban

dilapidated houses

Water

Over exploited status of ground water availability

Energy

90.3% of the *households in the district electrified

agriculture

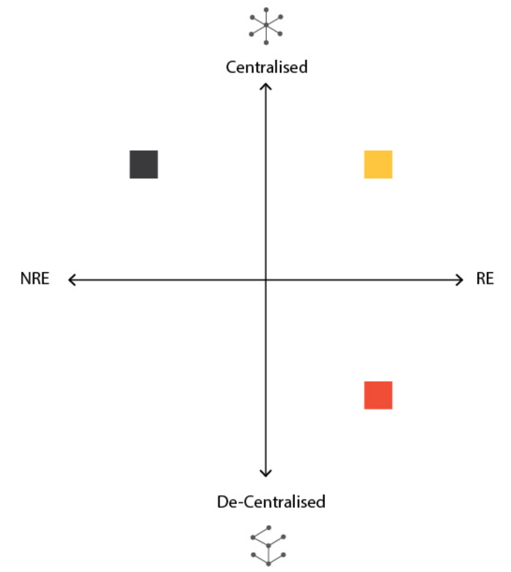
domestic

**Most of the households in villages that have electricity connections, the state-grid is only able to provide electricity to the households for only around 2-6 hours a day, instead of 24x7*

Air

177 ug/mg3 annual mean concentration of PM10

High levels of PM10 exceeded the WHO standards by 295% in Haryana sub-region



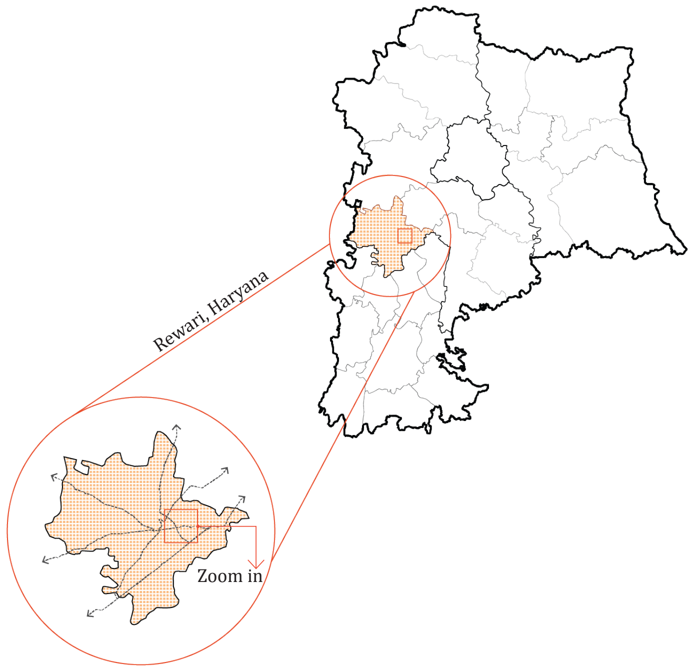


Fig 9.13 (a) : Scenarios studied on Rewari

Fig 9.13 (b): Satellite image
Source: Google earth, 2019

Fig 9.14 : *Streets of Rewari*
Source: SEL projects

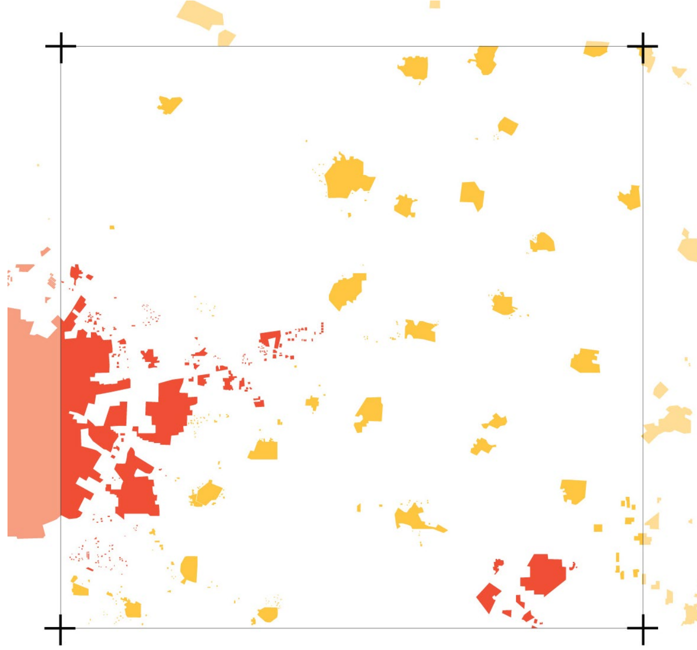
Fig 9.15 : *Agricultural fields of Rewari*
Source: SEL projects

Built up area : 12 km^2
Urban: 8km^2
Rural: 4km^2

Urban built up

Rural built up

Fig 9.16: Built environment
Source: Author



Main roads link one urban area in the districit to the urban area in the next district.

Road connections connecting rural villages are weak and do not host many economic zones.

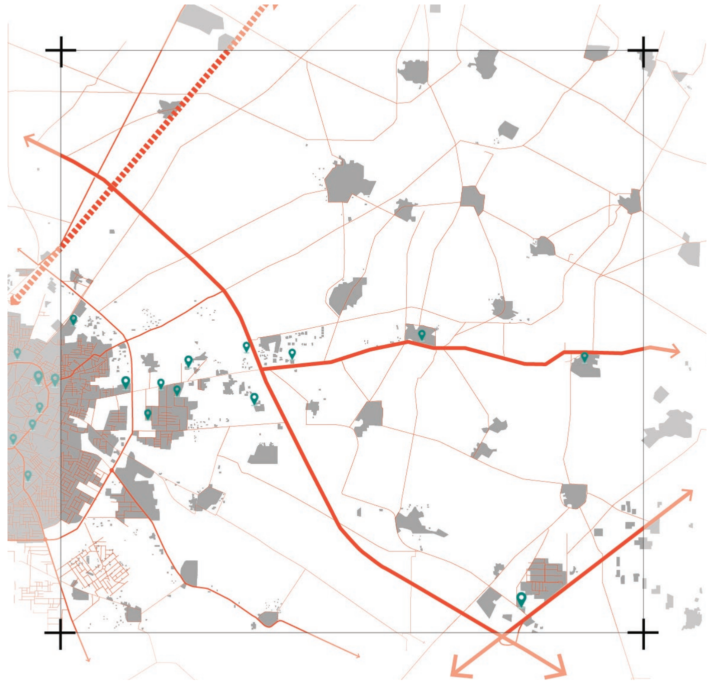
Most activities are situated in the city area.

Connections

Main Connections

RailwayConnections

Fig 9.17: Infrastructure lines
Source: Author



Water is in a critical phase in Rewari due to the deficit in rainfall. The large areas of agriculture depend on water that is brought by the JLN (Jawaharl Lal Nehru) canal that conveys water from the Yamuna river that passes through Haryana. New canals are proposed to help in irrigation of the agricultural lands of the area where wheat is the main crop that is grown.
Calculated agriculture area : 60km2

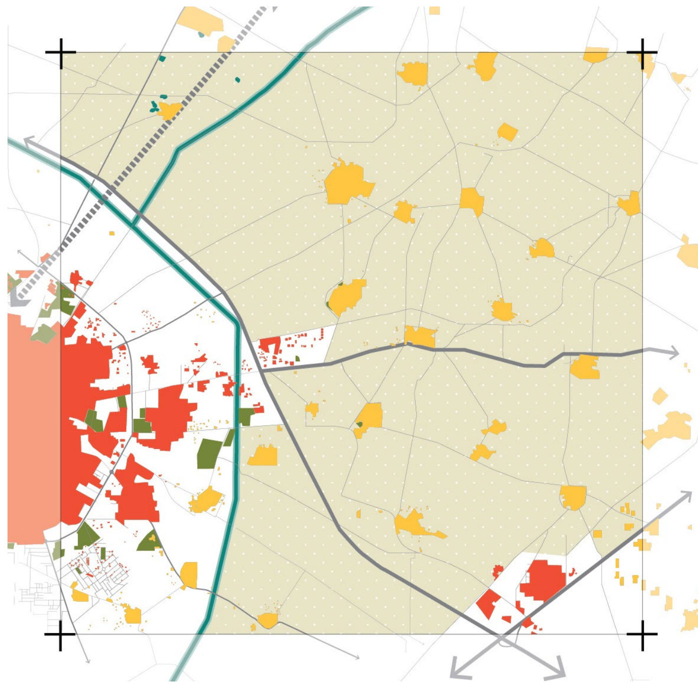
Urban built up

Rural built up

Water canal

Green areas

Fig 9.18: Green-blue network
Source: Author



| Main principles

Densify	Densify areas to prevent sprawling into rural areas and agricultural fields
Transit support	Creating strong infrastrucuture lines to facilitate movement and encourage development
Economic zones	Possibilities of starting economic zones in the area
Natural system preservation	Focusing on ways in which the impacts on the ecological system is reduced

| Rewari, Haryana 2051

The below tables show the extrapolated data for population density, energy consumption and the daily power generation required for the year 2051. The extrapolated data has taken into account the growth rate and decline based on previous year's trends.

Year	2011	2021	2031	2041	2051
Population	900332	1027607	1136909	1218044	1262338
Growth Rate (GR) (%)	17.64	14.14	10.64	7.14	3.64
GR Decline (%)	3.5	3.5	3.5	3.5	3.5
Pop Density (p/km2)	564.83	644.67	713.24	764.14	791.93

Per capita consumption (kWh/p/year)	Year	2017	2018	2019	2020	2021	2031	2041	2051
	Haryana	1975	2074	2177	2286	2401	3910	6370	10375
	Growth Rate (%)	2.0	5.0	5.0	5.0	5.0	62.9	62.9	62.9

2051	Population Density (p/km2)	Population (p)	No. of households	Per Capita Consumption (kWh/p/year)	Total Energy Consumption (GWh/year)	Daily Energy Generation (kWh/day)
	791.93	79193	15839	10375	821.66	2251115

Increase in population by 2051 requires a projected 2 times increase in built up area to 25km². To prevent the sprawl of the city a strong green belt is added just outside the ring road.

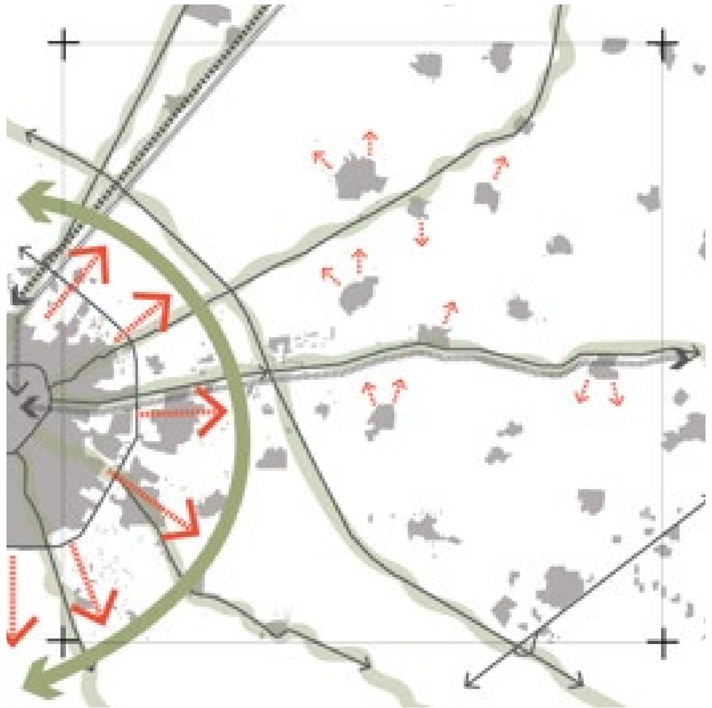


Fig 9.19 : Expansion of built area
Source: Author

New infrastructure lines are added into the spatial development linking the rural areas to each other and urban to rural areas.

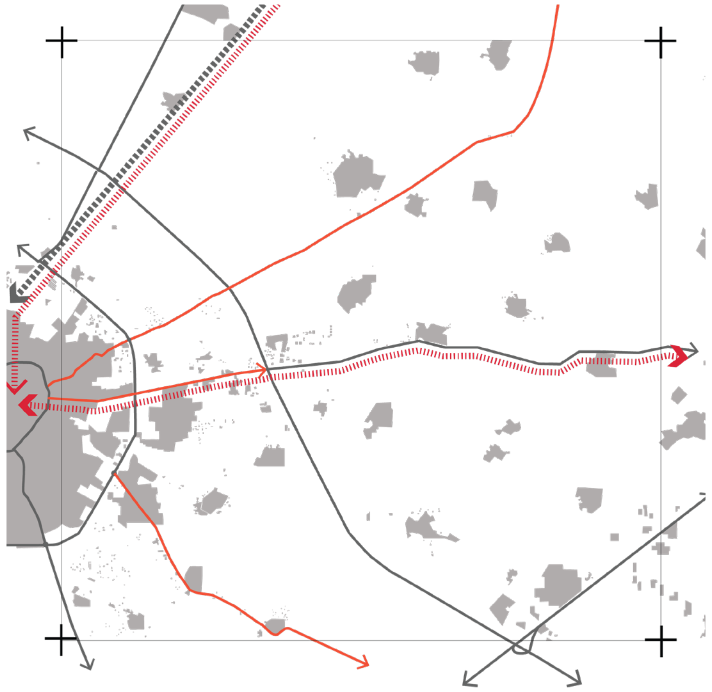


Fig 9.20: New infrastructure lines
Source: Author

Green buffer areas along the main infrastructure lines to create an inter connected green zone network.

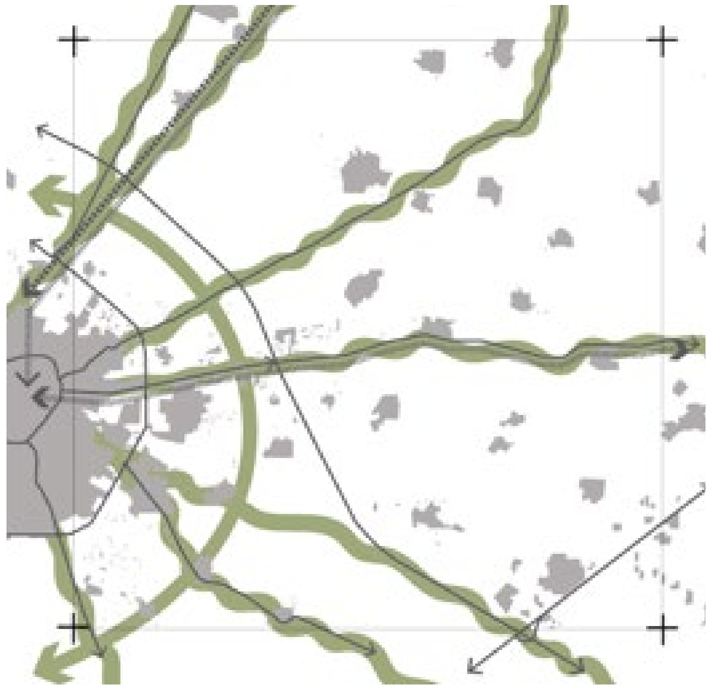


Fig 9.21: Green networks
Source: Author

The scenario development of using a N.R.E system began with looking at the area required for the establishment of the thermal power plant. The power plant generates power to meet the future energy demands.

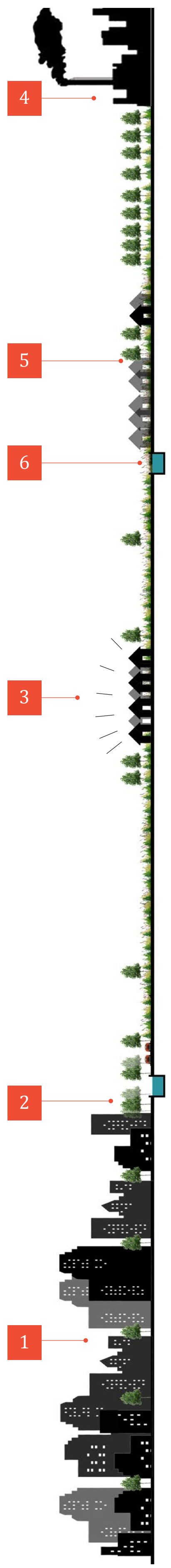
Year 2051

In the year 2051, new infrastructural developments are seen. The lines link Rewari to the other cities in the region and also has important link to other states. Rapid transport systems like the extension of the metro region to Rewari is established. As mentioned by (Bansal, 2017), the development of the region lies along the infrastructure lines spread across the region. The economic zones are developing along these new lines.

The power plant had to be established away from densely populated areas.For the setting up of the power plant, villages need to be relocated to a safe distance to avoid poor health conditions. The green belt around the plant makes a sponge for a number of harmful gases. A new water canal has been added into the area, to reduce the problems of water shortage and also to supply water to the power plant for electricity production.

A few villages are developing due to the proximity to the infrastructure lines. All the villages are connected to the grid system that is powered by the power plant. The following sections will explain regarding the ecological, social and economic flows related to this scenario.

1. Increase in population by 2051 requires a projected 2 times increase in built up area to 25km² and then, over years can densify instead of sprawling.
2. Green belt to prevent outward spawling of the city.
3. Small economic zones developing along new infrastructure development that links the urban and rural systems
4. Coal power plant; 1.5km² area
5. Villages relocated + green belt 3km radius to act as buffer between power plant and human habitation
6. Additional water system helps with water retention and caters to the added water required by power plant. The canal will be connected to the JNL canal that conveys water from the Yamuna river.



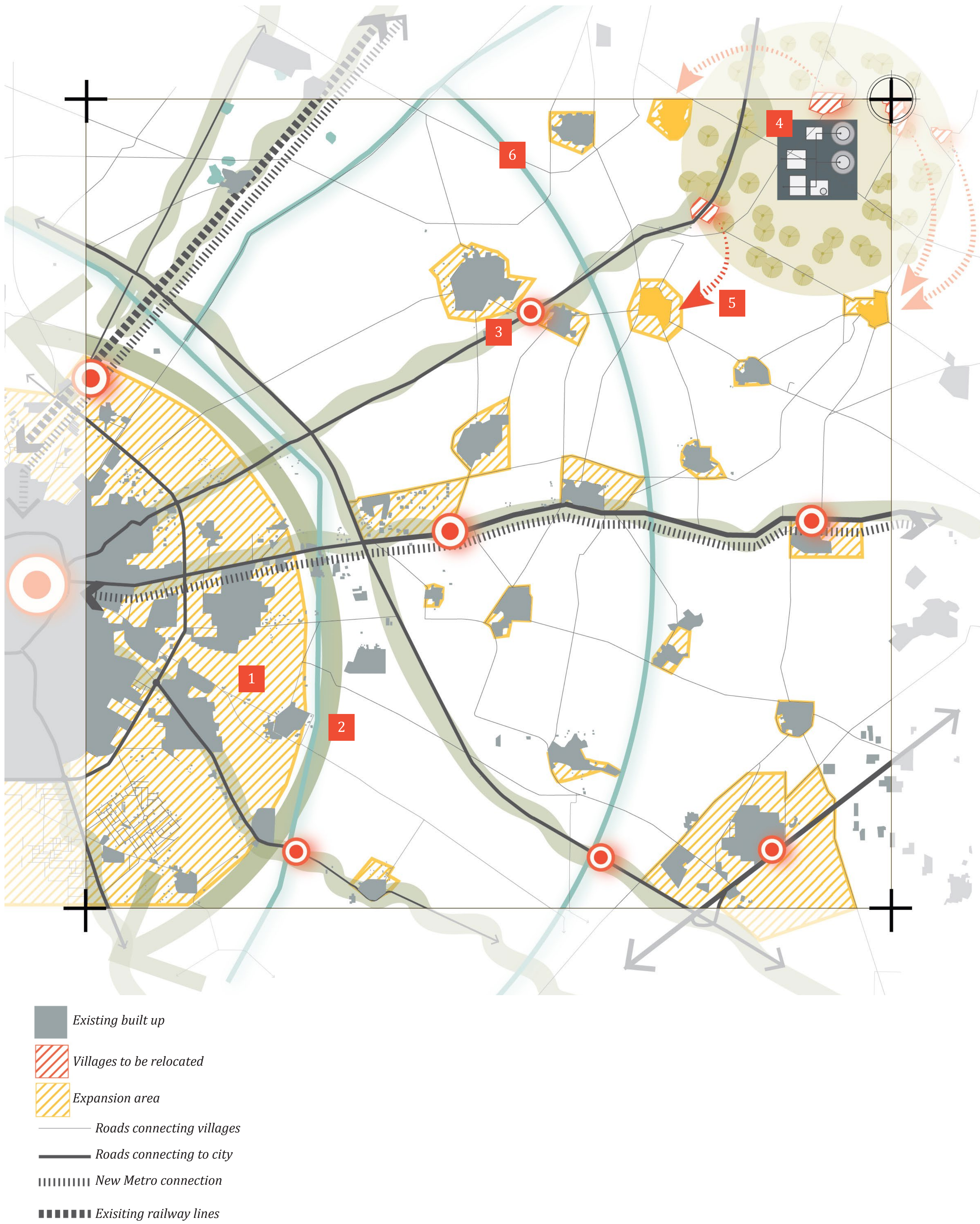


Fig 9.22: Scenario depiction on a spatial level
Source: Author

Energy Calculations for the Area

In the case of scenario 1, a thermal power plant would be built in Rewari to supply electricity in the future. Based on the projected 2051 population density of the region and household energy consumption of the state, the below calculations are done for the 100km² (10km x 10km) chosen area. This is to achieve a rough estimate of the area required for implementing a thermal energy system in this area.

Year 2051: Energy demands and area requirement

Rewari has a population density of approximately 800p/km2 , over 16,000 households (census of India considers 5 people per household (NCRPB, 2013)) and energy consumption of 900GWh/year.

For the purpose of calculations, the following assumptions are made. The thermal power plant is coal based and runs for 350 days/year (approximately two weeks maintenance). Since this area does not have mining fields, the plant will have to run on imported coal. As per standards, the power plant will consume 5m³ of water per MW power generated with ash water re-circulation system and releases around 340 ton/GW of CO_2 (Vreuls, 2004; C.E.A, 2010).

To meet the energy demand, a thermal power plant of 107 MW will be required. The report for land requirement suggests that with thermal power plants, they generate more for a larger consumption (for energy export to other regions). And since the standards are based on 2x500MW plants, the scenario incorporates the same. A thermal power plant of 2x500MW requires an area of 1.5km². A large percentage of the area goes towards well established ash pond and a green belt (C.E.A, 2010). However, the spatial design will consider a green belt of 3km radius around the power plant. A total of 7.5km² (1.5km² thermal power plant and 6km² green belt) for this type of energy production system is adapted into the spatial development of the area. The vastness of the green area is taken to give back to the agricultural land that existed and studies show that inhabitation is best at least 3km away from a thermal power generation plant to reduce heath degradation (Ha et al., 2015).

Upon overlaying the thermal power plant along with the other developments of the area, the spatial development has been mapped out to depict scenario 1. The following sections evaluates this energy based spatial development on 3 aspects; ecological, social and economic.

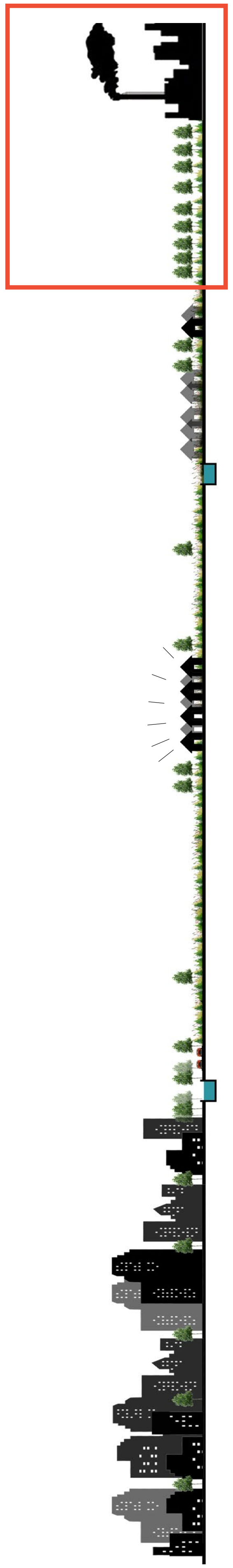


Fig 9.23 : Section showing the scenario of implementing a N.R.E source in the area.
Source: Author

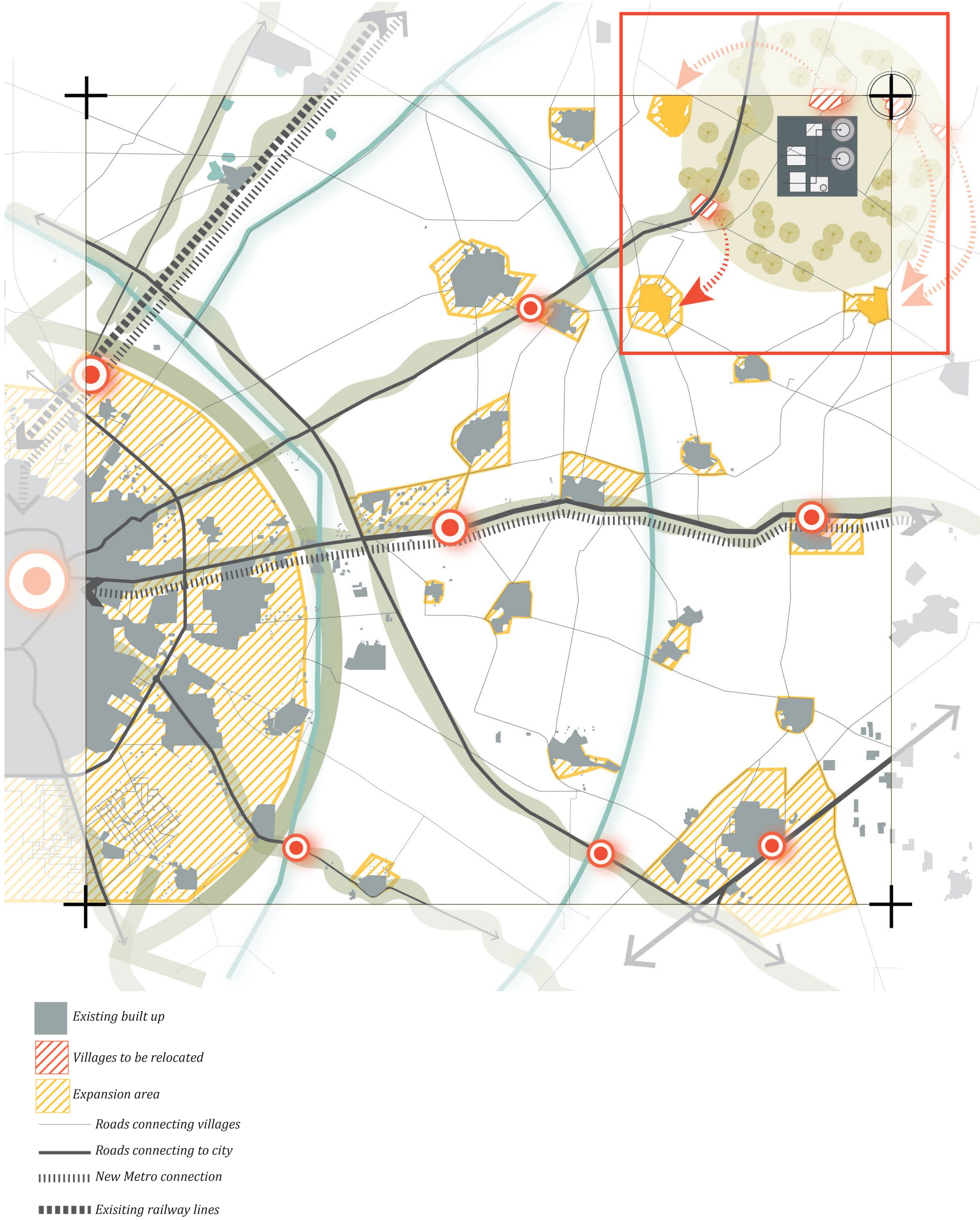


Fig 9.24: Scenario depiction on a spatial level
Source: Author

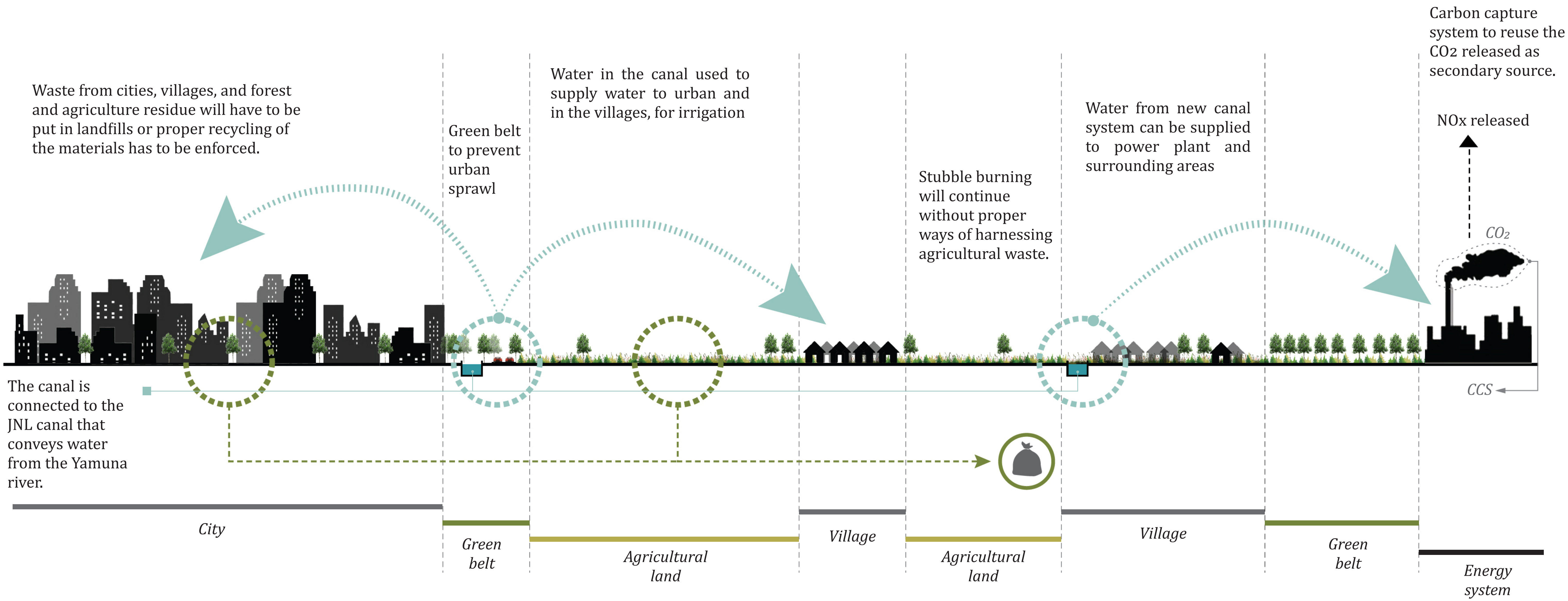
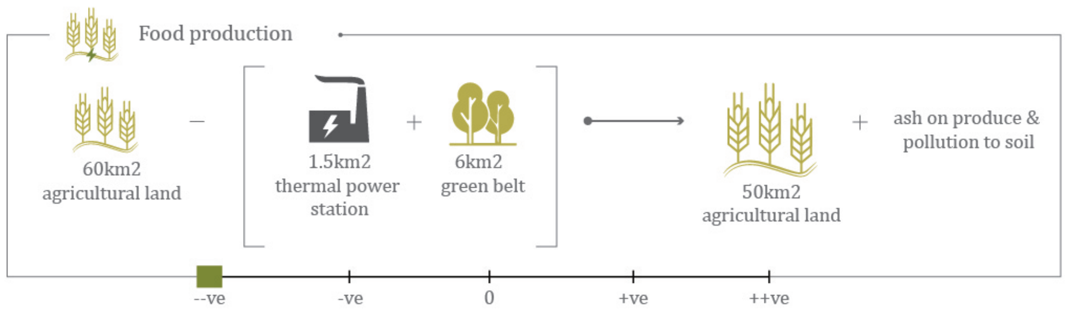
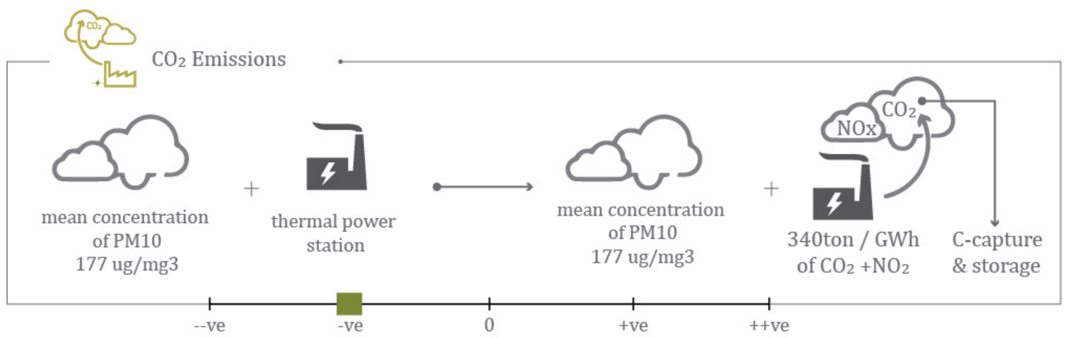


Fig 9.25: Section showing the ecological flows in the implementation a N.R.E source in the area.
Source: Author

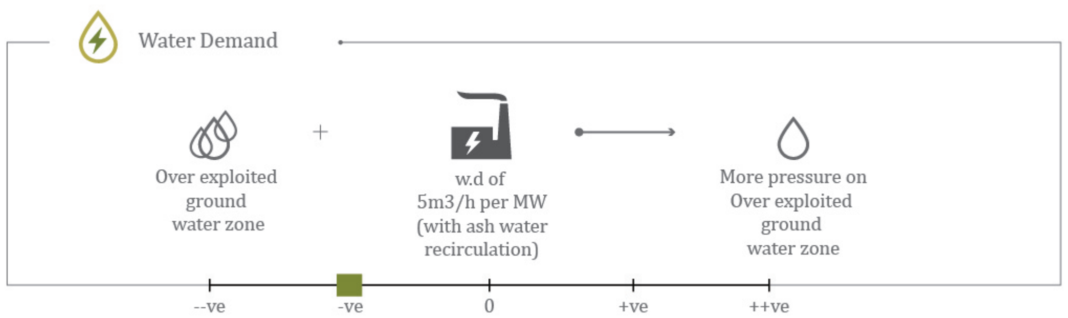
Ecological



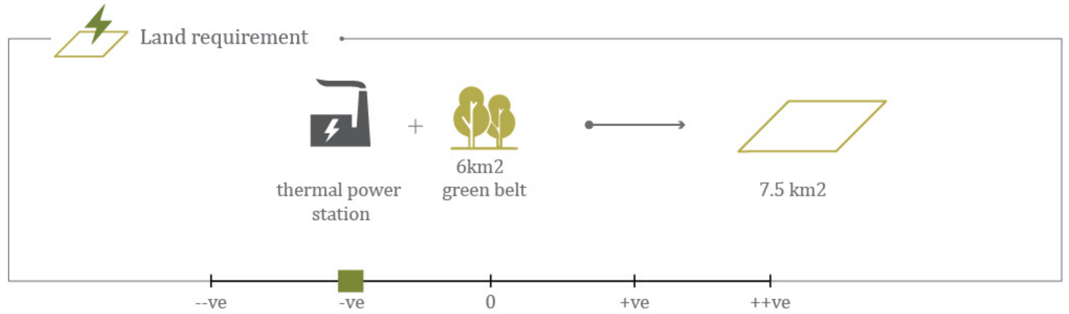
1. Food production: The energy system not only reduces the area for agricultural production. The ash pond over time can cause harm and degrade the soil quality, thus reducing food production on the long run. The energy system does not help in reusing any resources and it is marked (--ve) as it is a negative change to the existing status quo and embodies no value of sustainable development and circular economy.



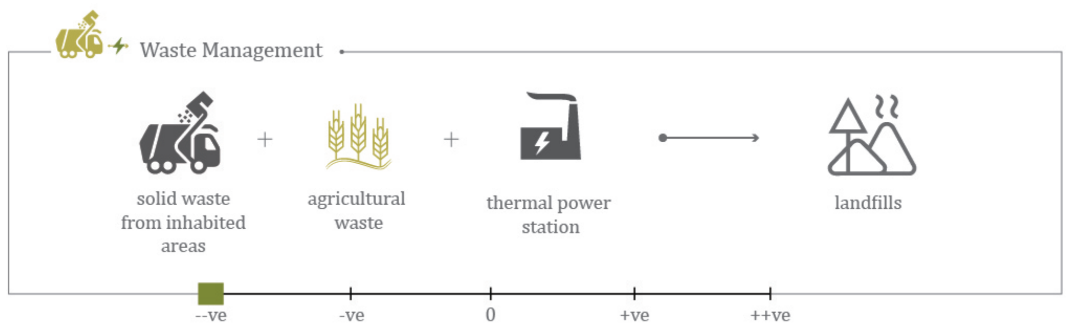
2. CO2 emissions: The plant will produce approx. 340 tons of CO_2 per GWh it produces. The gaseous emissions also include NO_2 which can add to the air pollution. With Carbon capture technology (Cell Press, 2019), carbon dioxide emissions can be significantly reduced. But the area already has a higher PM10 value and the NOx gas released can add to the degradation of air quality. However, the carbon capture allows for carbon dioxide to be reused to create a secondary resource. It is marked (-ve) as it is a negative change to the existing status quo but embodies one aspect of circular economy.



3. Water demand: Rewari comes under the water classification of over exploited. With a really low ground water table and higher water demand due to agriculture. The spatial development takes into consideration additional water systems to the area. But an energy system that uses $5m^3/h$ per MW of water that cannot be reused for any other purposes adds more pressure to the water table. The system of ash water recirculation in the power plant would still mean that certain amount of water can be reused again in the energy system. It is marked (-ve) as it is a negative change to the existing status quo but the reuse of waste water embodies one aspect of circular economy.



4. Land requirement: The area required for the power plant is $1.5km^2$ and this land will be degrading over time. The remaining land is a thick green belt that can help preserve the remaining environment and it is marked (-ve) as it is a negative change to the existing status quo but embodies one aspect of circular economy as the green belt helps reuse the land for other non-inhabitation.



5. Waste management: The energy system plays no role in reducing the waste produced. Most waste will end up in landfills. This energy system has a negative impact by producing additional waste materials. It is marked (--ve) as it is a negative change to the existing status quo and embodies no values of sustainable development and circular economy.

Legend

***--ve** : A very negative change and embodies no values of sustainability or circular economy, creating a long-lasting chain of negative events*
***-ve** : A negative change to the existing status quo but embodies one aspect of sustainability or circular economy*
***0** : Has no impact on the existing status quo*
***+ve** : A positive change to the existing status quo and embodies one aspect of circular economy or sustainability*
***++ve** : A very positive change and embodies multiple aspects of sustainability or circular economy.*

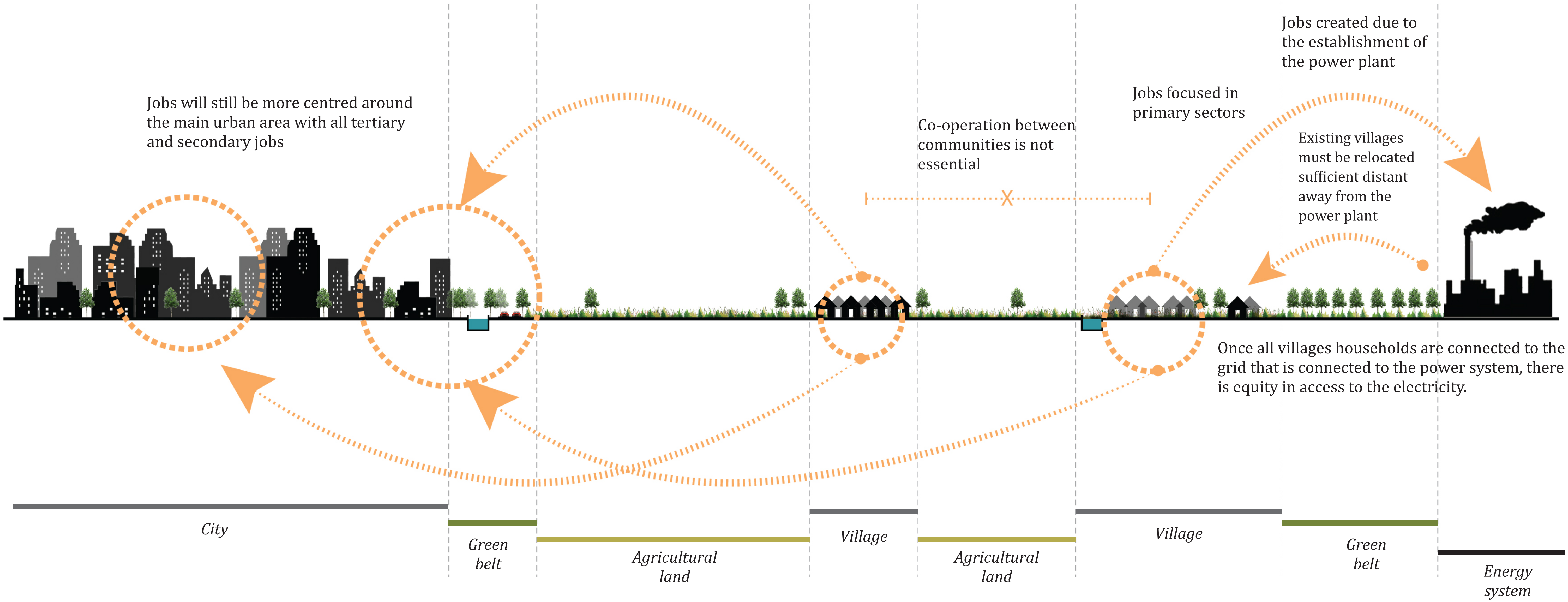
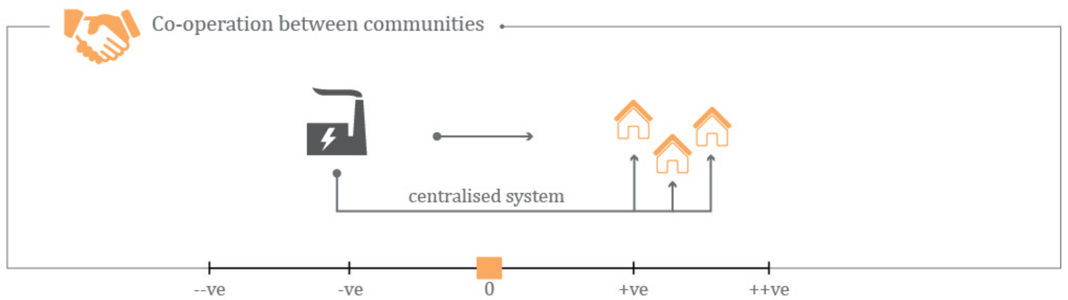


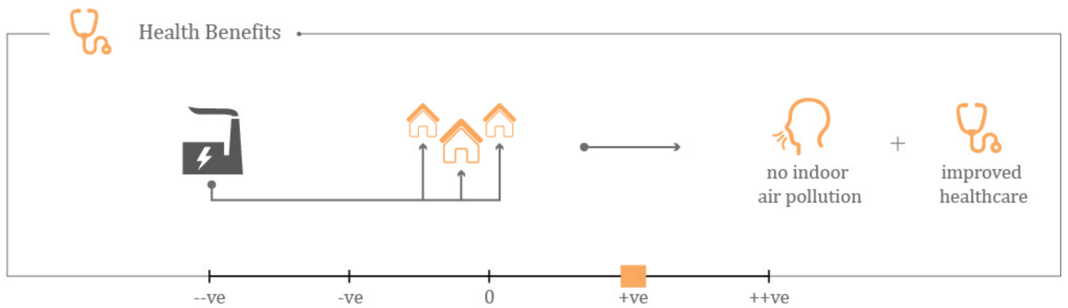
Fig 9.26: Section showing the social flows in the implementation a N.R.E source in the area.
Source: Author

Social

1. Village location: With the introduction of a power plant in the spatial development of the area. Few existing villages must be relocated sufficient distant away from the power plant. This relocation can have a negative impact on the people as many of them have lived there since generations. Interviews with organisations made it clear that relocation of communities can lead to various disparities like difficulty adjusting, protests and if not properly rehabilitated can lead to even homelessness. It is marked (-ve) as it is a negative change to the existing situation but embodies one aspect of sustainability as the relocation is for improving the social well-being of the communities.

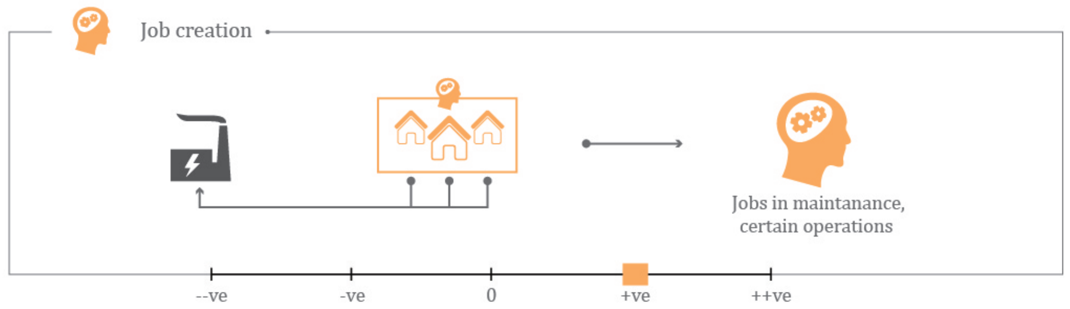


2. Co-operation between communities: The energy system does not inculcate the need for co-operation between communities. So it is marked (0) as the energy system has no impact on the existing status quo.



3. Health benefits: The power plant will be able to meet electricity demands of all. And this has a significant impact in improving the health conditions of people living in the households and to run healthcare centres in the area. It is marked (+ve) as it has a positive impact on the existing status quo and it embodies one aspect of sustainability by improving the social well-being of the communities.

4. Equity in access to electricity: Upon ensuring that the state government connects all households to the central grid that is connected to the power system, everyone will have equity in access to the electricity generated. However, there are chances that some people on lower income levels might find it difficult to afford continuous access to electricity. It is marked (+ve) as this is a positive change to the existing status quo and it embodies one aspect of sustainability by trying to facilitate the presence of electricity that can then be shared amongst all in the society.

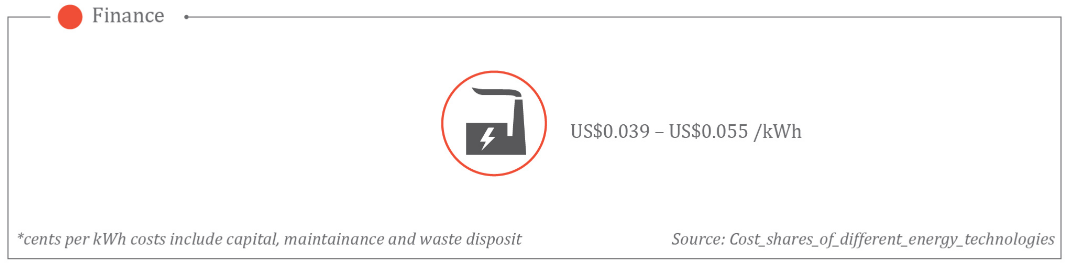


5. Job creation: There will be jobs that are created due to the establishment of the power plant. And access to electricity will help in running businesses in the rural areas. However, the access to electricity does not ensure the productive use of electricity to have economic development in the areas (Pueyo & Maestre, 2019). It is marked (+ve) as it is a positive change to the existing status quo and embodies one aspect of sustainability by creating additional jobs and facilitating the improvement of the social well-being of the communities.

Legend

--ve *: A very negative change and embodies no values of sustainability or circular economy, creating a long-lasting chain of negative events*
-ve *: A negative change to the existing status quo but embodies one aspect of sustainability or circular economy*
0 *: Has no impact on the existing status quo*
+ve *: A positive change to the existing status quo and embodies one aspect of circular economy or sustainability*
++ve *: A very positive change and embodies multiple aspects of sustainability or circular economy.*

Economic Flows



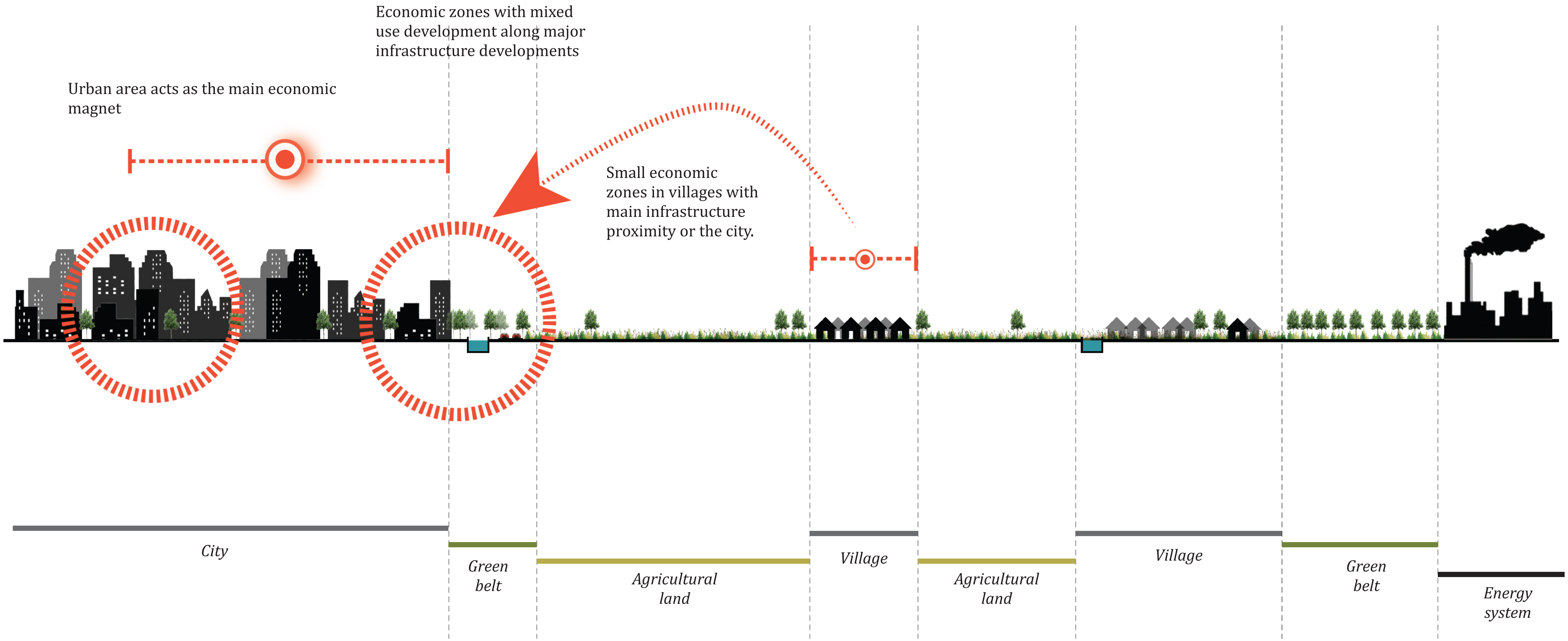
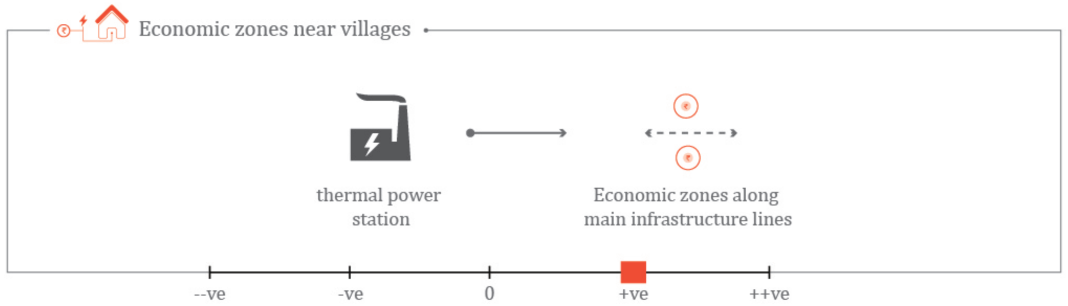
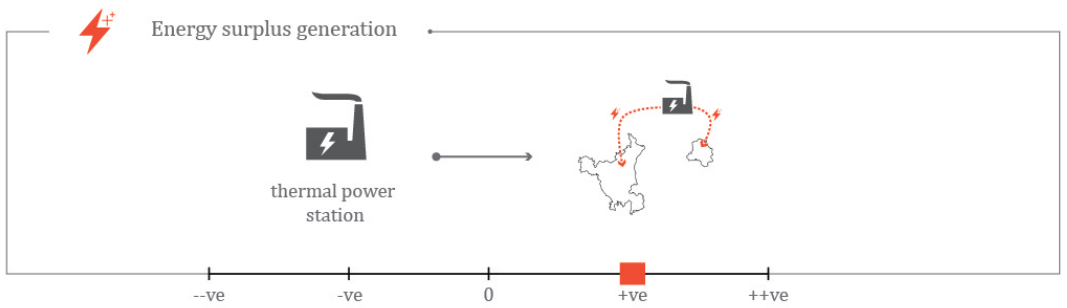


Fig 9.27: Section showing the ecoomic flows in the implementation a N.R.E source in the area.
Source: Author

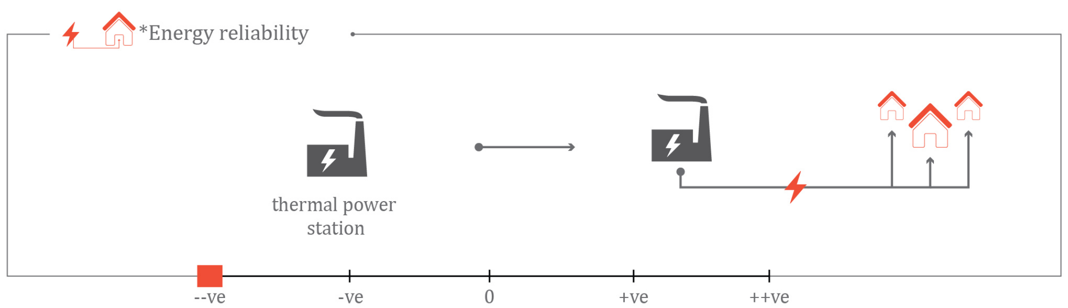
Economic



1. Economic zones near villages: One of the key enablers for economic development is access to electricity. However, the access to electricity does not ensure the productive use of electricity to have economic development in the areas (Pueyo & Maestre, 2019). It can be seen from the spatial development of the region that main infrastructure lines also play a key role developing economic zones (Bansal, 2017). So, the villages that are closely linked to main infrastructure lines have higher probability of having economic growth. It is marked (+ve) as it is a positive change to the existing status quo and embodies one aspect of sustainability by creating additional jobs and facilitating economic growth.



2. Energy surplus generation: The power plant is built for higher production values, this allows for surplus electricity to be supplied to other energy intensive industries in the state and also to other urban and rural areas of the state. Based on the interviews with organisations, it is evident that the current un-reliable supply of electricity is hindering the development of rural areas. Having surplus electricity would ensure an uninterrupted power supply which would cater to the development of economic zones. It is marked (+ve) as it is a positive change to the existing status quo and embodies one aspect of sustainability by promoting to the economic growth of the state.



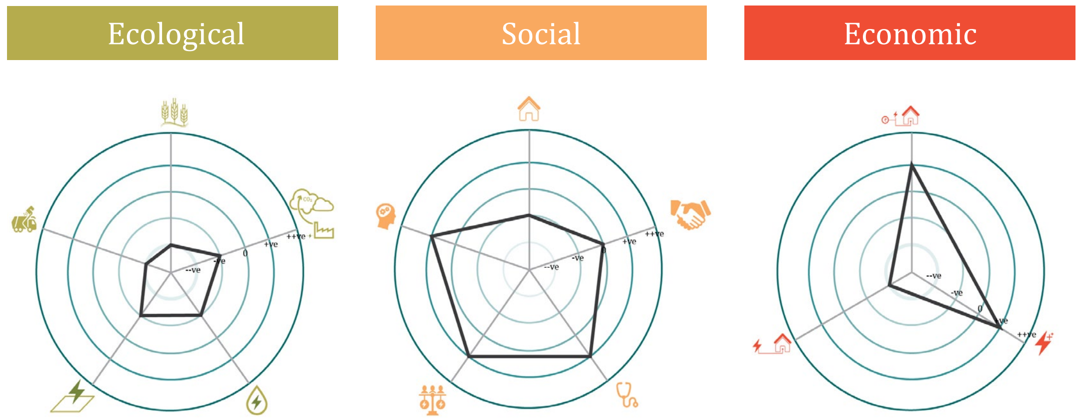
3. Energy reliability: Since thermal power plants are not influenced by the climatic conditions, they are reliable sources in power generation. However, the depletion of fossil fuels and the fact that it is a non-renewable energy source makes it a question of how humans wish to progress. Because relying on non-renewable sources is a negative change and embodies no aspects of sustainability or circularity, it is marked (--ve).

| Conclusions

The comparison between the impacts shows that the fossil based energy system has more positive social and economic impacts. This is also because just the ability to provide access to continous electricity (no matter what the source) is definitely boost the social well-being of the area. This also means chances of increased economic activities.

Since, the scenarios depict plausible futures to have less negative impacts on the ecology, the power plant has to be equipped with CCS technology to reduce the CO_2 emissions and to create secondary fuel sources. Water re-circualtion systems will ensure reuse of water to an extend. And having a strong green belt around the power plant will ensure better health conditions for inhabitants.

The webbed diagram below shows the consolidated impacts of the three aspects.



| Scenario 2: Rewari powered by 100% Centralised R.E system

The scenario development of using a R.E system began with looking at the area required for the establishment of solar farms or biomass farms. From the calculations, it is evident that having a centralised biomass system would require more area than the 100km² study area. For this scenario illustration, a solar farm will generate power to meet the needs of the future.

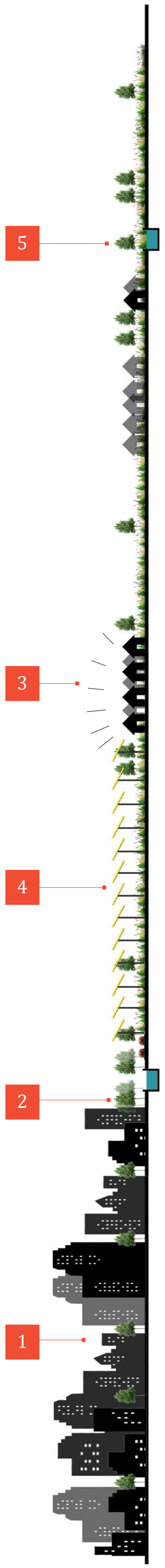
Year 2051

In the year 2051, new infrastructural developments are seen. The lines link Rewari to the other cities in the region and also has important link to other states. Rapid transport systems like the extension of the metro region to Rewari are established. As mentioned by (Bansal, 2017), the development of the region lies along the infrastructure lines spread across the region. The economic zones are developing along these new lines.

Keeping in mind the need for natural system preservation, energy is produced along with food crops. A study in Rajasthan, shows that food can be growth in the shade of the energy panels. This system is called Agri-voltaic (Singh, Meena, Kumawat, Mishra, & Jain, 2018). Crops that are not too tall and that can withstand shade are to be introduced in areas where solar micro-grids or areas in the agriculture fields where solar panels are set up. A study conducted in Jodhpur, Rajasthan (this area has similar climatic conditions with the NC region) shows that crops like certain beans, medicinal herbs etc grow in between panels and vegetable like cabbage, onions and more grow below the panels. A new water canal is added into the area, to reduce the problems of water shortage. This canal can also be used for irrigation purposes. The water used for cleaning the panels can be reused to crop production.

A few villages are developing due to the proximity to the infrastructure lines. All the villages are connected to the grid system that is powered by the power plant. The following sections will explain regarding the ecological, social and economic flows related to this scenario.

1. Increase in population by 2051 requires a projected 2 times increase in built up area to 25km² and then over years can densify instead of sprawling - to have around 4000 people/km² with more open spaces
2. Green belt to prevent outward spawling of the city.
3. Small economic zones developing along new infrastructure development that links the urban and rural systems
4. Solar farm; 5.3km² area (see appendix for calculations)
5. Addition blue system helps with water retention and caters to the addition water required by solar farm. The water used can also be reused or collected for crop production.



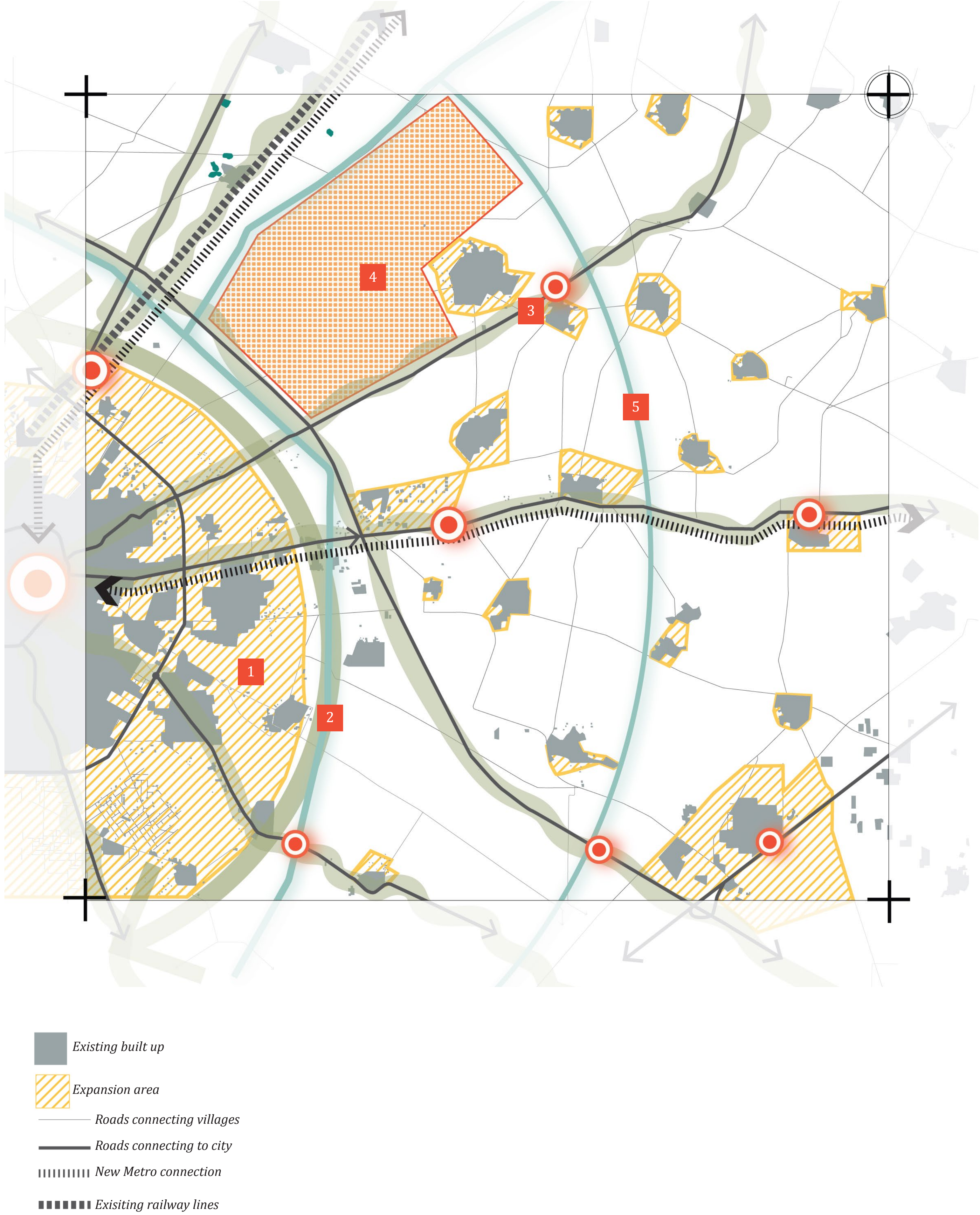


Fig 9.28: Scenario depiction on a spatial level
Source: Author

Energy Calculations for the Area

Considering the application of scenario 2, a centralised system of solar or biomass (two sources that has potential in the NCR) is built in Rewari to meet the electricity demands in the future. Based on the projected population density of the region in 2051 and the average annual per capita energy consumption of the state, calculations to estimate the solar and/or biomass energy requirements in the 100 km² area (10 km x 10 km) are performed.

Year 2051

Rewari has a population density of approximately 800 p/km², over 16,000 households (census of India considers 5 people per household (NCRPB, 2013)) and an annual energy consumption of around 822 GWh/year. The area receives around 4.9 peak sun hours per day (ESH) (kWh/m²/day) and has a total arable area of around 60 km².

This scenario considers that the total required energy for the region is produced centrally via either only a solar or only a biomass system.

In the case of solar energy system: an oversizing factor of 1.5 is considered to accommodate for the energy losses in the inverter, battery and cable; the panel conversion efficiency is assumed to be 20%; a panel spacing efficiency of 60% is assumed; and an overall efficiency improvement of 10% is assumed by 2051 considering the technology growth.

The total solar power generated is calculated using the formula:

$$\text{Total power output (kW)} = \text{Total panel area } (m^2) \times \text{Solar irradiance } (kW/m^2) \times \text{Conversion efficiency}$$

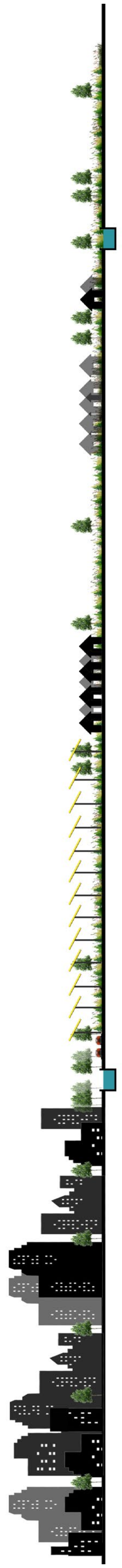
Based on the available energy requirement data, the total solar panel area is initially calculated, and by accommodating the panel spacing efficiency, the total land area required for the solar energy system is finally obtained. From the calculations, a total land area of *5.3 km²* is required to generate enough electricity to meet the energy demands within the 100 km² area in Rewari, using only solar as a source of energy.

In the case of biomass energy system, wheat is considered to be the main energy crop as it is one of the most grown crops in the area. The non-edible and residual part of the crop, i.e., wheat straw, is converted into energy (second generation biomass) which facilitates waste management as well as ensures food security. The wheat straw is assumed to be converted into energy in a combined heat and power (CHP) plant where the otherwise-wasted heat energy is also utilised to produce power. A CHP conversion efficiency of 90% is assumed in the energy calculations, considering the technology growth by 2051.

The total energy produced per ton of wheat is calculated using the formula:

$$\text{Total energy per ton wheat (GWh/ton)} = \text{Fraction of straw in wheat} \times \text{Calorific value of straw (dry basis)(GWh/ton)} \times \text{CHP efficiency}$$

Based on the available energy requirement data and the average annual yield of wheat in India, the total area required for wheat production is obtained. From the calculations, a total land area of *343 km²* is required to generate enough electricity to meet the energy demands within the 100 km² area in Rewari, using only biomass as a source of energy.



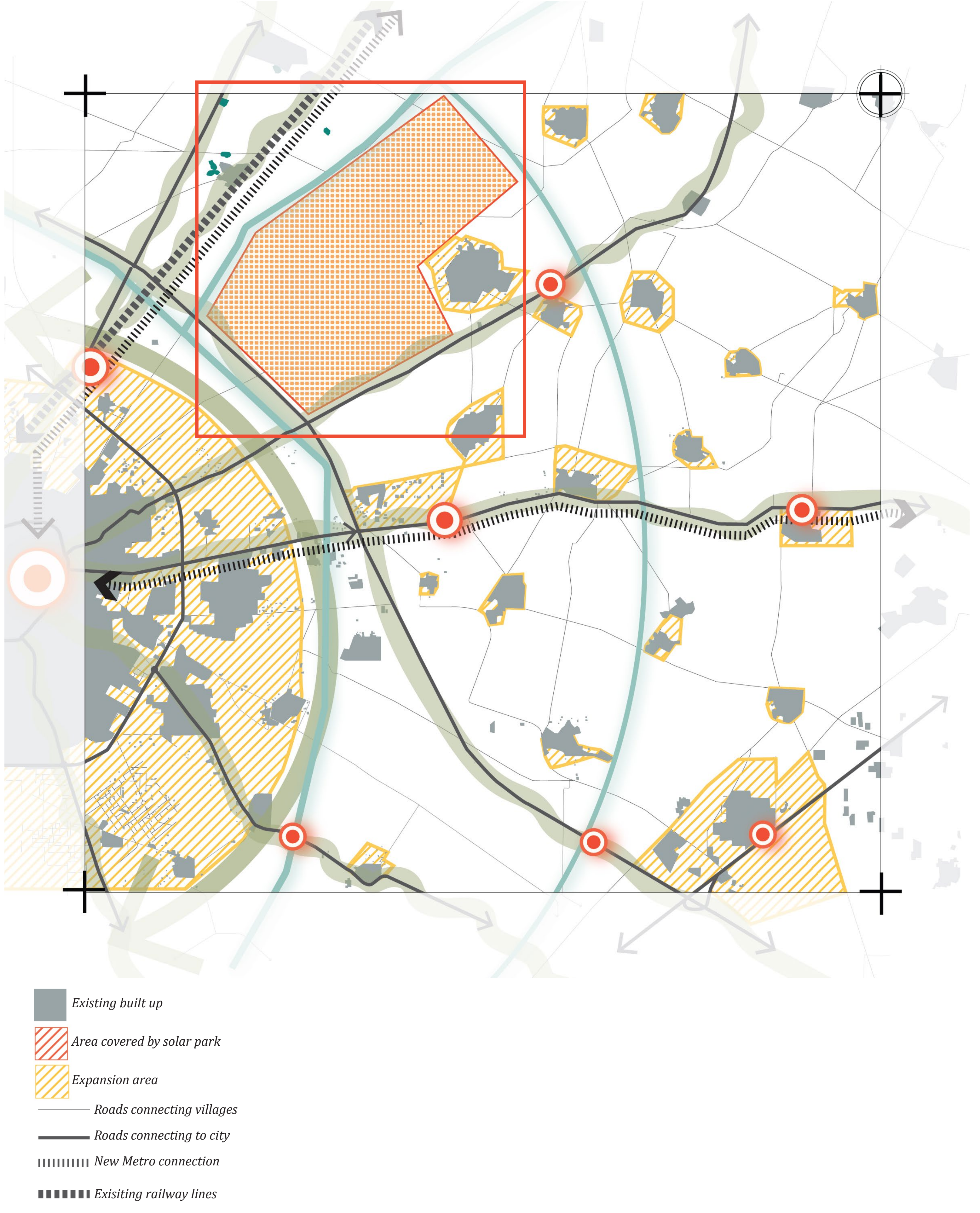


Fig 9.29: Scenario depiction on a spatial level
Source: Author

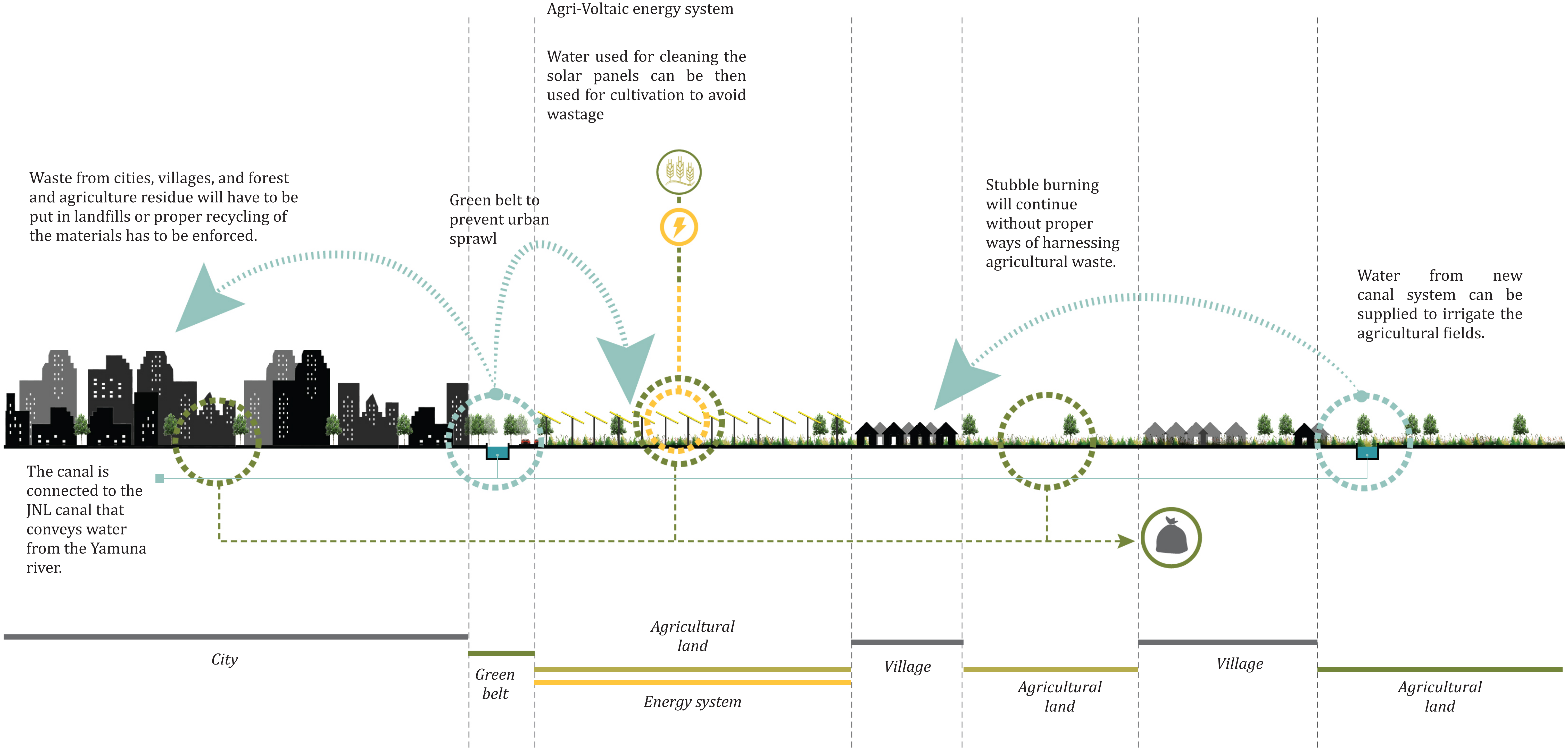
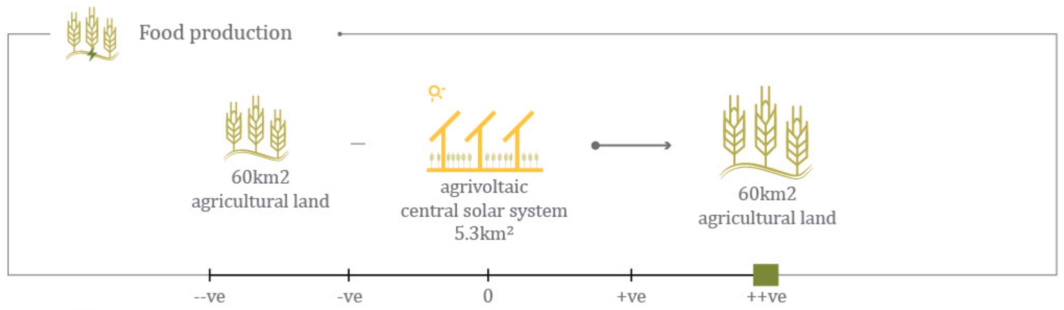
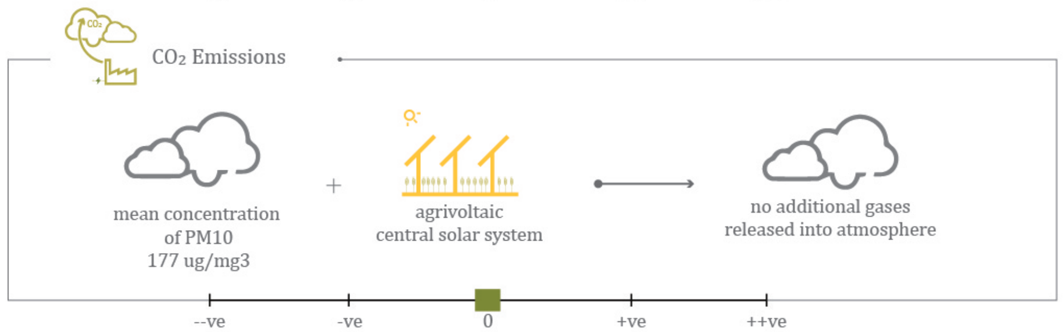


Fig 9.30: Section showing the ecological flows in the implementation a centralised R.E system in the area.
Source: Author

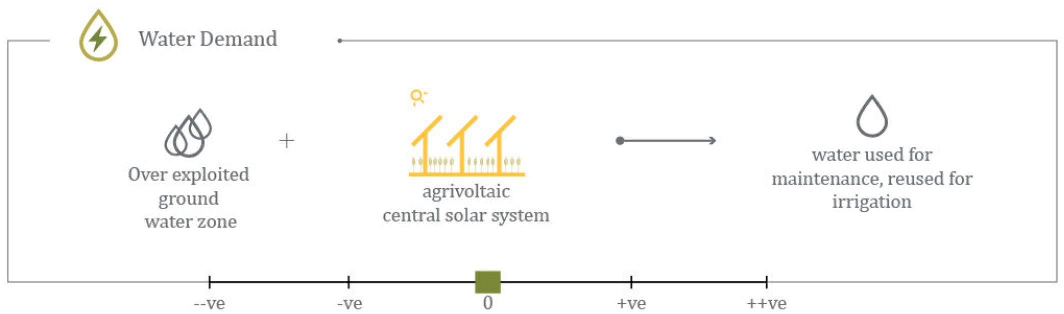
Ecological



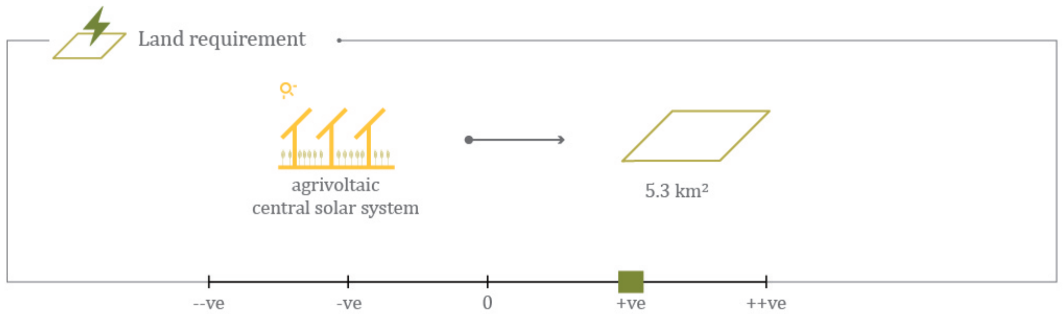
1. Food production: The energy system can be introduced along with the area for agricultural production; an agri-voltaic system. The production of energy and food simultaneously will encourage farmers to consider a change in farming methods. The energy system preserves the existing resources by combing energy and food production. The renewable source power generation is non-toxic to the soil and promotes to multiple usage of the land. It is marked (++ve) as it is a positive change to the existing status quo and embodies multiple aspects of circular economy.



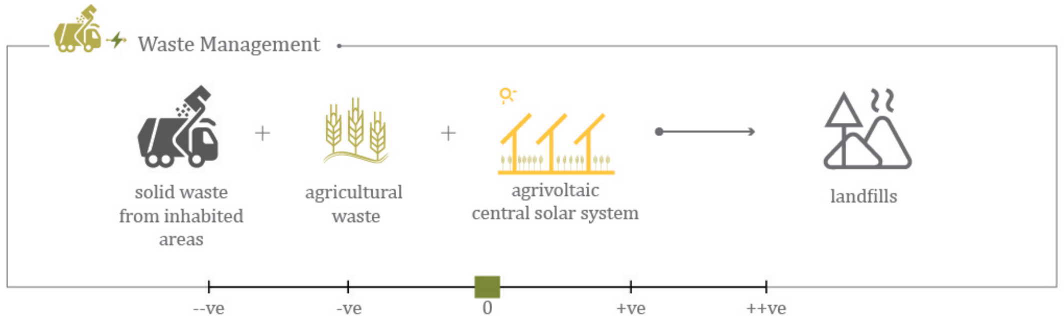
2. CO2 emissions: The solar farm will produce no CO_2 emissions during the power generation and hence it will have no impact on the existing air quality. Hence, it is marked (0).



3. Water demand: The water used for cleaning the solar panels can be used for irrigating the farm. This means that there is no addition water demand for the cleaning of solar panels. It is marked (+ve) as it embodies the reuse of water for farming purposes.



4. Land requirement: The area required for the solar farm is 5.3km^2 and this land is used for both food and energy production. Upon the removal of solar panels, the land will still have value due to the food production. It marked (+ve) as the resource which is land is used efficiently which is an aspect of circular economy leading to a positive change.



5. Waste management: The energy system plays no role in reducing the waste produced. Most waste will end up in landfills. This energy system produces no additional waste materials. It is marked (0) as it has no impact on the existing status quo.

Legend

--ve *: A very negative change and embodies no values of sustainability or circular economy, creating a long-lasting chain of negative events*
-ve *: A negative change to the existing status quo but embodies one aspect of sustainability or circular economy*
0 *: Has no impact on the existing status quo*
+ve *: A positive change to the existing status quo and embodies one aspect of circular economy or sustainability*
++ve *: A very positive change and embodies multiple aspects of sustainability or circular economy.*

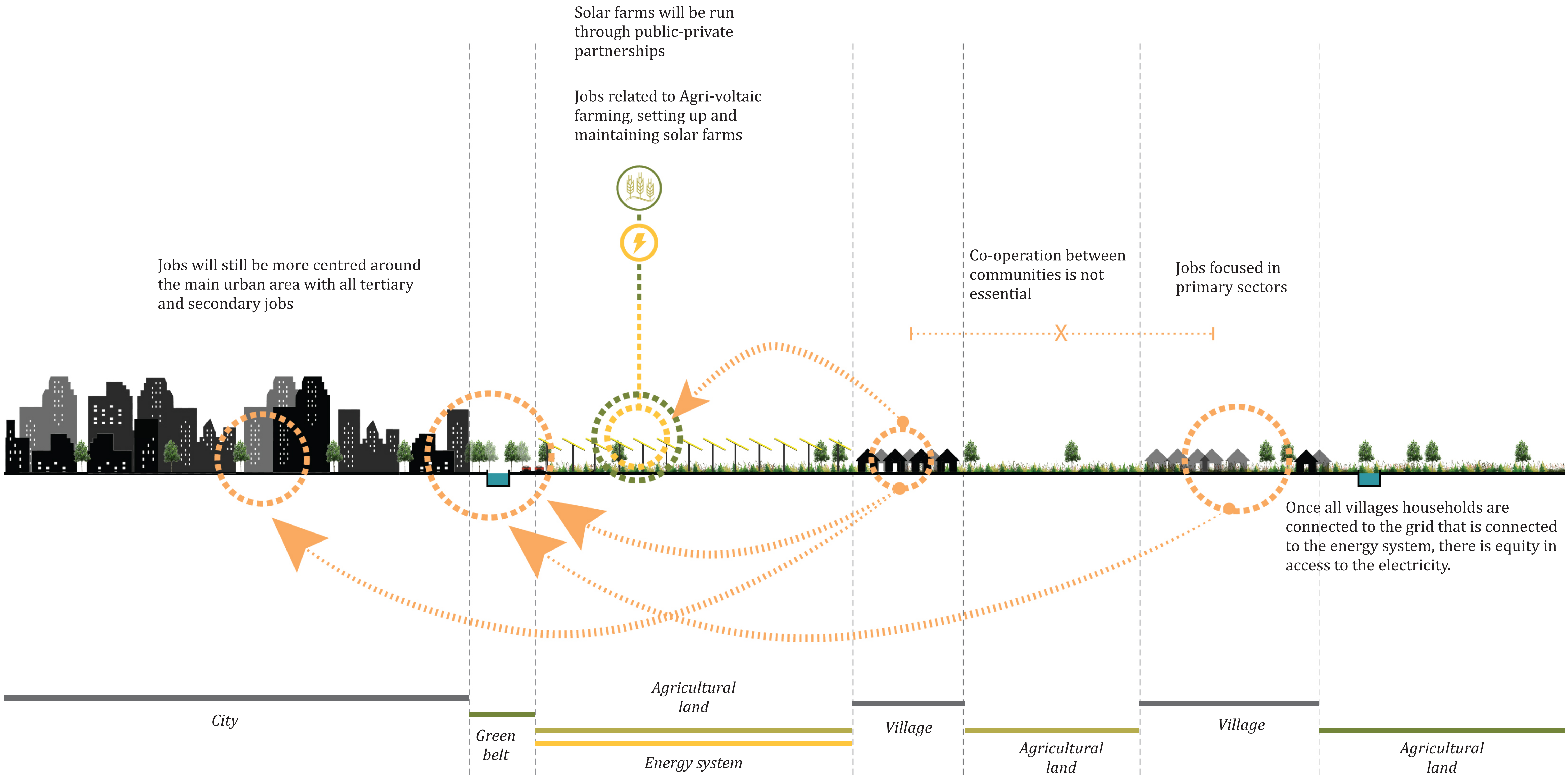
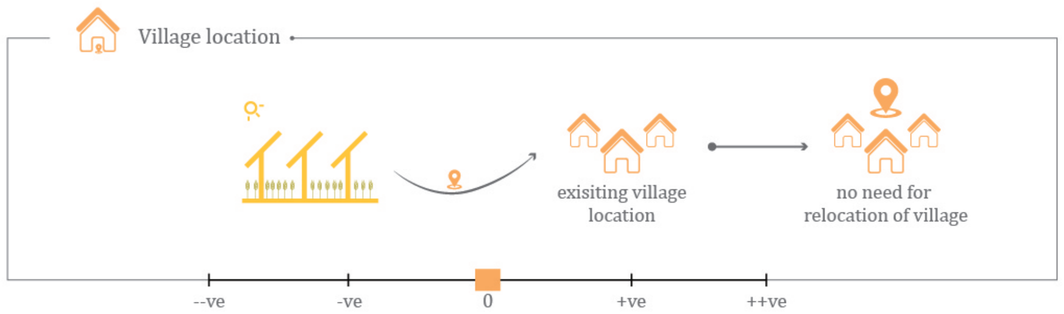
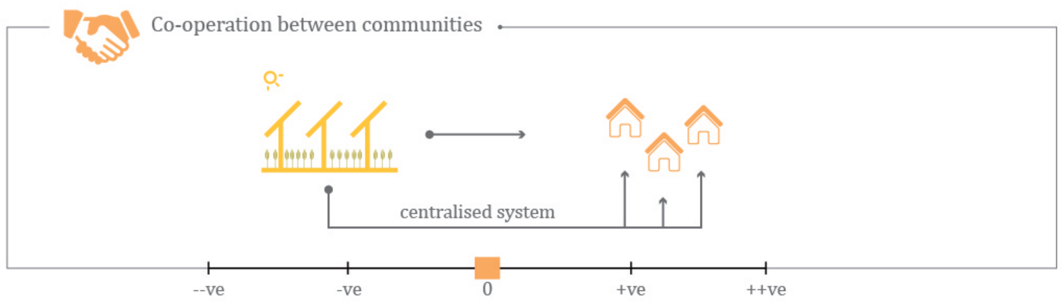


Fig 9.31: Section showing the social flows in the implementation a centralised R.E system in the area. Source: Author

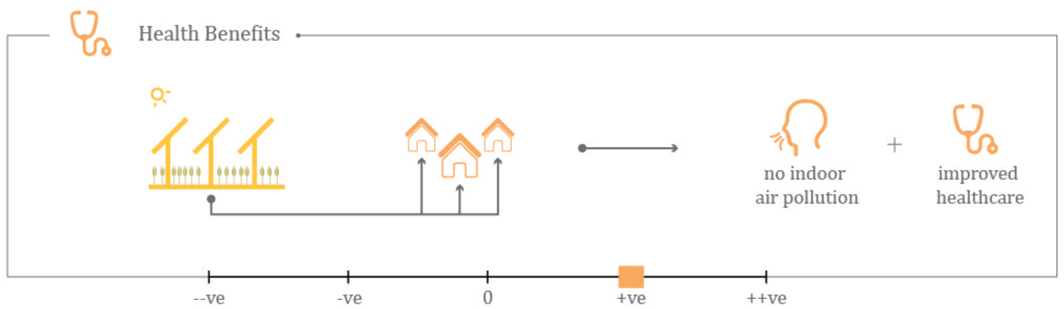
Social



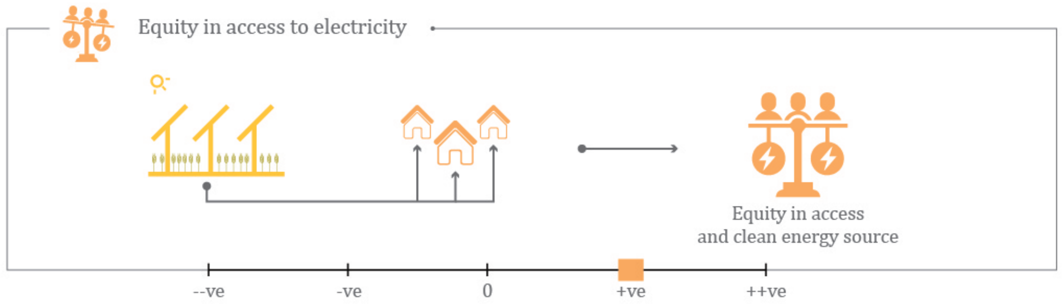
1. Village location: With the introduction of a solar farm in the spatial development of the area, no villages have to be relocated. The availability of vast land allows for setting up of a solar farm in the farmlands. It is marked as (0) as the energy system has no impact on the village location.



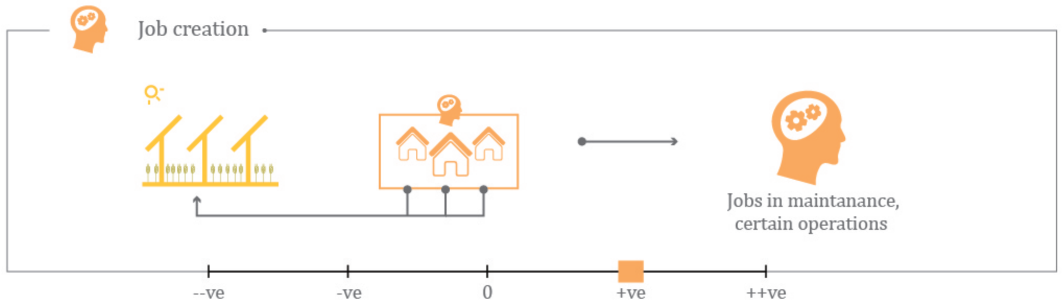
2. Co-operation between communities: The energy system does not inculcate the need for co-operation between communities. So it is marked (0) as the energy system has no impact on the existing status quo.



3. Health benefits: The solar farm will be able to meet electricity demands of all. And this has a significant impact in improving the health conditions of people living in the households and to run healthcare centres in the area. It is marked (+ve) as it has a positive impact on the existing status quo and it embodies one aspect of sustainability by improving the social well-being of the communities.



4. Equity in access to electricity: Upon ensuring that the state government connects all households to the central grid that is connected to the power system, everyone will have equity in access to the electricity generated. However, there are chances that some people on lower income levels might find it difficult to afford continuous access to electricity. It is marked (+ve) as this is a positive change to the existing status quo and it embodies one aspect of sustainability by trying to facilitate the presence of electricity that can then be shared amongst all in the society.



5. Job creation: There will be jobs that are created due to the establishment of the solar farm. And access to electricity will help in running businesses in the rural areas. However, the access to electricity does not ensure the productive use of electricity to have economic development in the areas (Pueyo & Maestre, 2019). It is marked (+ve) as it is a positive change to the existing status quo and embodies one aspect of sustainability by creating additional jobs and facilitating the improvement of the social well-being of the communities.

Legend

--ve *: A very negative change and embodies no values of sustainability or circular economy, creating a long-lasting chain of negative events*
-ve *: A negative change to the existing status quo but embodies one aspect of sustainability or circular economy*
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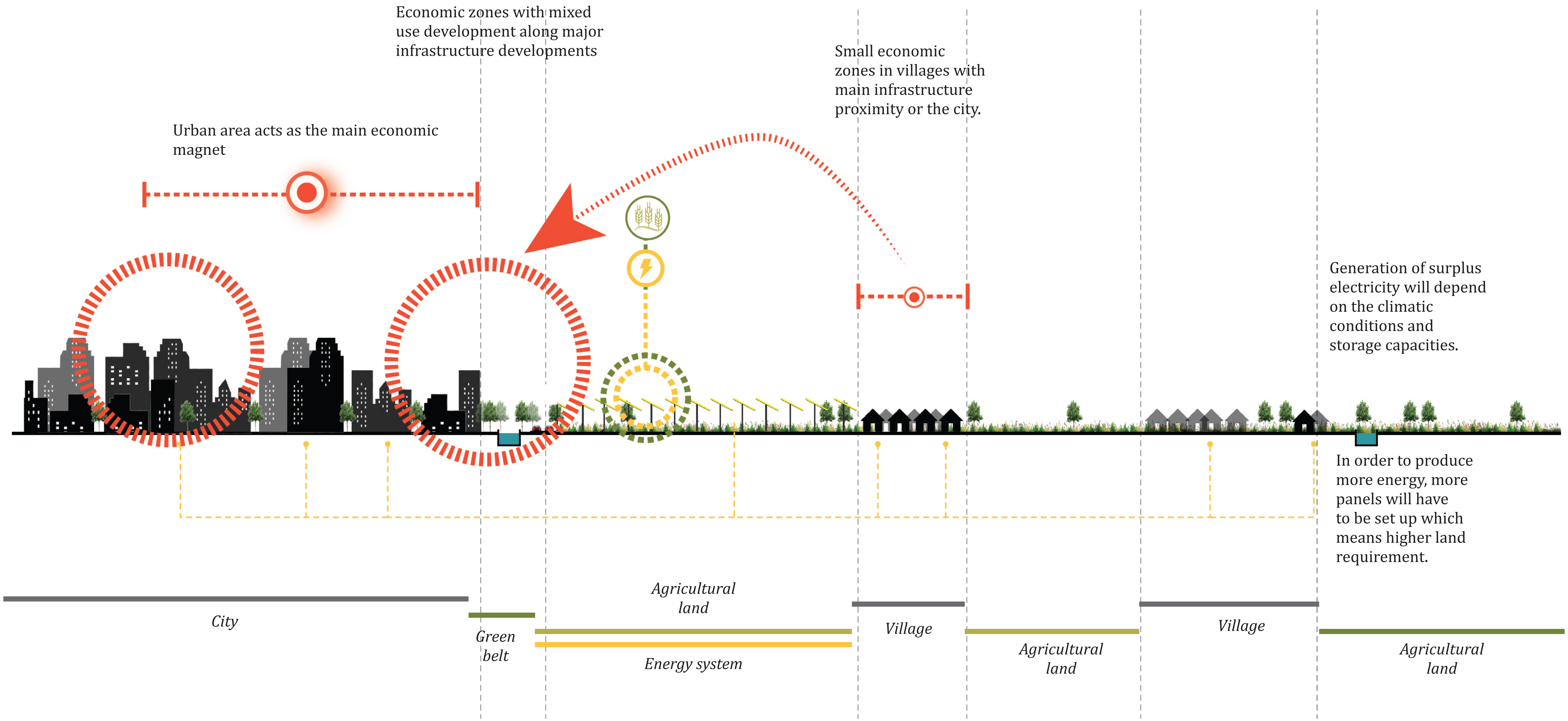
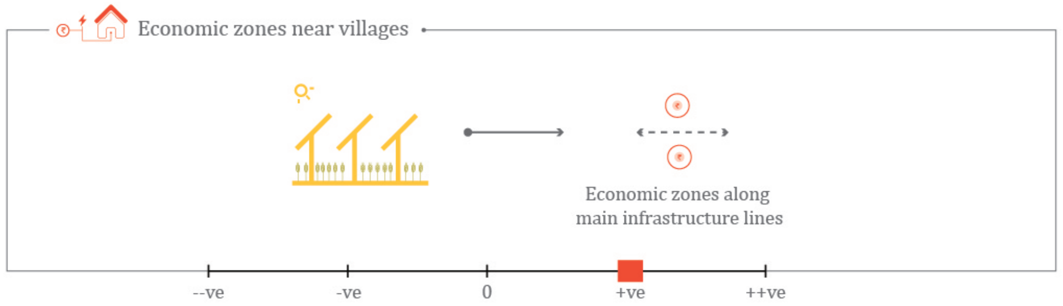
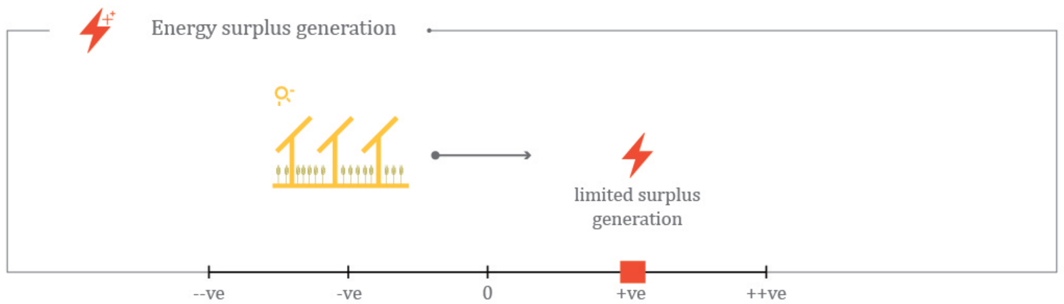


Fig 9.33: Section showing the economic flows in the implementation a centralised R.E system in the area.
Source: Author

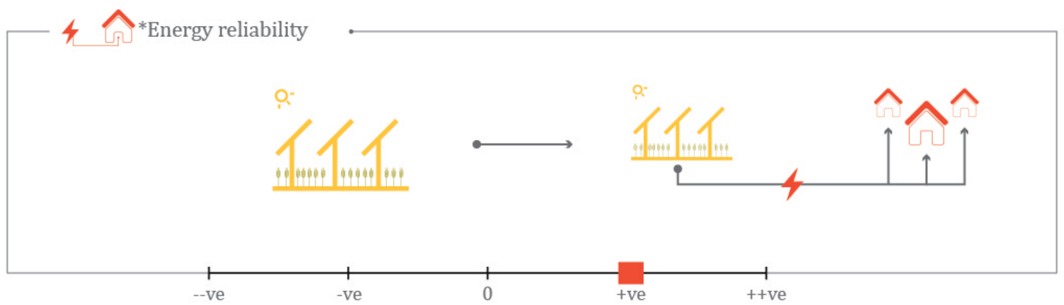
Economic



1. Economic zones near villages: One of the key enablers for economic development is access to electricity. However, the access to electricity does not ensure the productive use of electricity to have economic development in the areas (Pueyo & Maestre, 2019). It can be seen from the spatial development of the region that main infrastructure lines also play a key role developing economic zones (Bansal, 2017). So, the villages that are closely linked to main infrastructure lines have higher probability of having economic growth. It is marked (+ve) as it is a positive change to the existing status quo and embodies one aspect of sustainability by creating additional jobs and facilitating economic growth.



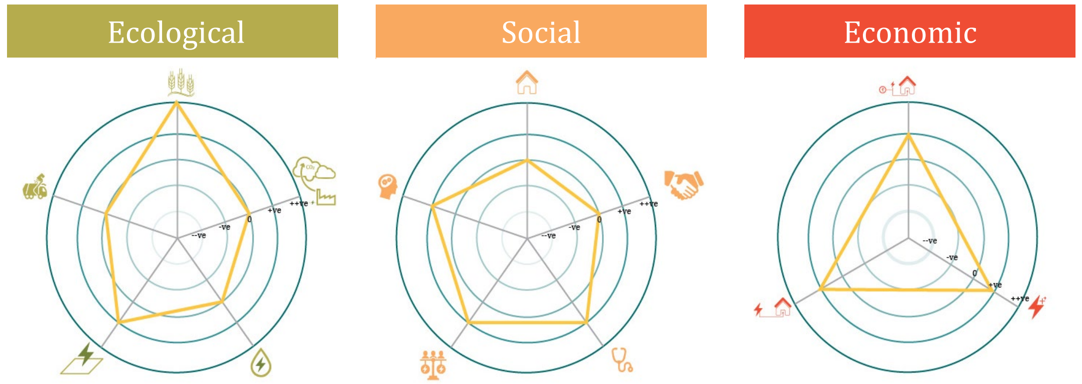
2. Energy surplus generation: The solar farm is built for meeting the future demands of the area. And the chances of generation of surplus will also depend on the climatic conditions and storage capacities. Based on the interviews with organisations, it is evident that the current un-reliable supply of electricity is hindering the development of rural areas. Having electricity generated to meet the needs of the area would ensure the development of few economic zones. In order to produce more energy, more panels will have to be set up. It is marked (+ve) as it is a positive change to the existing status quo and embodies one aspect of sustainability by promoting to the economic growth of the state.



3. Energy reliability: Since solar farm are influenced by the climatic conditions, they are reliable sources only if there are proper storage of energy produced. However, switching to a renewable source of power generation is a step towards sustainability. Hence, it is marked (+ve).

Conclusions

The comparison between the impacts shows that the centralised renewable based energy system weigh more positive on all 3 criterias. The parameters like waste management and co-operation scored as no impact. With access to storage facilities the unreliability of solar can be made more reliable. The step towards a clean energy system definitely embodies all 3 pillars of sustainable development. The webbed diagram below shows the consolidated impacts of the three aspects.



| Scenario 3: Rewari powered by 100% Decentralised R.E system

The scenario development of using a decentralised R.E system began with looking at the percentage of biomass crops and solar grid area required to meet the energy demands. The combined potential of both the energy sources gives rise to a more resilient energy system. The biomass power generation takes into account the type of crop grown in the area and power calculations are done based on its waste materials. The spatial development seen involves more local circles of resource circulation and potentials for economic developments in every village.

Year 2051

In the year 2051, new infrastructural developments are seen. The lines link Rewari to the other cities in the region and also has important link to other states. Rapid transport systems like the extension of the metro region to Rewari is established. The production of renewable energy by the villages themselves raises the social well-being. Communities come together to form co-operatives that can support the transition to renewable energy. People are mobilised in the villages to be involved in activities like forming maintenance groups, biomass collectors and initiate various small scale businesses. This raises the values of the villages enabling exchange of knowledge and resources.

The local flows of resource involves reusing of water in the agri-voltaic systems, and waste from the crops is collected and converted into energy. The biomass plants are also installed with CCS(carbon capture and storage) systems to reduce the CO_2 emissions. In villages with poor building conditions a primary building is built to support the energy production.

The urban area is also involved in the production of energy through rooftop solar power generation and the existing grid is also connected to the biomass power plant. All the villages are connected to the grid system that is powered by combination of decentralised system of solar and biomass power plants.

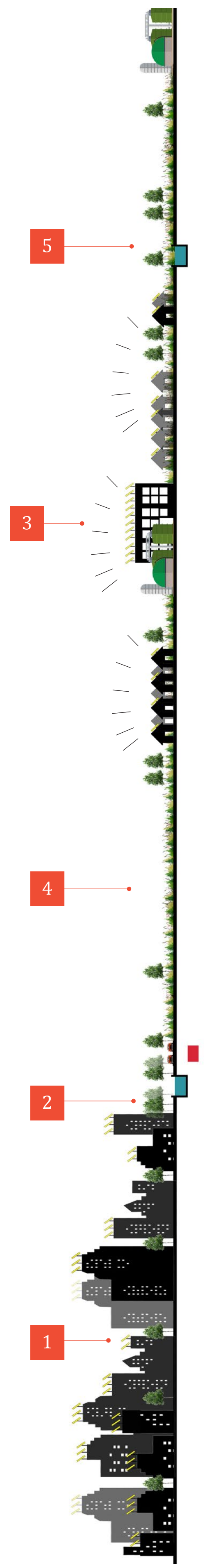
1 Increase in population by 2051 requires a projected 2 times increase in built up area to 25km2 and then over years can densify instead of sprawling - to have around 4000 people/km2 with more open spaces

2 Green belt to prevent outward spawling of the city.

3 Local circles of resource circulation and potentials for economic developments in every village. Primary buildings that can support the energy production in areas with poor building conditions are built.

4 Solar area of 4.8km^2; Biomass crop area of 30km^2 (see appendix for calculations)

5 Addition blue system helps with water retention and caters to the addition water required for crop production and supplied to biomass plant.



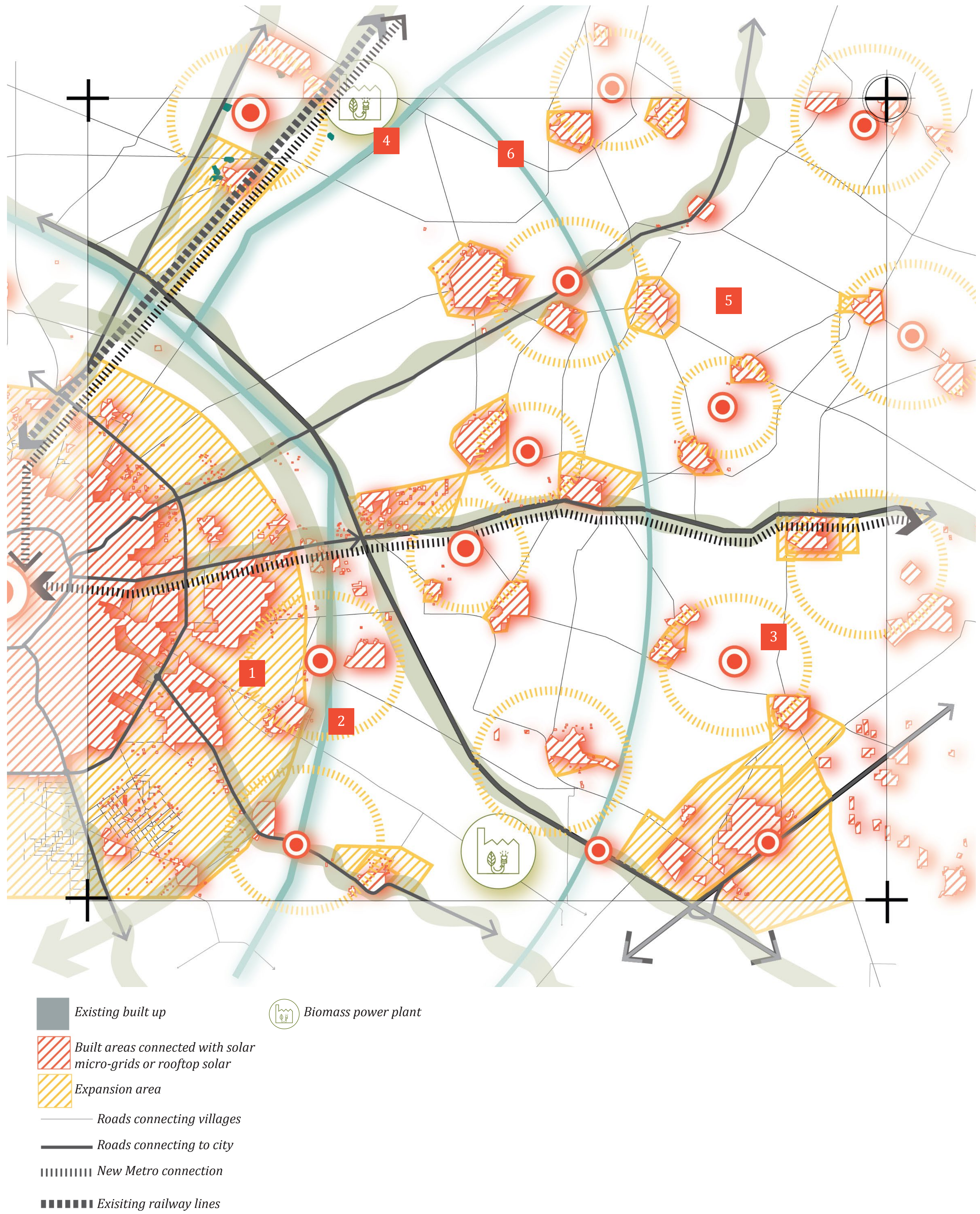


Fig 9.34: Scenario depiction on a spatial level
Source: Author

Energy Calculations for the Area

In the case of scenario 3, a completely decentralised system of solar and biomass will be built in Rewari to meet the electricity demands in the future. Based on the projected population density of the region in 2051 and the average annual per capita energy consumption of the state, calculations to estimate the requirements for a decentralised energy system in the 100 km^2 area (10 km x 10 km) are performed.

Year 2051

Rewari has a population density of approximately 800 p/km^2, over 16,000 households (census of India considers 5 people per household (NCRPB, 2013)) and an annual energy consumption of around 830 GWh/year. The area receives around 4.9 peak sun hours per day (ESH) (kWh/m^2/day) and has a total arable area of around 60 km^2.

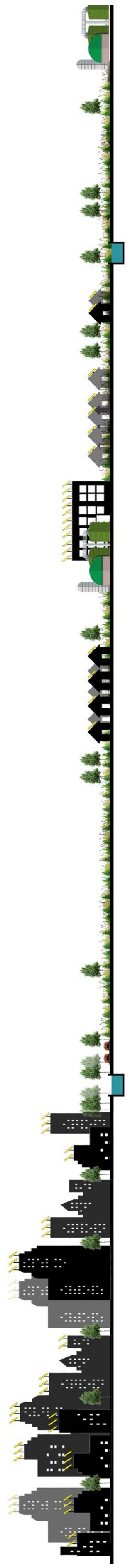
This scenario considers that the total required energy for the region is produced partially via a biomass system and the remaining via a solar system. It is assumed that 50% of the total arable area in the region is used for biomass production. Wheat is considered to be the main biomass energy crop as it is one of the most grown crops in the area. The non-edible and residual part of the crop, i.e., wheat straw, is converted into energy (second generation biomass) which facilitates waste management as well as ensures food security. The wheat straw is assumed to be converted into energy in a combined heat and power (CHP) plant where the otherwise-wasted heat energy is also utilised to produce power. A CHP conversion efficiency of 90% is assumed in the energy calculations, considering the technology growth by 2051.

Based on the average annual yield of wheat in India, the total energy produced from cultivating wheat in 30 km^2 area is only around 72 GWh/year, which contributes to only less than 9% of the annual energy demand (around 822 GWh/year) in the region. Hence, the remaining energy of around 750 GWh/year has to be produced via a solar system.

In the case of solar energy system: an oversizing factor of 1.5 is considered to accommodate for the energy losses in the inverter, battery and cable; the panel conversion efficiency is assumed to be 20%; a panel spacing efficiency of 60% is assumed; and an overall efficiency improvement of 10% is assumed by 2051 considering the technology growth.

Based on the available energy requirement data, the total solar panel area is initially calculated, and by accommodating the panel spacing efficiency, the total land area required for the solar energy system is finally obtained. From the calculations, a total area of *4.8 km^2* (land/rooftop) is required to generate the remaining energy of 750 GWh/year.

Thus, in order to completely meet the energy demands within the 100 km^2 area in Rewari using a decentralised energy system, an additional land/rooftop area of *4.8 km^2* is required for solar power generation and the production of biomass crop, wheat, in an area of *30 km^2*. The built up area will span over 25km^2 and that gives immense potential for harvesting roof top solar or micro-grids across the urban-rural area. Biomass will encourage better waste management as well.



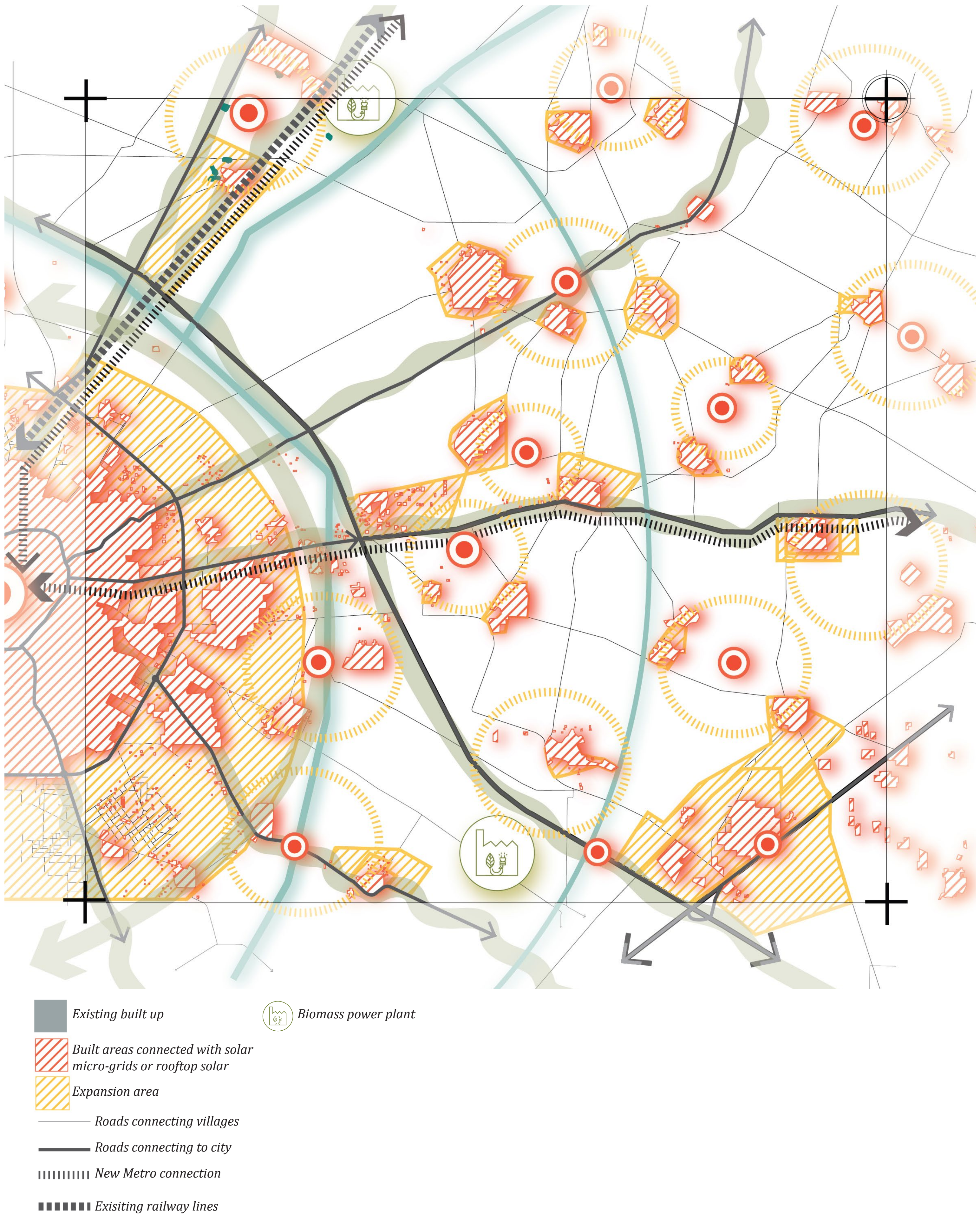


Fig 9.35: Scenario depiction on a spatial level
Source: Author

Ecological Flows

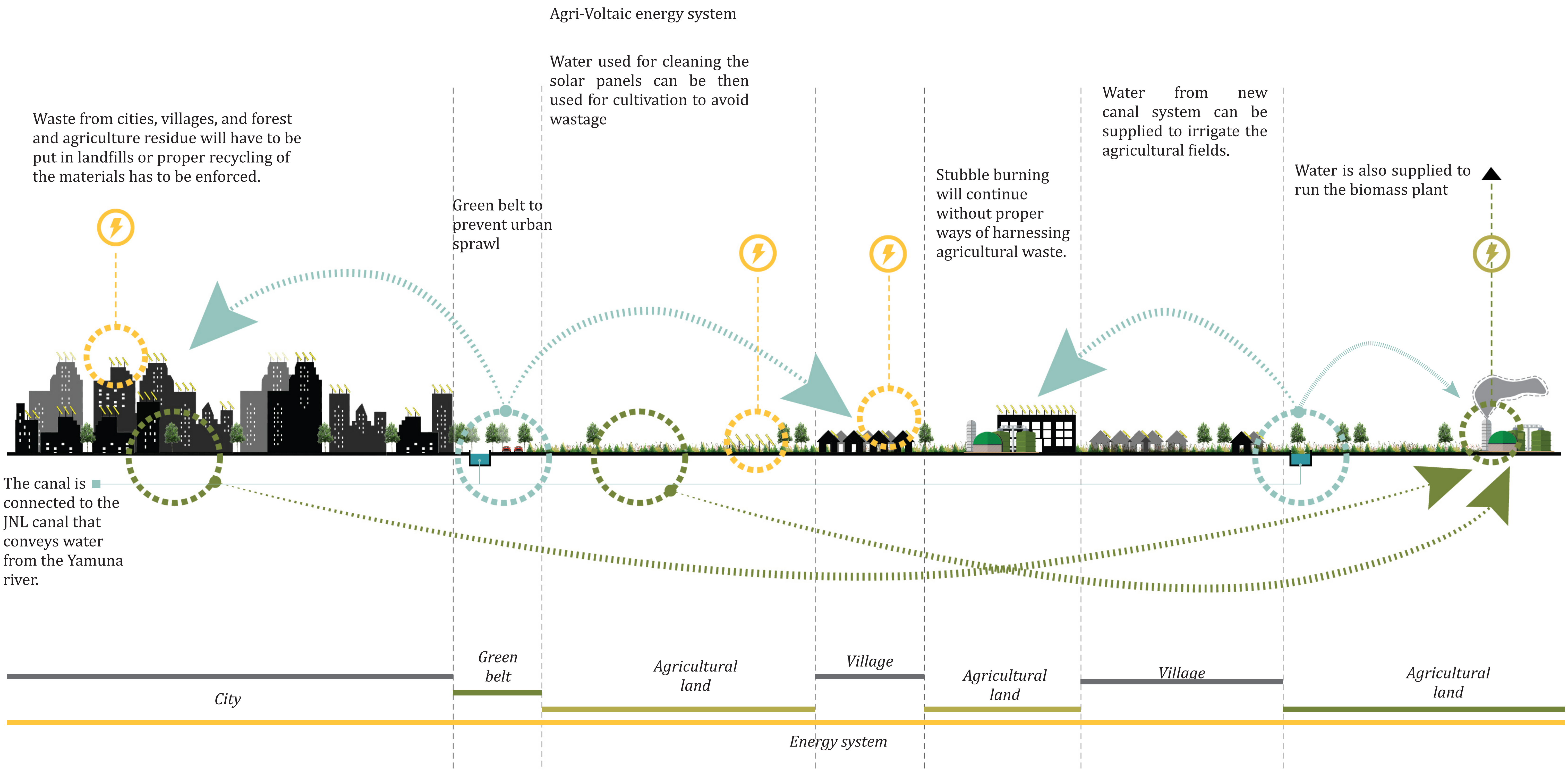
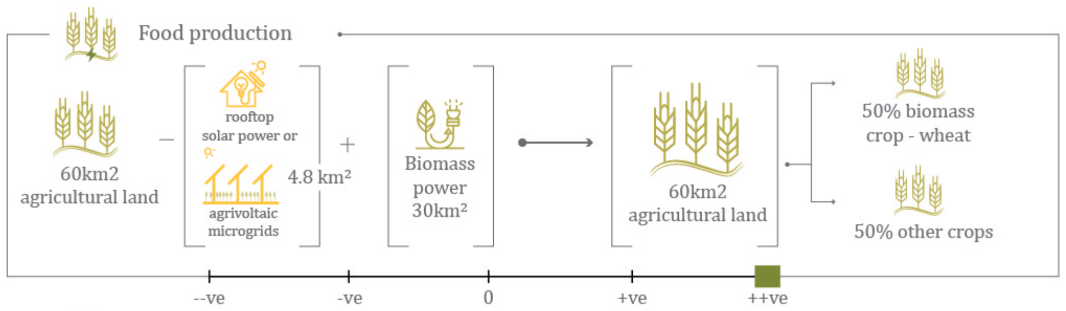
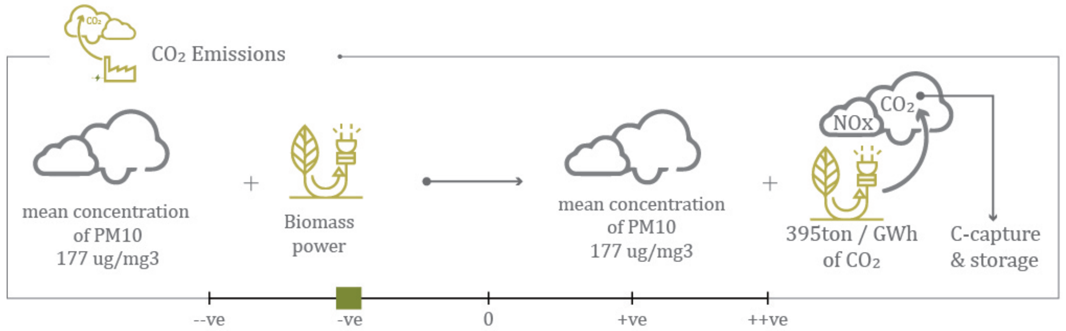


Fig 9.36: Section showing the ecological flows in the implementation a de-centralised R.E system in the area. Source: Author

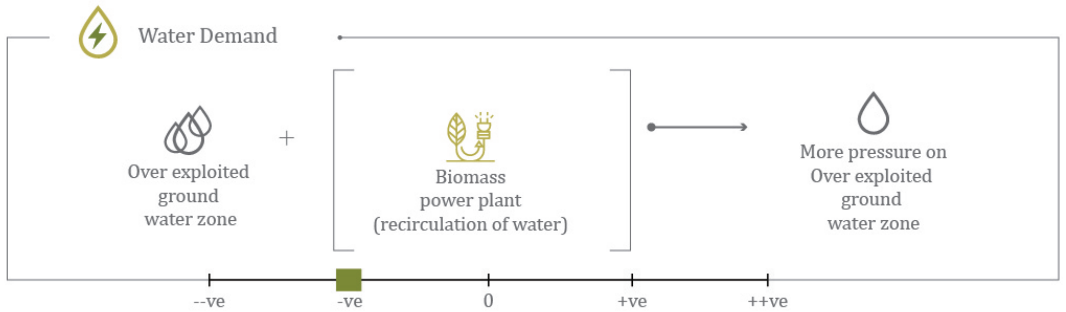
Ecological



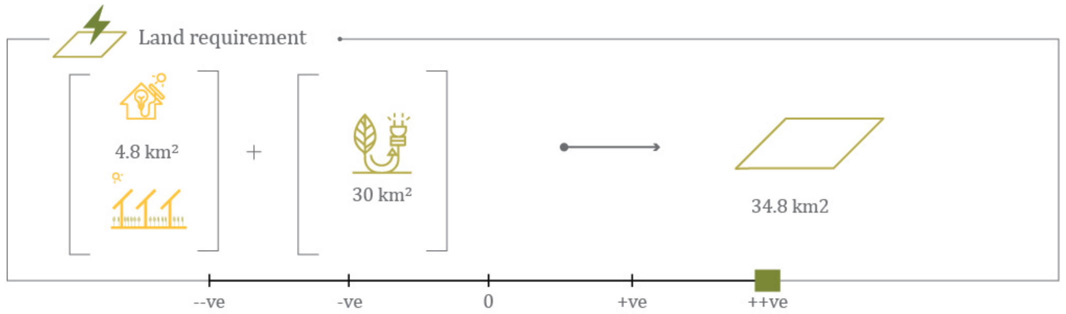
1. Food production: The solar based energy system can be introduced along with the area for agricultural production; an agri-voltaic system (Singh et al., 2018) The production of energy and food simultaneously will encourage farmers to consider a change in farming methods. The biomass energy system allows for the reuse of harvest waste to be used to generate electricity instead of burning the stubble. It is marked (++ve) as it is a positive change to the existing status quo and embodies multiple aspects of circular economy.



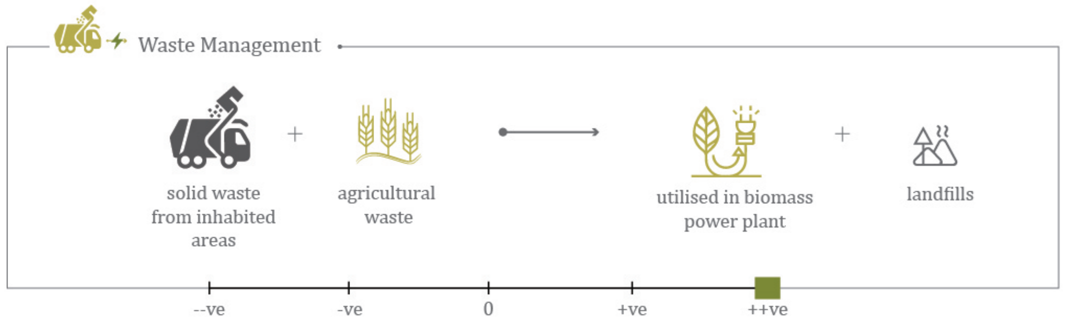
2. CO2 emissions: The biomass plant will produce approx. 395 tons of CO_2 per GWh it produces. The gaseous emissions also include NO_2 which can add to the air pollution. With Carbon capture technology (Cell Press, 2019), carbon dioxide emissions can be significantly reduced. But the area already has a higher PM10 value and the NOx gas released can add to the degradation of air quality. However, the carbon capture allows for carbon dioxide to be reused to create a secondary resource. It is marked (-ve) as it is a negative change to the existing status quo but embodies one aspect of circular economy.



3. Water demand: The area has a really low ground water table and has a higher water demand due to agriculture. The spatial development takes into consideration additional water systems to the area. But an energy system that uses 5m^3/h per MW of water that cannot be reused for any other purposes adds more pressure to the water table. The system of ash water recirculation in the power plant would still mean that certain amount of water can be reused again in the energy system. It is marked (-ve) as it is a negative change to the existing status quo but the reuse of waste water embodies one aspect of circular economy.



4. Land requirement: The area required for the solar energy production is 4.8km^2 and 30km^2 of biomass crop production. This land is used for both food and energy production. The biomass crop is not grown separately. The area already produces wheat and the husk of the wheat is being used for energy production in the biomass plants. It marked (++ve) as it is a positive change and embodies multiple aspects of circular economy by the resource which is land is used efficiently and the existing resources are reused and preserved.



5. Waste management: The biomass based renewable energy system plays an important role in reusing the waste produced by agricultural farms and inhabited areas. It also encourages the communities to segregate waste and reuse the degraded produce in farming and also in generating biogas. It is marked (++ve) as embodies multiple aspects of circular economy.

Legend

--ve *: A very negative change and embodies no values of sustainability or circular economy, creating a long-lasting chain of negative events*
-ve *: A negative change to the existing status quo but embodies one aspect of sustainability or circular economy*
0 *: Has no impact on the existing status quo*
+ve *: A positive change to the existing status quo and embodies one aspect of circular economy or sustainability*
++ve *: A very positive change and embodies multiple aspects of sustainability or circular economy.*

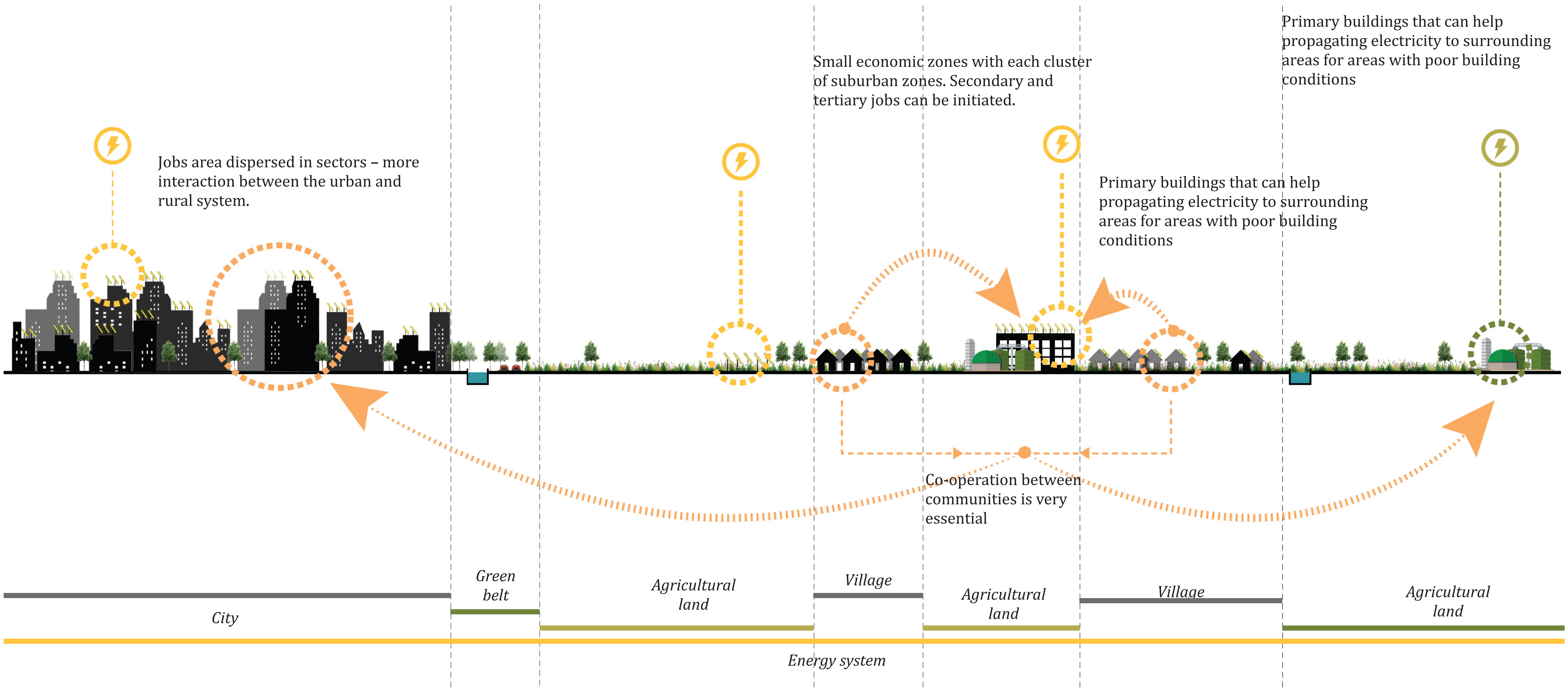
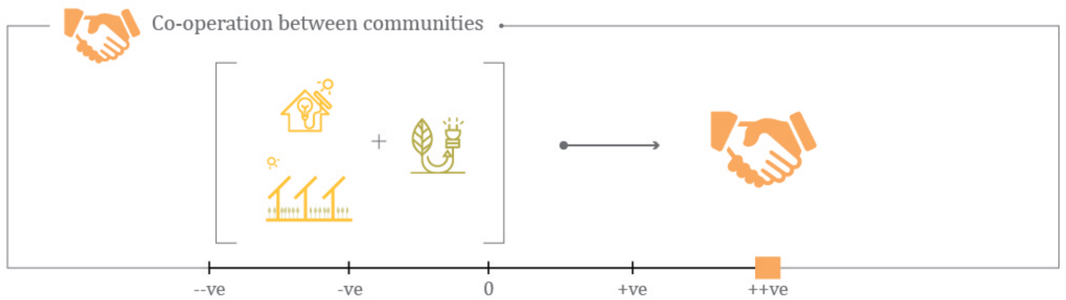


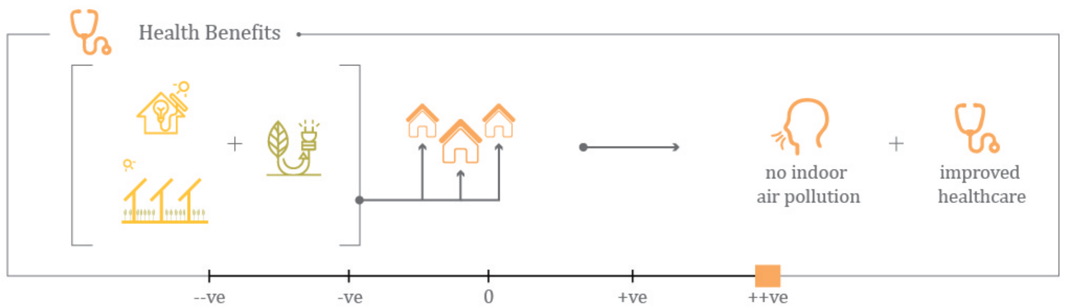
Fig 9.37: Section showing the social flows in the implementation a decentralised R.E system in the area. Source: Author

Social

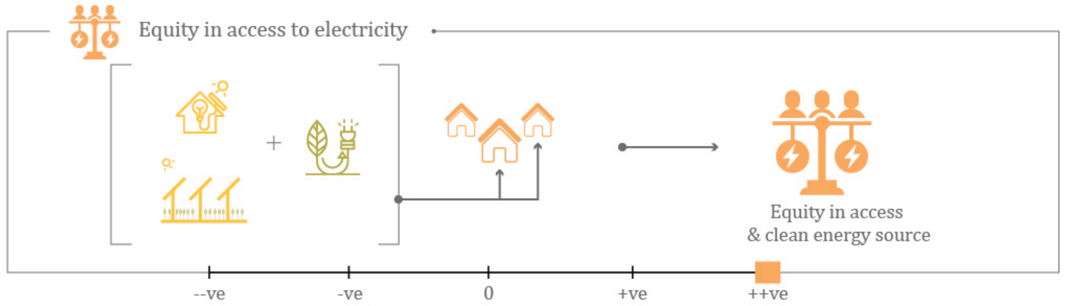
1. Village location: With the introduction of a solar micro-grids or biomass crop production in the spatial development of the area, no villages have to be relocated. The availability of vast land allows for setting up of such a combined energy system in the farmlands. It is marked as (0) as the energy system has no impact on the village location.



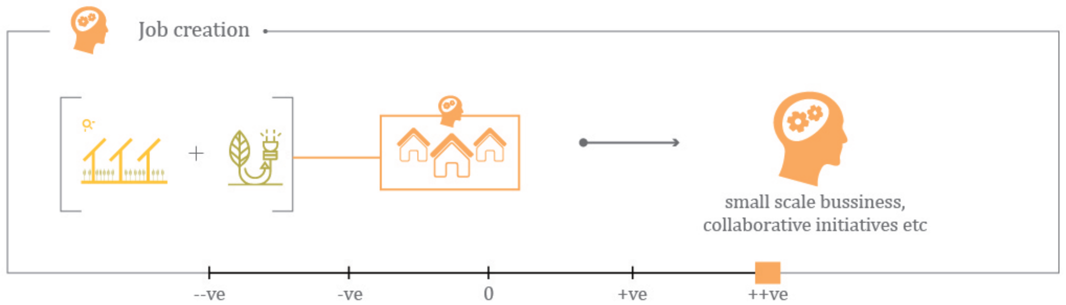
2. Co-operation between communities: The de-centralised energy system means that the energy is produced and consumed by the community. This is a lifestyle change that will promote to a sustainable way of living and also improve the social well-being of the communities. Interview with organisations shows that co-operations between communities always provides for a positive change in rural development. As mentioned, this is a positive change that can be harnessed to improve the local social structures and also embodies multiple aspects of sustainability. Hence, it is marked (++ve).



3. Health benefits: The combines renewable energy system will be able to meet electricity demands of all. And this has a significant impact in improving the health conditions of people living in the households and to run healthcare centres in the area. Since, the level of development is based on the community's ability to produce energy, it pushes the actions to be taken for the social wellbeing of the community and inculcate lifestyle changes as a community. It is marked (++ve) as it has a positive impact on the existing status quo and it embodies multiple aspects of sustainability.



4. Equity in access to electricity: Since the energy is produced by the communities in the society, there will be the possibilities of sharing of resources in a fair and equal manner. The people with lower income levels can seek the co-operation of the community to gain access to electricity. This will also reduce social inequalities. It is marked (++ve) as this is a positive change to the existing status quo and it embodies multiple aspects of sustainability by trying to facilitate the presence of electricity that can then be shared in a fair manner amongst all in the society.



5. Job creation: There will be jobs that are created due to the establishment renewable energy systems. And the range of jobs are more wider. They can be from solar rooftop installers to solar engineers, to maintain ace teams, biowaste collectors to business owners. The combined aspects of co-operation and access to electricity will help in running businesses in the rural areas. (Pueyo & Maestre, 2019) says that bringing together communities and strengthening them allows for more productive use of electricity. It is marked (++ve) as it is a positive change to the existing status quo and embodies multiple aspect of sustainability by creating additional jobs and facilitating the improvement of the social well-being of the communities.

Legend

--ve *: A very negative change and embodies no values of sustainability or circular economy, creating a long-lasting chain of negative events*
-ve *: A negative change to the existing status quo but embodies one aspect of sustainability or circular economy*
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Economic

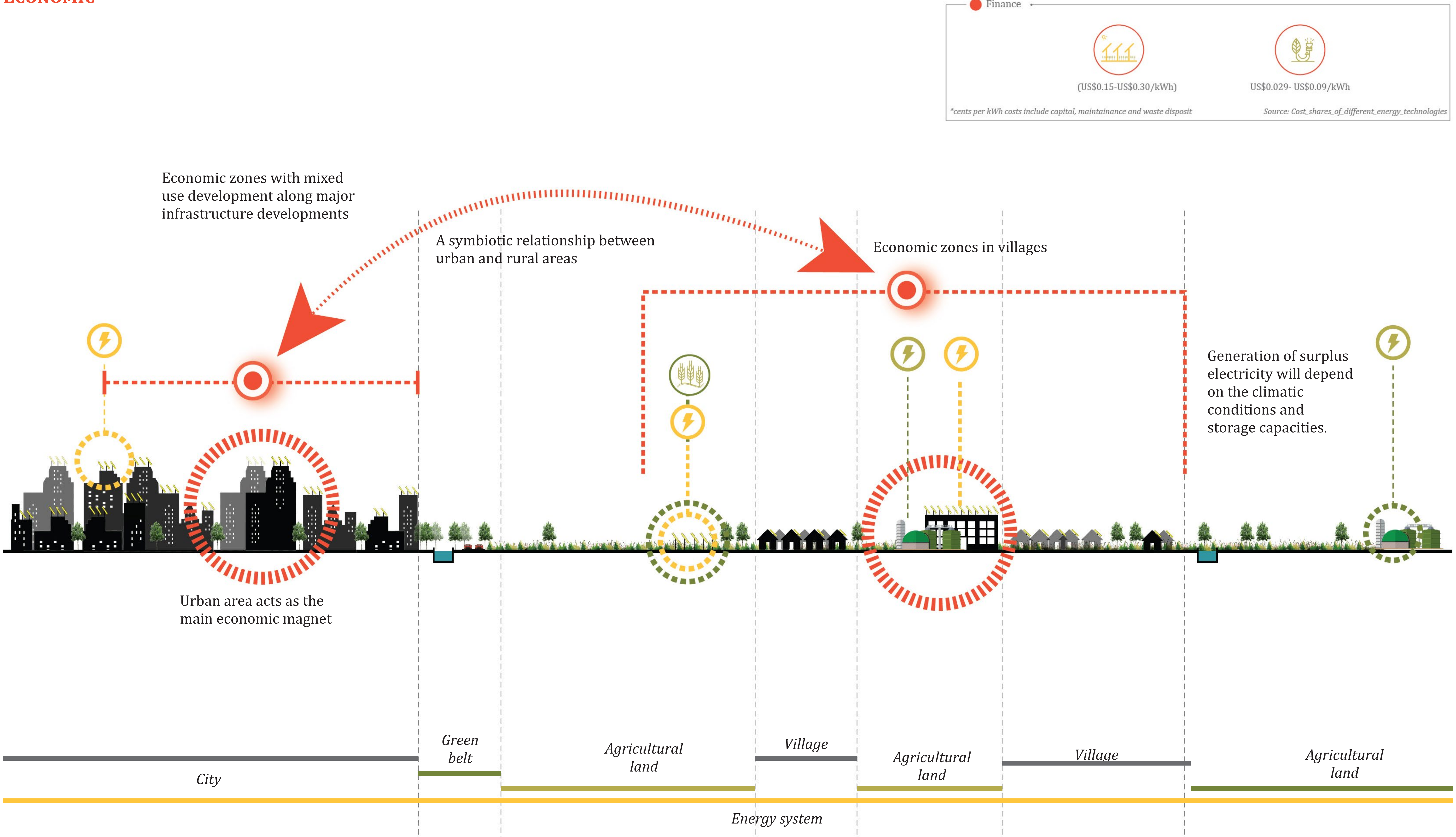
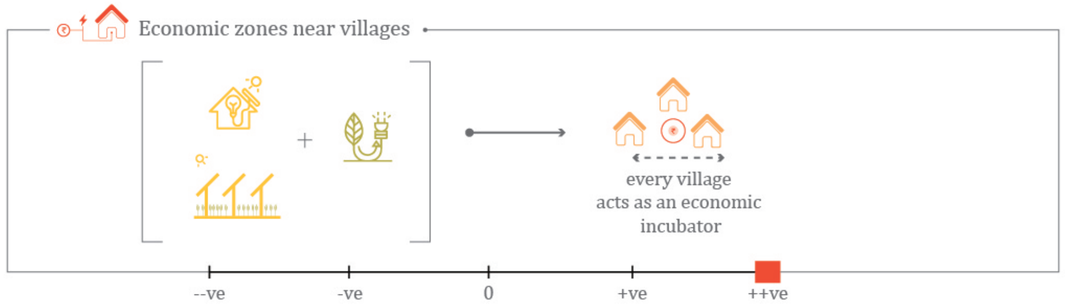
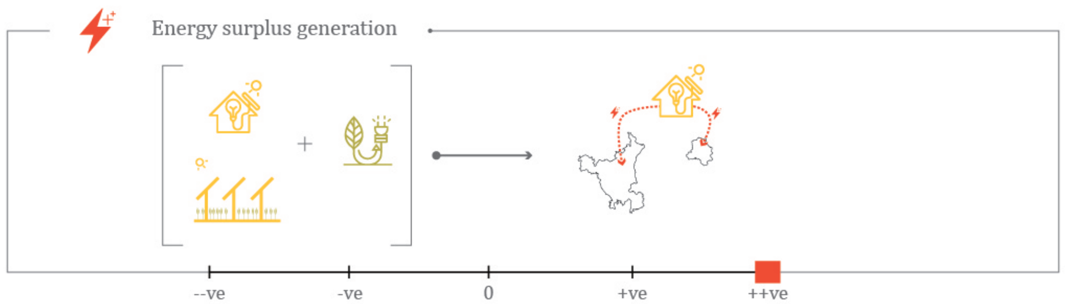


Fig 9.38: Section showing the economic flows in the implementation a decentralised R.E system in the area. Source: Author

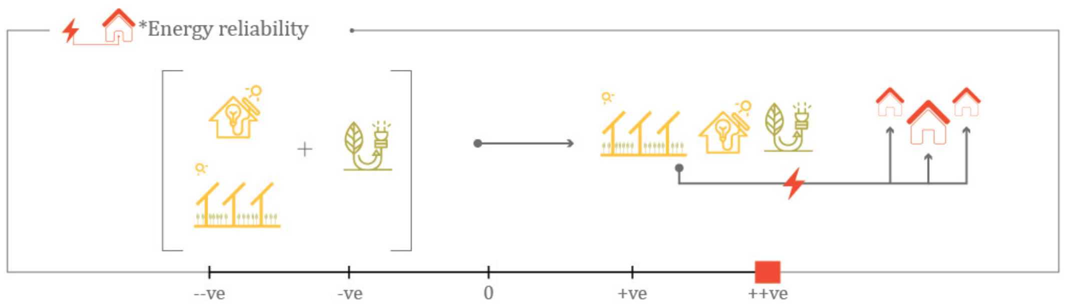
Economic



1. Economic zones near villages: (Pueyo & Maestre, 2019) says that bringing together communities and strengthening them allows for more productive use of electricity. This shows that the chance of economic growth is more and with infrastructural support local economic zones development can be facilitated. The economic zones created will be based on environmental sustainability and managing resources efficiently. It is marked (++ve) as it is a positive change to the existing status quo and embodies multiple aspects of sustainability.



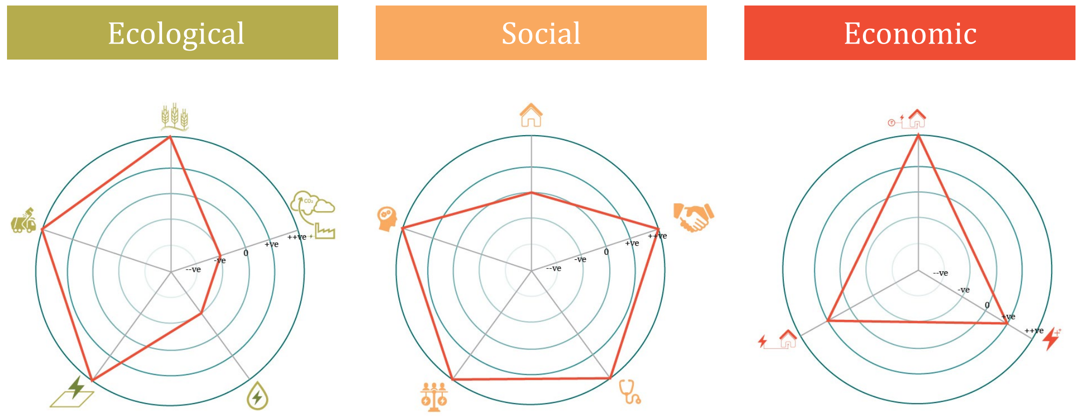
2. Energy surplus generation: The combined renewable energy system is built for meeting the future demands of the area. And the chances of generation of surplus will also depend on the climatic conditions and storage capacities. Based on the interviews with organisations, it is evident that the current un-reliable supply of electricity is hindering the development of rural areas. Having electricity generated to meet the needs of the area would ensure the development of few economic zones. In order to produce more energy, more panels will have to be set up. This is based on the community's capacity to set up micro-grids and roof top panels. It is marked (+ve) as it is a positive change to the existing status quo and embodies one aspect of sustainability by promoting to the economic growth of the state.



3. Energy reliability: Since solar and biomass are influenced by the climatic conditions and the agricultural produce, they are reliable sources only if there are proper storage of energy produced. However, switching to a renewable source of power generation is a step towards sustainability. Hence, it is marked (+ve).

Conclusions

Positive ecological and social impacts are seen in the decentralised energy system, as it urges for changes to be made in the society. From learning new methods of farming to reutilising the waste to produce energy to creating community co-operatives, higher levels of positive changes in aspects of circular economy and sustainability were noted in creating local flows of resource and people. The webbed diagram below shows the consolidated impacts of the three aspects.



9.5 | Comparisons and conclusions

The conclusion drawn from the comparison of the three scenarios is based on the ecological, social and economic impacts. Positive ecological, social and economic impacts are seen in the decentralised R.E system, as it urges for changes to be made in present society.

Higher levels of positive changes in aspects of circular economy and sustainability were noted in creating local flows of resource and people. This approach also increases the awareness on ways of reducing the impacts of the FEW systems. To reduce the impacts on the FEW nexus, the energy systems like Agri-voltaic systems (where solar farms or microgrids and agriculture go hand in hand), using CCS (carbon capture technology) to reduce CO_2 emission and create secondary fuels that can be reused. Water channels along solar grids can be used to collect water which can then be reused for irrigation. Promoting the collection of agricultural waste to produce energy and to change the current method of stubble burning is another positive change that can be adopted. From a sustainability standpoint (Serageldin & Steer, 1994), this is 'bearable' development where social and environmental development meet.

The economic impacts are positive when the people in society are more involved through increased community participation. It promotes better reliability, equity in access, economic and human development. By having a more decentralised local development, the community is accountable for its planning and development. Hence, more positive impacts were seen during the scenario planning process. This indicates an 'equitable' development where benefits can be shared among the people of the community in a just manner.

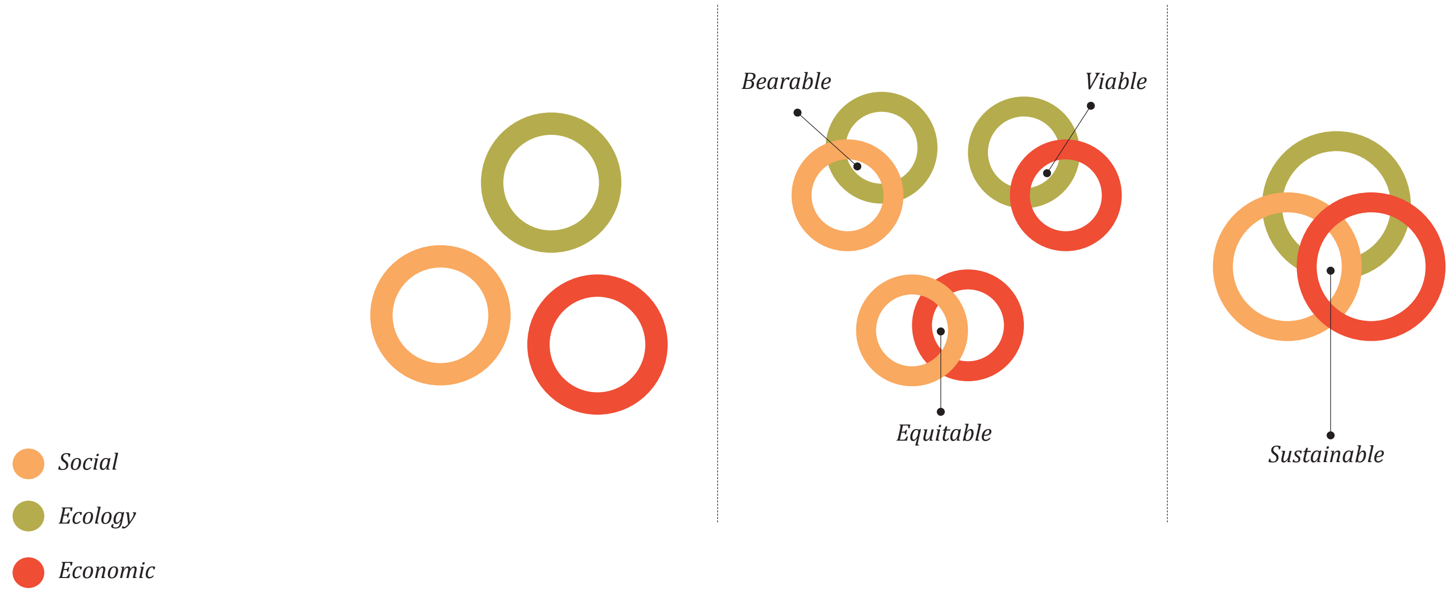
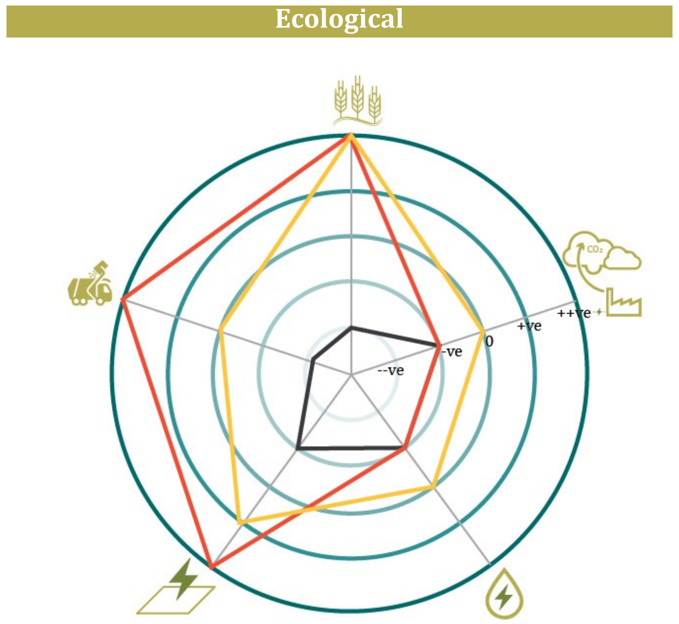
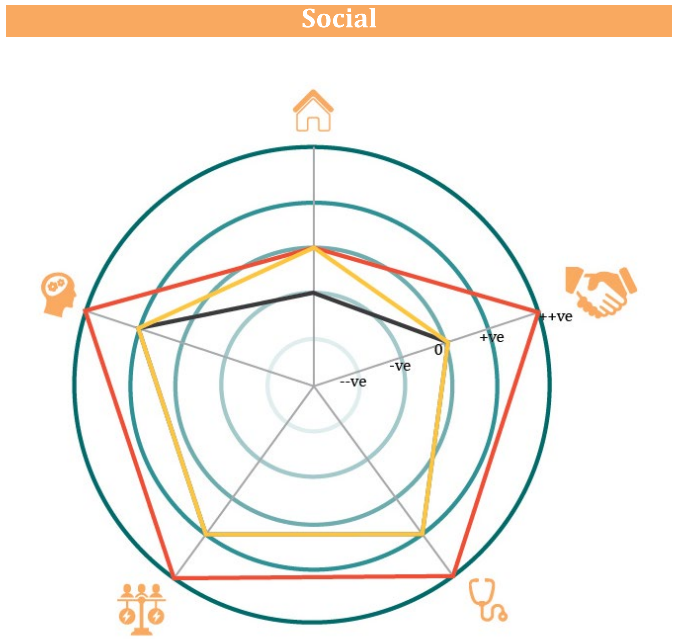
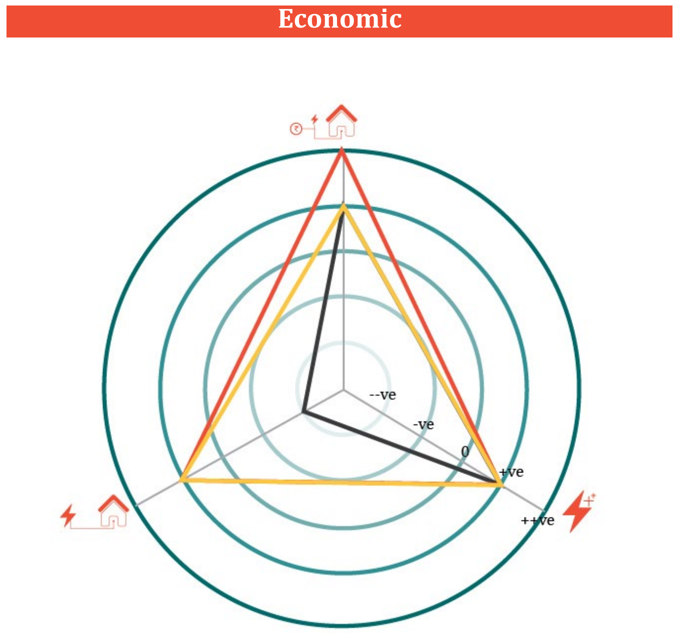


Fig 9.39: Sustainability venn diagram
Source: Adapted from

When the economic benefits are based on the production and consumption of resources that are environmentally benign, it is a 'viable' development. Generating energy through renewables makes the production of resources more sustainable. Re-use of waste and responsible use of energy is seen while relying on renewable energy production. Either a centralised or decentralised renewable energy source implies more renewable contribution into the energy mix. Combining these three areas together is when a just renewable energy transition can be achieved. The following chapter discusses the regional vision and strategies that are based on the combined analysis and conclusions drawn so far.







Scenario 1
Scenario 2
Scenario 3

Legend

--ve *: A very negative change and embodies no values of sustainability or circular economy, creating a long-lasting chain of negative events*
-ve *: A negative change to the existing status quo but embodies one aspect of sustainability or circular economy*
0 *: Has no impact on the existing status quo*
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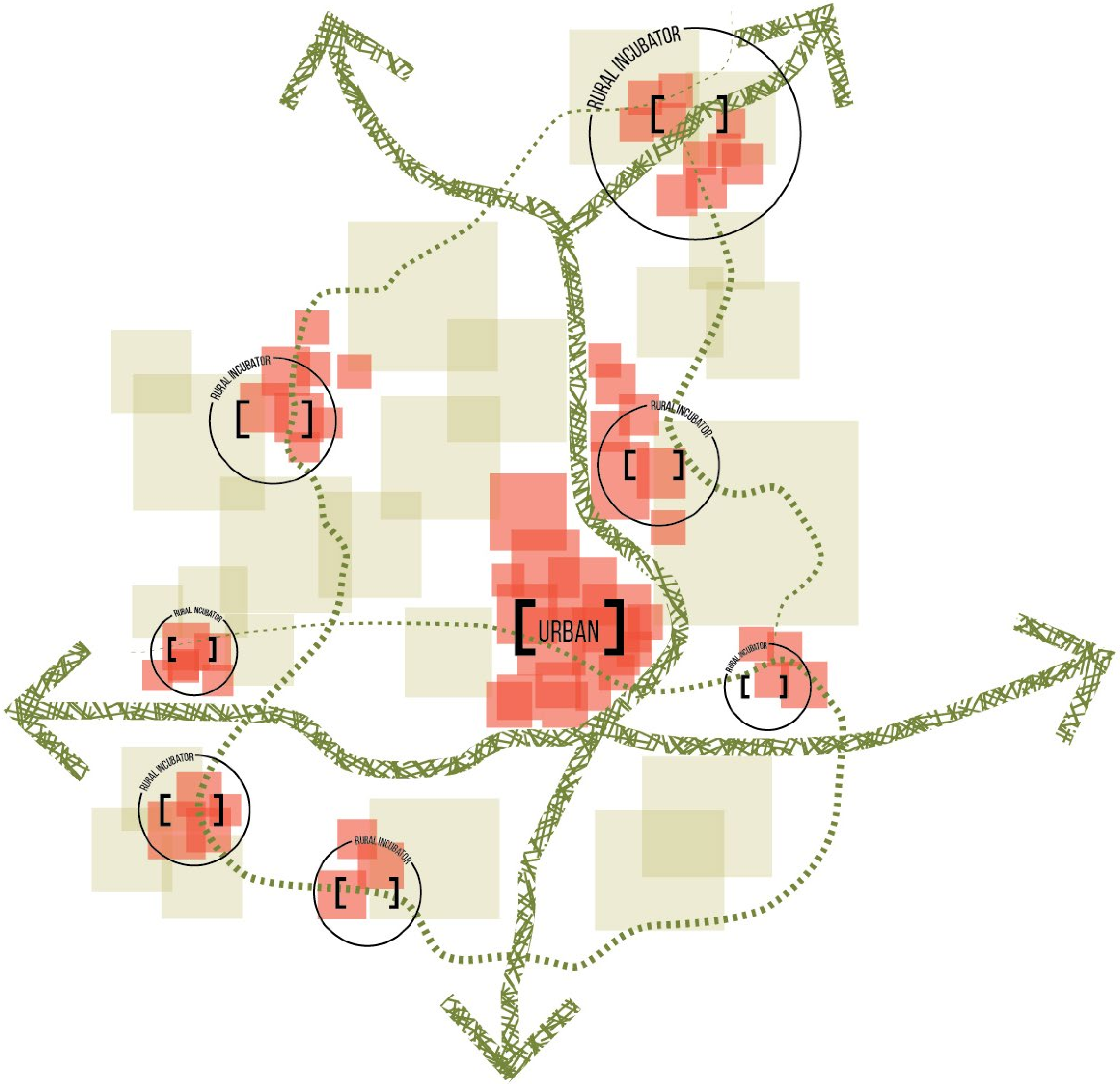
++ve *: A very positive change and embodies multiple aspects of sustainability or circular economy.*

10

Vision 2051 & strategies



" To have an interlinked network of rural incubators, that has a reciprocal relationship with urban areas and is supported by well-connected transit lines and promotes knowledge exchange to have a just renewable energy transition in the National Capital Region"

Fig 10.1: Conceptual diagram showing elements of the vision
Source: Author

From the conclusions of the previous chapters it was evident that choosing an energy system that creates more social benefits has more of a positive impact on the rural systems. So, in short the requirement is the adaptation of 'a sustainable energy system' that should be renewable, at the same time, promoting social and economic activities. This is most certainly seen better by creating local circles of resource generation and exchange (in terms of the resource used, social and economic aspects).

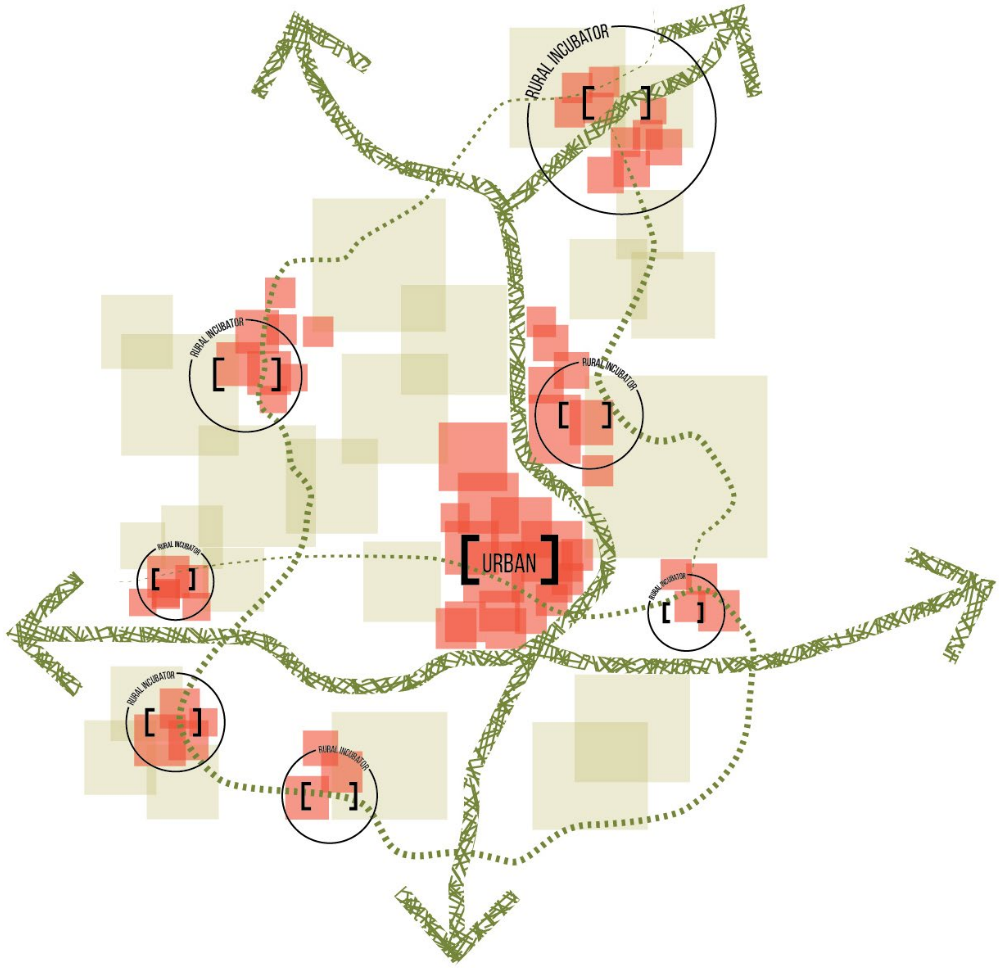
Taking the inference of scenario planning and the impact assessment done on the local scale, the vision is formed by upscaling the inferences to the regional level. The focus is on generating a decentralised system of development in terms of resource usage and governance strategies.

So, to create these local decentralised circles for the betterment of the rural areas, every village should be a producer and consumer of energy. They must become "incubators" (Stremke, Sven ; Dobbelsteen, 2013) of sustainable energy production and consumption. The traditional thought of rural areas being the source and urban area being the sink needs to change. Thus one of the aspects for the vision of the region is to **change the source-to-sink relationship between rural and urban areas** which implies *urban areas are the sources* and can support rural areas in the transition to an incubator.

According to (Stremke, Sven ; Dobbelsteen, 2013), incubator stands for a place with new line of development. The definition goes along these lines, "urban **incubators** that, through their status as energy landscapes and cauldrons of emergent energy practices, become nurturing places for business models aimed at car-bon reduction and the awareness of a society, that is, awareness of the need for the lifestyle changes necessary to meet national and global targets." Though the discussion in the book is about creating "urban incubators", for this project, roles are being reversed to form "**rural incubators**".

The addition to this definition in the context of the project is that the incubators should also be a nurturing place for community co-operation. It acts as a platform to build up their lives to reduce the existing urban-rural divide and to help alleviate energy poverty. The paper, "Smart-Cities for India: Why not Open-Source Villages?"(Varghese, 2017), discusses how the concept of *open-source and leapfrogging technologies* will help in development of communities by keeping them well informed and provided with deeper knowledge base for making better decisions. Exchange of knowledge between communities, that can be developed using their localised solutions will bring better liveability in rural areas.

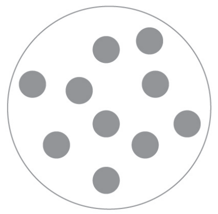
"Rural incubators, are that which has their identity as a nurturing place for sustainable energy pro-duction and consumption, through community co-operation and social capacitating to empower local business models that creates awareness on lifestyle changes, promotes exchange of knowledge and resource, and help the region have a sustainable energy transition"



Goal 1: Proper community organisations are set up in urban and rural areas.

Biennales and training camps are conducted in Local Area Planning and RE transition.

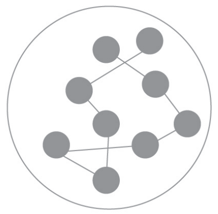
Urban buildings start to become a source of energy generation.



Goal 2: Urban centers are consistant producers of energy.

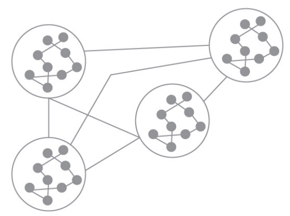
Rural areas are setting up decentralised grids.

Infrastructure lines connecting the rural and urban areas are built.



Goal 3: Surplus energy is used to fuel energy intensive industries in the region.

Economic zones start to form in the rural areas with exchange of knowledge and resources between the urban-rural systems and amongst rural areas as well.



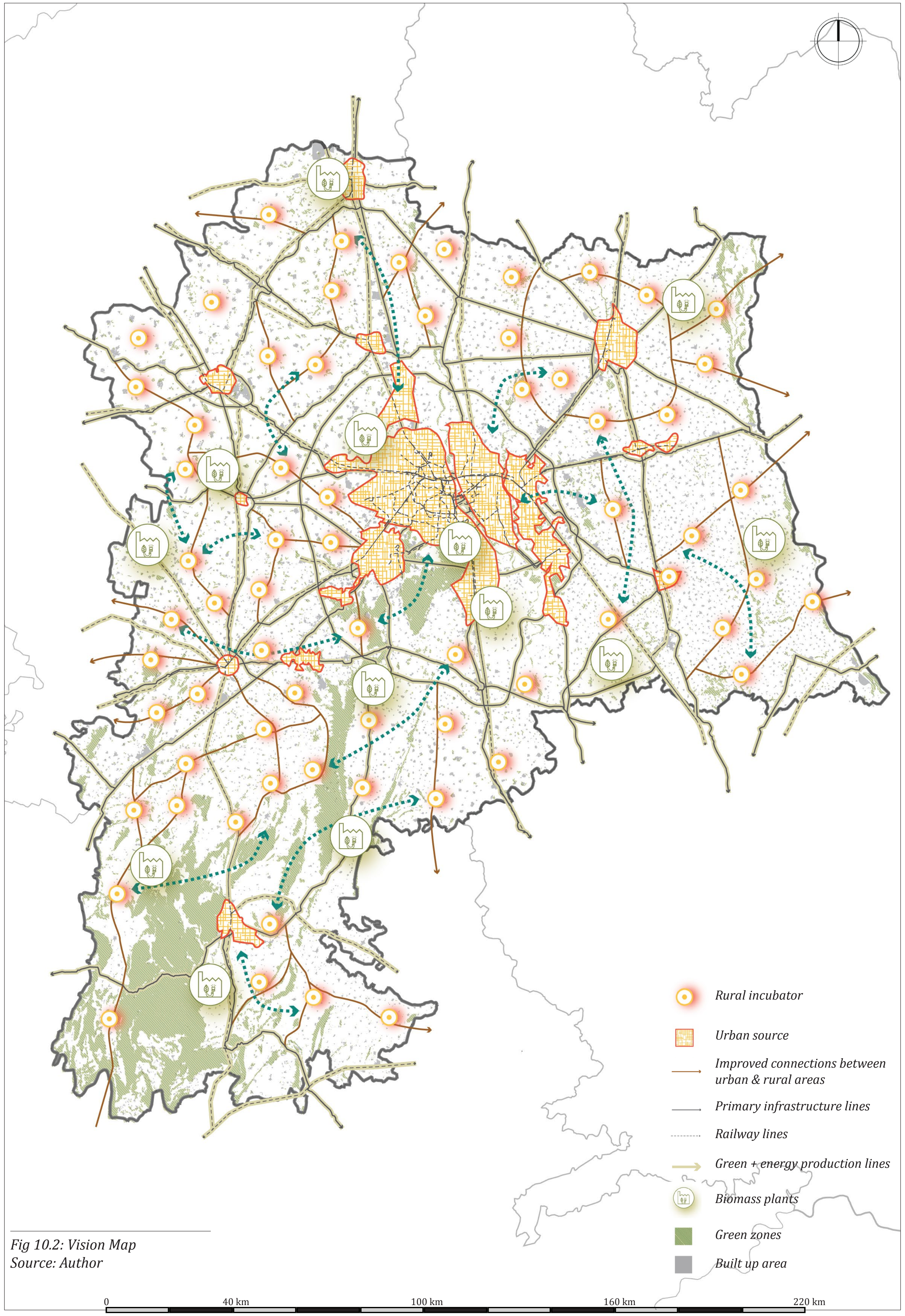


Fig 10.2: Vision Map
Source: Author

10.2 | Strategies and actions

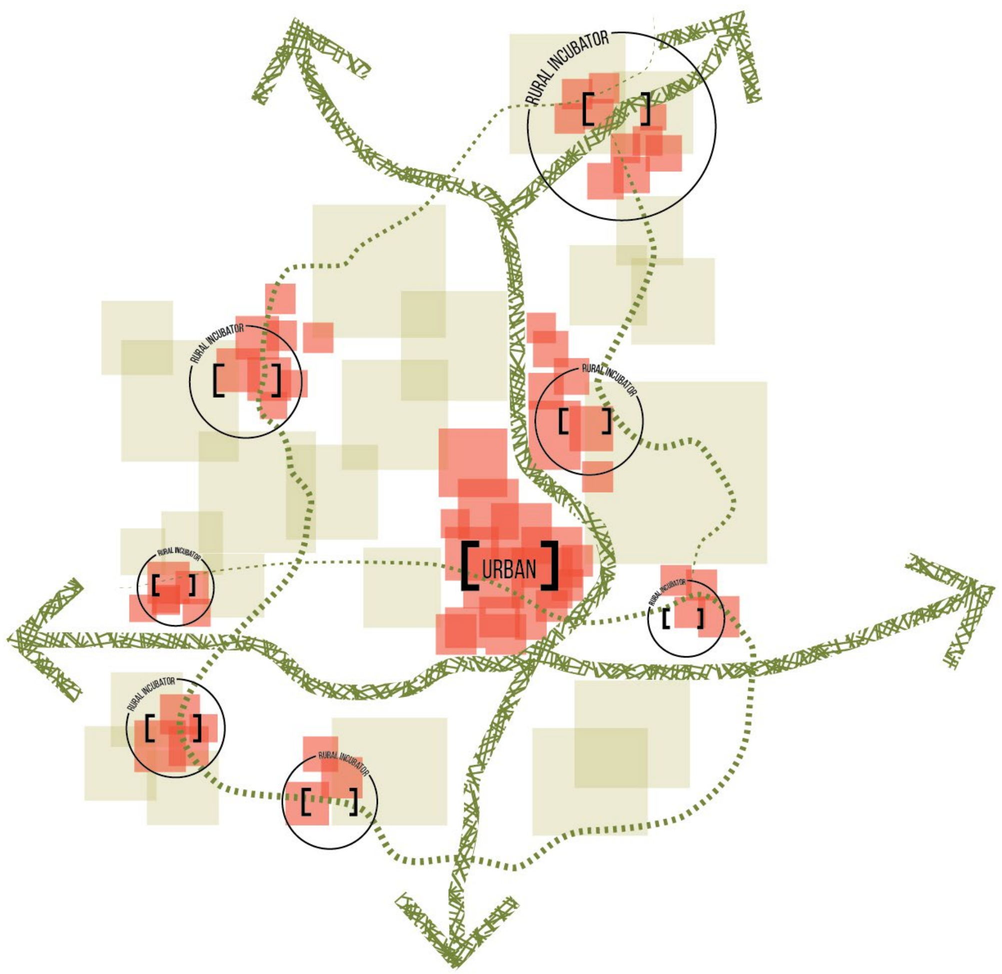


Fig 10.3: Conceptual diagram showing elements of the vision
Source: Author

" To have an interlinked network of rural incubators, that has a reciprocal relationship with urban areas and is supported by well-connected transit lines and promotes knowledge exchange to have a just renewable energy transition in the National Capital Region"

Reversing the rural to urban relationship →	Shifting the role of dense urban areas: creating an urban source
Incubator **Open-source villages** →	Setting up open source rural incubators: Empowering the rural areas
Spatial connections →	Extending transit lines to improve urban-rural connectivity
Leapfrogging technologies →	Rethinking “vs energy” as “and energy”: Cross-functional uses with technology

Shifting the role of dense urban areas: creating an urban source

City level energy Biennale showing various energy scenarios and showing the benefits of transitioning into an energy smart city will be held to create awarness and educate the society.

Mohalla sabha (neighbourhood assembly) are formed in urban areas to address issues and propagate energy transition.

Subsidies and incentives are offered to the people living in urban areas to switch to solar rooftops and promote waste segregation (which can be used for biomass power generation.)

Buildings with sufficient structural stability should be retrofitted with solar panels and be a producer of renewable energy. The excess energy produced can be supplied back into the grid or stored. Building-integrated photovoltaics (BIPV) in dense urban areas – especially in new buildings should be introduced in the guidelines of building construction.

Train community groups and create work groups (from the rural areas) to help with solar installations and maintainace in the urban areas. And for every installation a portion of the money can go towards the betterment of rural communities.

Dense urban areas will densify to accommodate the growing population and sprawl towards rural areas will be prevented by a strong green belt. This will prevent exploitation of agricultural land.

Intergrate energy production in city and landscape elements using solar micro-grids, solar street lighting, parking lot rooftops, as shading devices in bus and train stops and other open areas with limited shade where solar energy can be harnessed efficiently.

The exisiting transmission lines are to be updated to reduce transmission losses. The electricity transmission lines should be supplied with electricity generated through a renewable sources.

Surplus electricity produced will be stored or supplied to areas with existing connections to the state grid and are suffering from electricity shortage. Surplus energy can be used to fuel energy intensive industries in the region.

Setting up open source rural incubators: Empowering the rural areas

In villages that lack a primary public building like school or government structure, a building with a rooftop solar system is to be built. This will be overseen by the block and village level governance bodies. Such a structure will act as an initial platform for supplying electricity to households, a place for organising awareness camps, setting up of small businesses and other activities.

Set up community organisations in every village of the NC region. These organisations will help in breaking the financial and societal barriers of renewable energy transition. Every household in a village will be accountable to the head of their community organisation. The head will be a person who will be directly linked to the block and municipal corporations. Once the system has been well established the position can be transferred to an elected member of the community organisation.

Participatory budgeting to encourage the rural communities to create flexibity in order of implementation of strategies related to development and renewable energy transition. PB will include a percentage of funds set aside for R.E transition. Strong emphasis will be given to switch to solar rooftops or connect to solar micro-grids, include an agrivoltaic food production and harness the agriculture waste for energy production.

Financial aid groups can be formed within the organisations to bear the initials costs of setting up renewable energy systems. People involved in the organisations can pool in money to set up micro-grids for the village or individual solar rooftops. If a micro-grid is set up, a cash card system can be introduced, so that the people can pay before hand for a set amount of KWh. This can ensure that payments are made regularly, to avoid misuse of electricity.

Issues of women and men will be addressed separately to have a holistic approach in creating awareness about the need for renewable energy in the development of rural communities in the region.

Women shall be mobilised and included in activities like starting of small businesses that sell good quality electric stoves or setting up shops that enhance local trade and tourism, teaching new agricultural methods like incorporating energy and food production, forming renewable energy installation and maintenance groups and in agriculture waste collection groups.

Biomass plants will be set up along rural incubators that are situated near forest areas. State governments will oversee the setting up of biomass plants in the rural areas. Biomass waste will be collected from rural incubators and sent to a biomass storage facility near the biomass plants.

All buildings in the village will be connected to a decentralised micro grid. The de-centralised grid will then be linked to renewable energy sources of solar and biomass.

Villages will become a rural incubator that is developed in a sustainable manner. It will include strong social connections, environmental awareness and economic activities.

Villages will involve in exchange of resources amongst other villages to form a cluster of incubators that benefit from each other and the urban developments.

Extending transit lines to improve urban-rural connectivity

Primary transit lines that link urban centres (like state highways and national roads) should be linked to renewable energy production.

Secondary transit lines connecting the urban-rural areas and with rural areas should be implemented in the development of rural areas. This allows easy commute between areas and promote business opportunities in the rural areas.

Incubator villages should be linked to a secondary or primary transit line to promote increased movement of people and resources in the rural areas.

Rethinking “vs energy” as “and energy”: Cross-functional uses with technology

Agriculture and energy production : Crop production and photovoltaic-based electricity generation from a single land unit is to be adopted by farmers. This agrivoltaic type of farming is essential in reducing the food vs energy issues.

Water harvesting and energy production : The panels can be used to harvest rainwater, that can be used for irrigation. Water collector channels are to be placed along with setting up the solar system. Urban areas can harvest water along with energy production

The technology used in harnessing energy should be kept updated and informed in both urban and rural areas to have a more efficient energy system.

Biomass plants and existing thermall power plants have to be equipped with CCS (carbon capture and storage) technology. This will allow the reuse of carbon for the production of other resources.

Fuel switching (to biomass or other waste materials) in existing thermal power plants should be implemented. Downsizing of existing power plants to biomass or hydrogen-based alternatives should be considered.

Fig 10.4: Layers showing the 4 strategies
Source: Author

| Stakeholders - Existing Status Quo

Existing relations are weak between the local area (gram panchayat), the municipal corporation and the state government. This makes implementation of strategies more difficult.

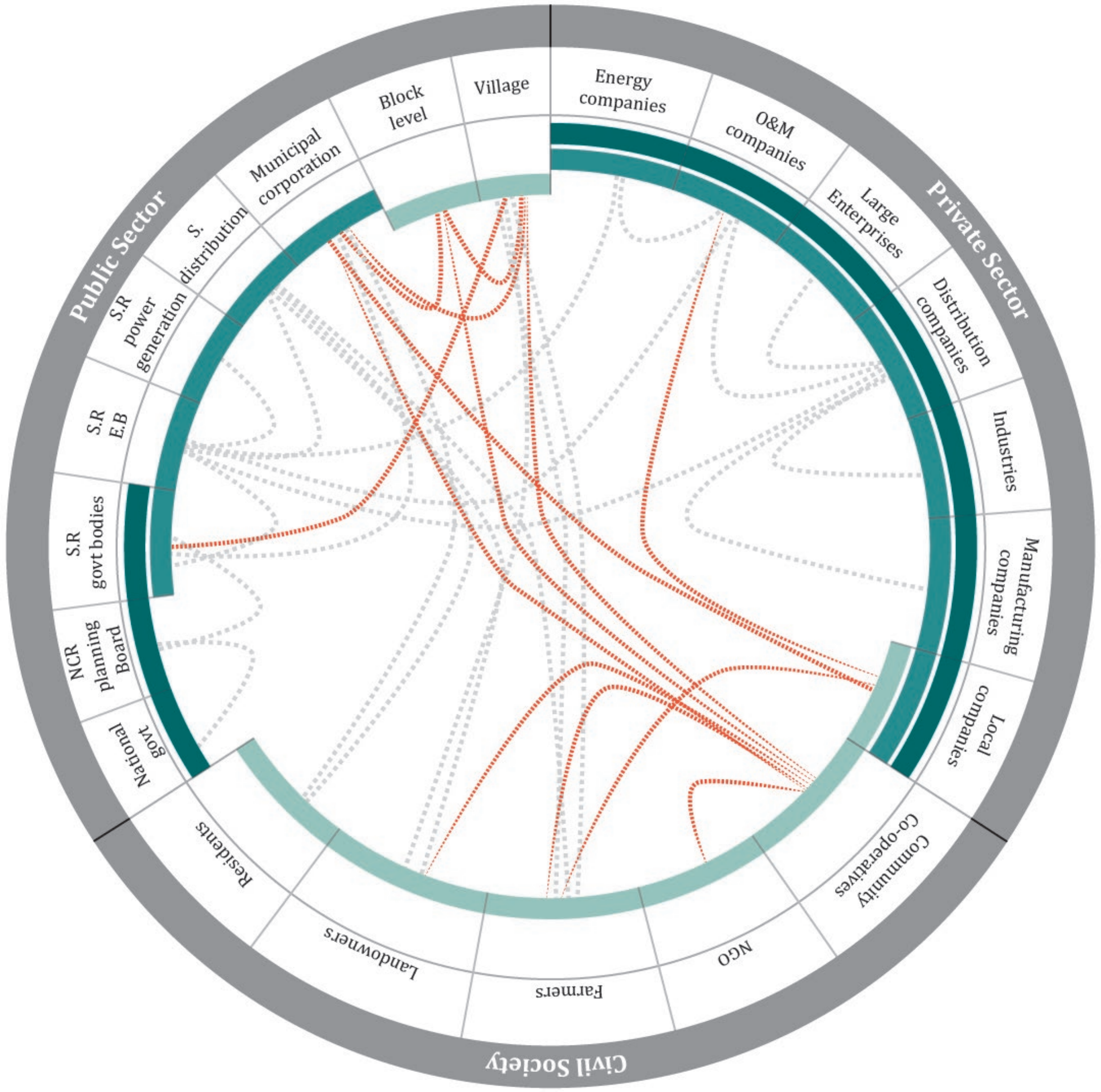
73rd CAA (Constitution Amendment Act) gave power to village level in rural areas to improve situation of the areas based on local understanding. However, due to weak relations, implementation of strategies do not happen in a desired manner (Frenkiel & Tawa Lama-Rewal, 2019).

For strategies to be successful at a local scale, it is important to build strong relations between the state, district and the local level. Strategies like participatory budgeting or setting up the rural incubator systems will require awareness and education camps to be conducted to educate the people on local area planning, sustainable energy transition and the importance of community-co-operatives.

Legend
- *Regional level*
- *Sub-regional level*
- *Local level*
- *Existing relations*
- *Weak relations*

Fig 10.5 : Diagram showing exisitng stakeholder relations
Source: Author

| Stakeholders - Desired relations



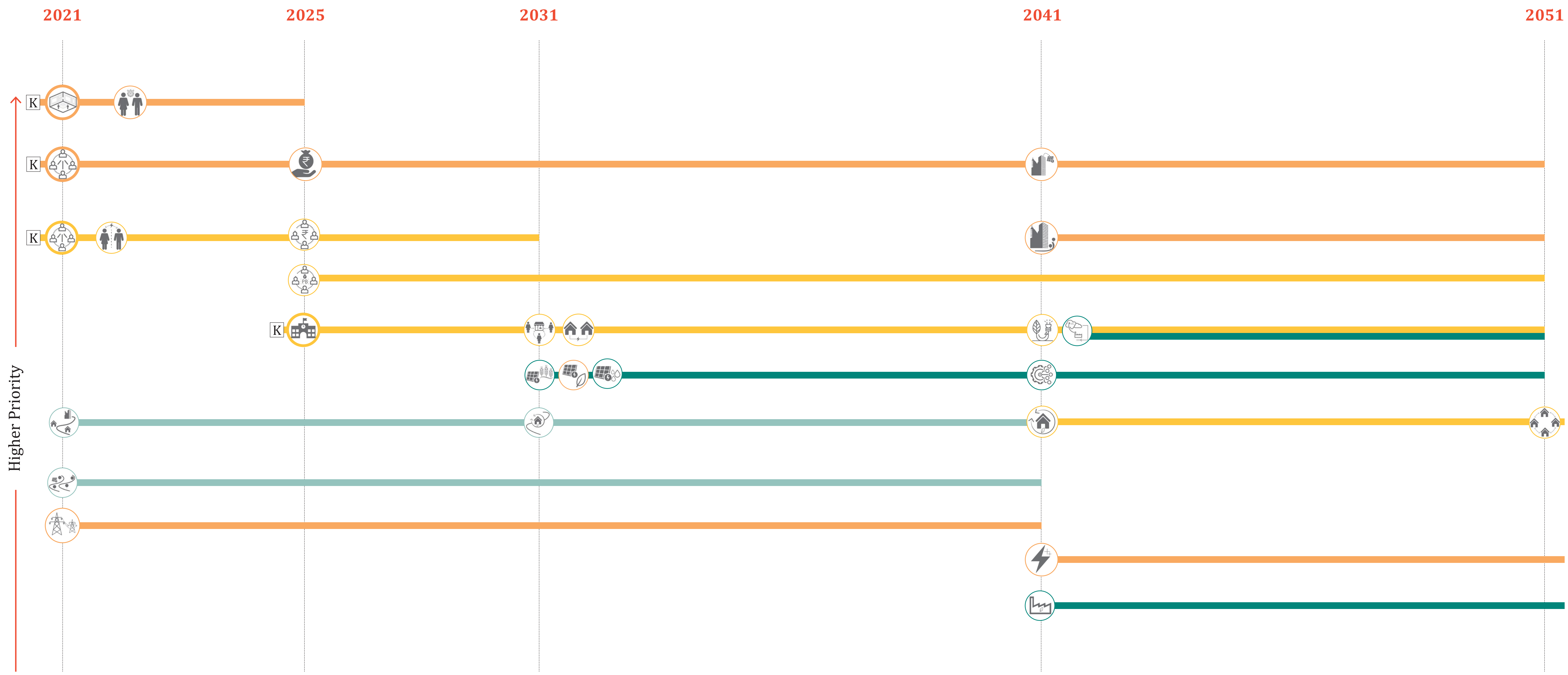
Legend
- *Regional level*
- *Sub-regional level*
- *Local level*
- *Desired relations*
- *Existing relations*

Fig 10.6 : Diagram showing desired stakeholder relations
Source: Author

Educational programs regarding energy consumption, energy efficiency and renewable energy production should be held for 3 levels- state, district and local. Trainees from state govt. bodies who will advocate the cause and help in improving communication between levels should be involved. They will deal with local area planning and development and propagation of transition to renewable energy sources. The authorities involved will be State level trainees, district level (deals with communication from local to higher) and local level propogators (groups formed in neighbourhoods in both urban and rural setting). This is a method that is seen to be successful and has been done in the state of Kerala, India to improve relations across governance scales (Frenkiel & Tawa Lama-Rewal, 2019).

Involving the public & private sectors (who mainly operate in the urban areas) together can boost the possibilities of economic activities in the rural areas.

10.3 | Phasing



The above diagram shows the phasing of strategies for the rural area. The strategies shown in the same lines horizontally are dependent on each other and the priorities of strategies increase vertically from bottom to top. The phasing is based on the actions that has to be taken in order to realise the regional vision. The next sections discuss the phasing in the transect scale.

Strategy 1: Shifting the role of dense urban areas: creating an urban source

Strategy 2: Setting up open source rural incubators: Empowering the rural areas

Strategy 3: Extending transit lines to improve urban-rural connectivity

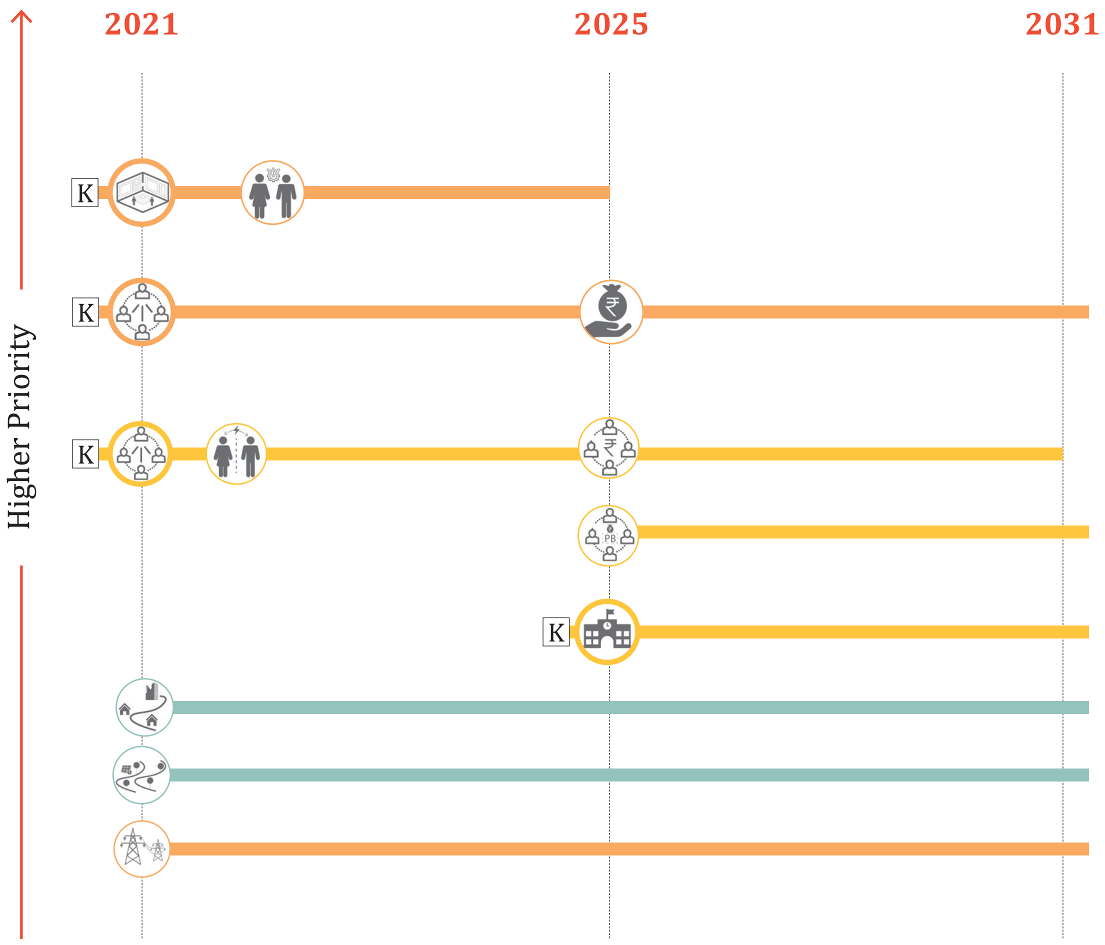
Strategy 4: Rethinking "vs energy" as "and energy": Cross-functional uses with technology

K *key projects/trigger projects*

Fig 10.7: Phasing of strategic action in the region

10.4 | Strategy implementation on transect scale

Phase 1



Phase 1 - Local scale interventions:

1. Trigger projects will start with urban centres like Delhi and Gurgaon that have a higher HDI (Human development index) and lower MPI (Multiple poverty index) along with areas with higher energy access percentage.

2. Areas with increased biomass potential should start with the setting up community organisations and building primary structures in villages with poor building conditions. The biomass potential in the Alwar is higher, so biomass plants can be set up. Alwar region is seen to have a higher percentage of villages with poor building conditions which should be addressed by building primary structures.

3. Secondary lines to increase connectivity and movement of resources between nodes should begin execution.

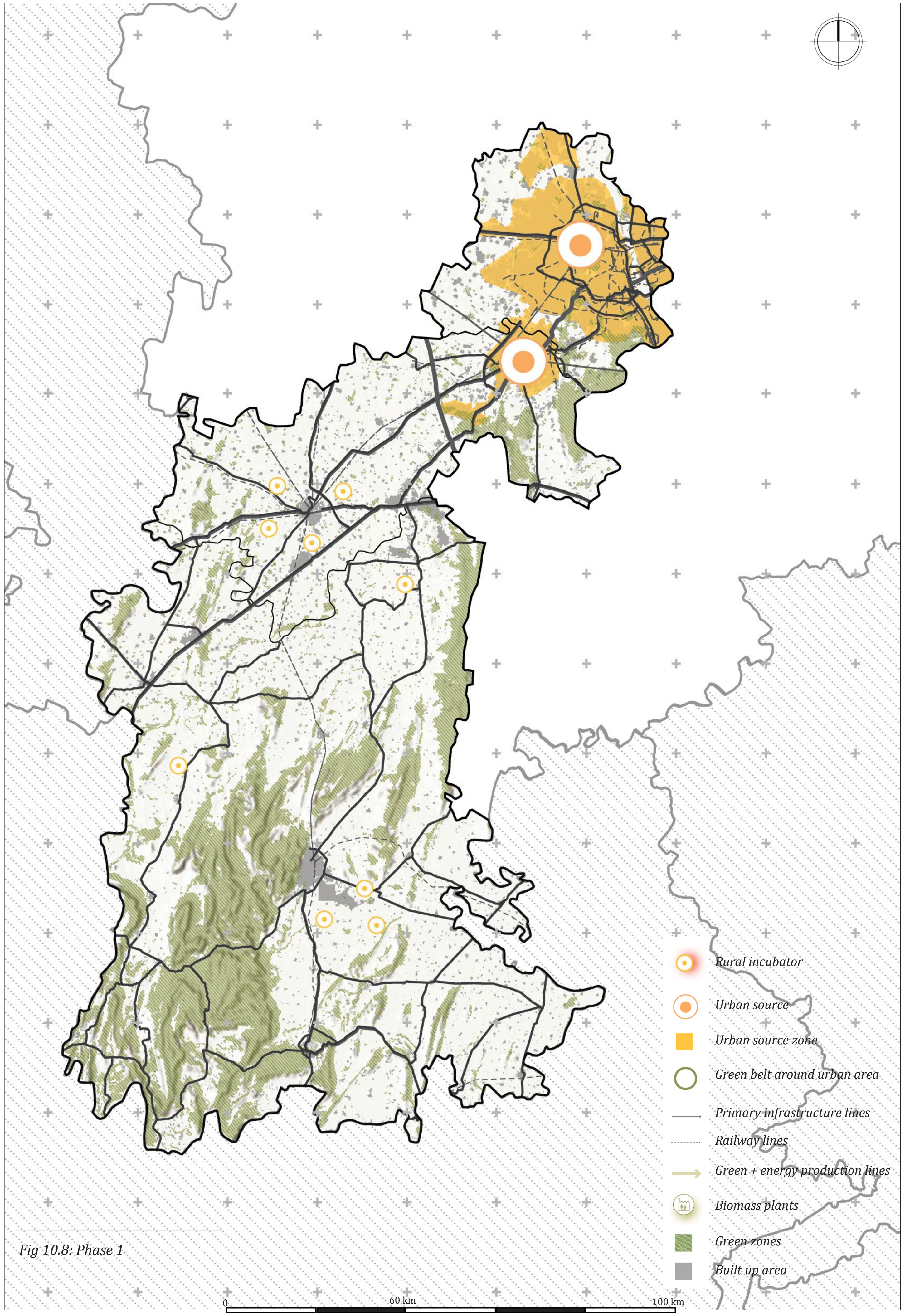
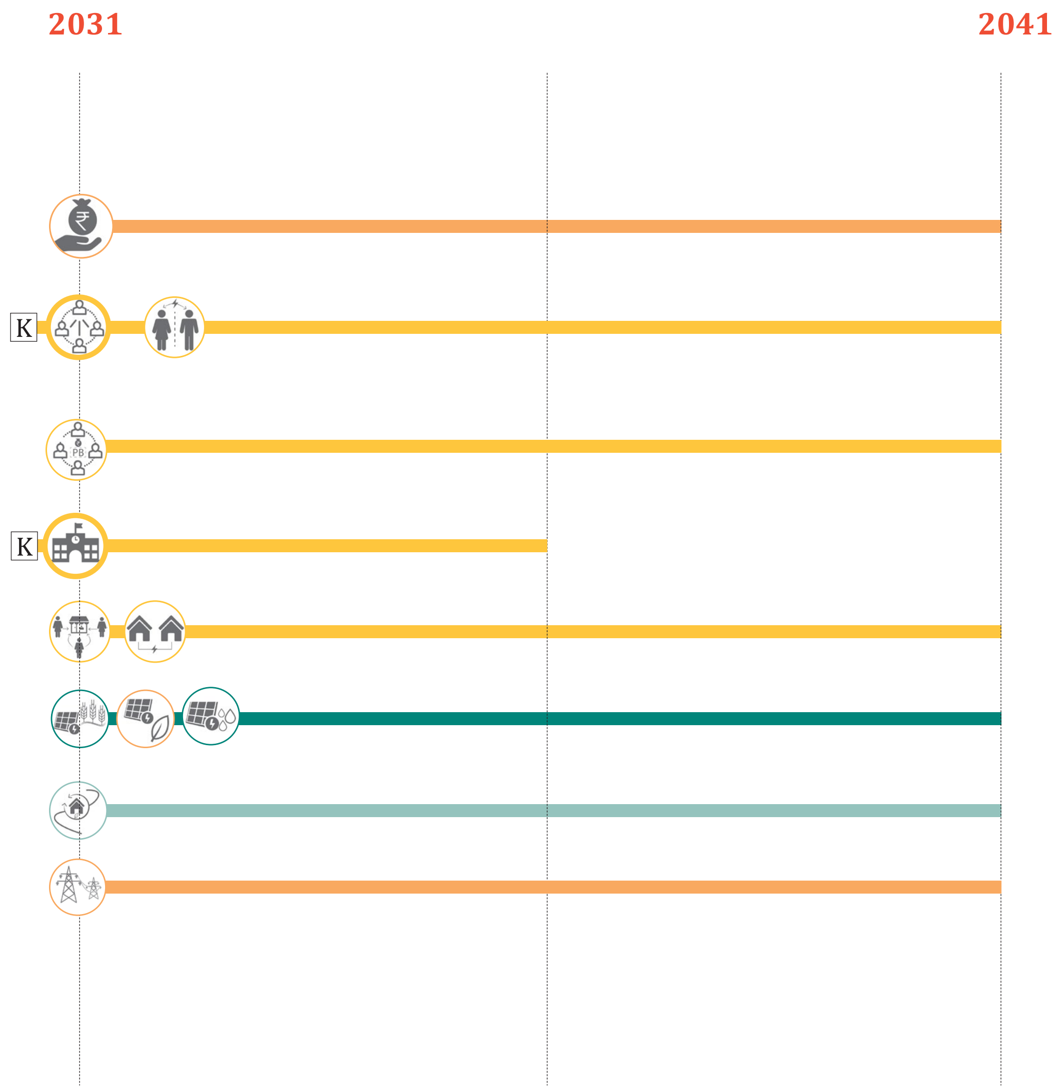


Fig 10.8: Phase 1

Phase 2



Phase 2 - District scale interventions:

1. Community organisations will continue to be set up in rural areas within the region. This will be promote bringing in electricity through renewables. Energy poverty is alleviated to an extend by the end of phase 2.

2. Secondary transit lines will begin along areas with lesser connections especially towards Alwar where infrastructure connections are low.

3. More biomass plants are set up in areas with higher biomass potential- crop and forests.

4. Work groups are mobilised to work in urban areas to facilitate the transition

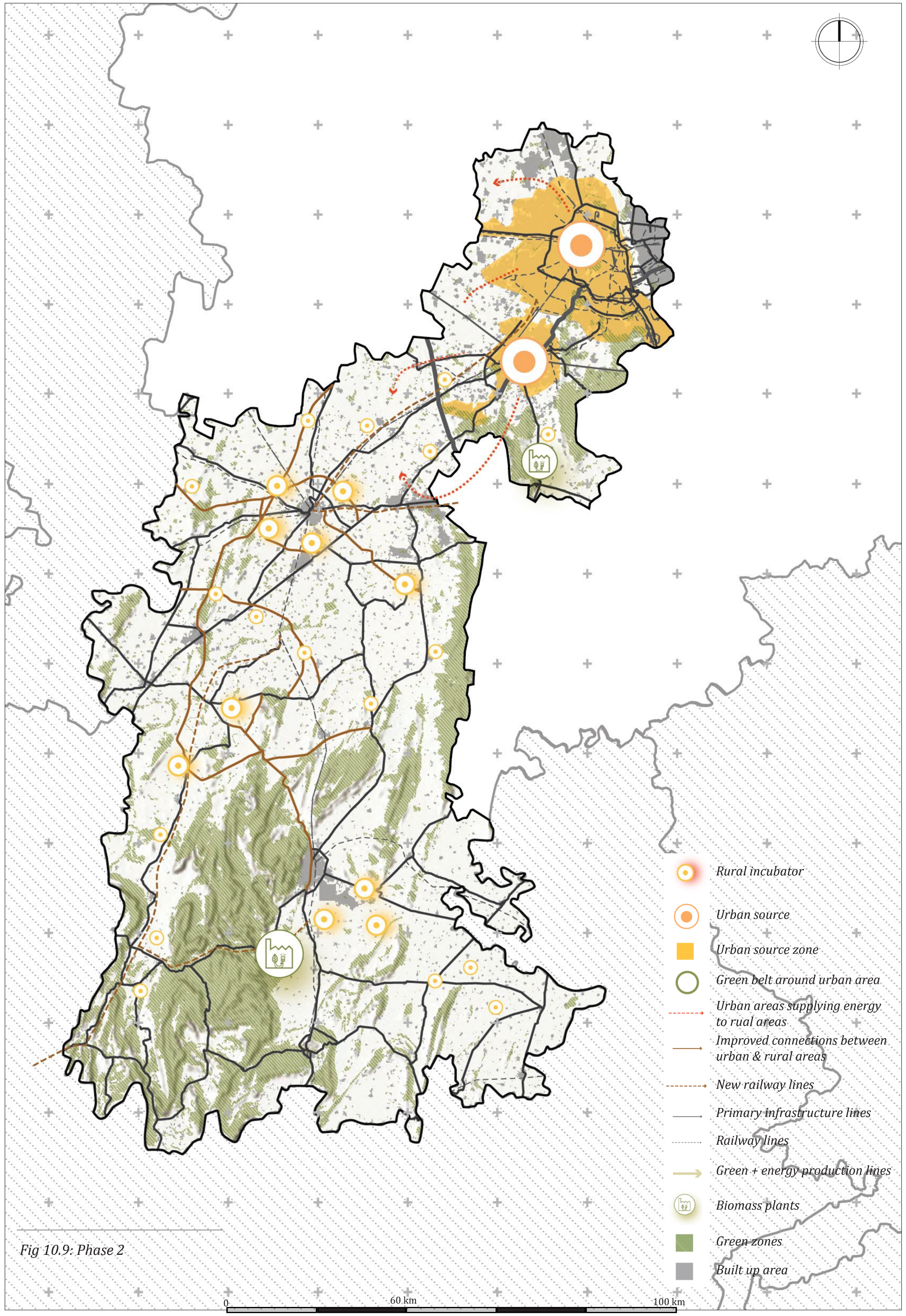
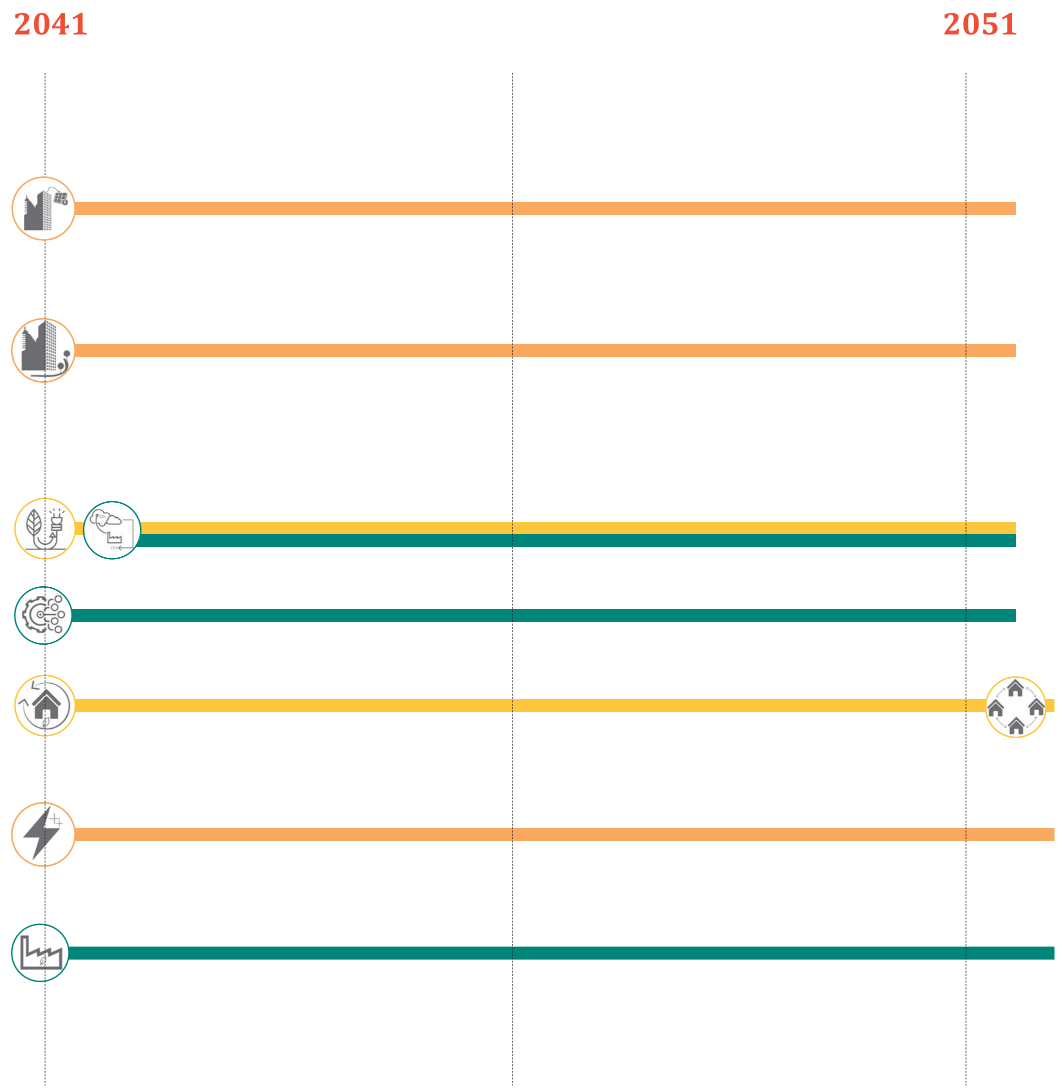


Fig 10.9: Phase 2

Phase 3



Phase 3 - Regional scale connections

1. Rural incubators are well established and linked to sustainable energy production.

2. Infrastructure connections are strengthened and are also producers of energy to support transit based energy requirements.

3. Using these connection there is exchange of resources leading to better living standards and development of rural areas with alleviation of energy poverty, and equality in access to facilities.

4. Surplus energy produced by the urban-rural system is used to fuel energy intensive industries in the region.

5. Villages will begin exchange of knowledge and resources that promote better human and economic development in the region.

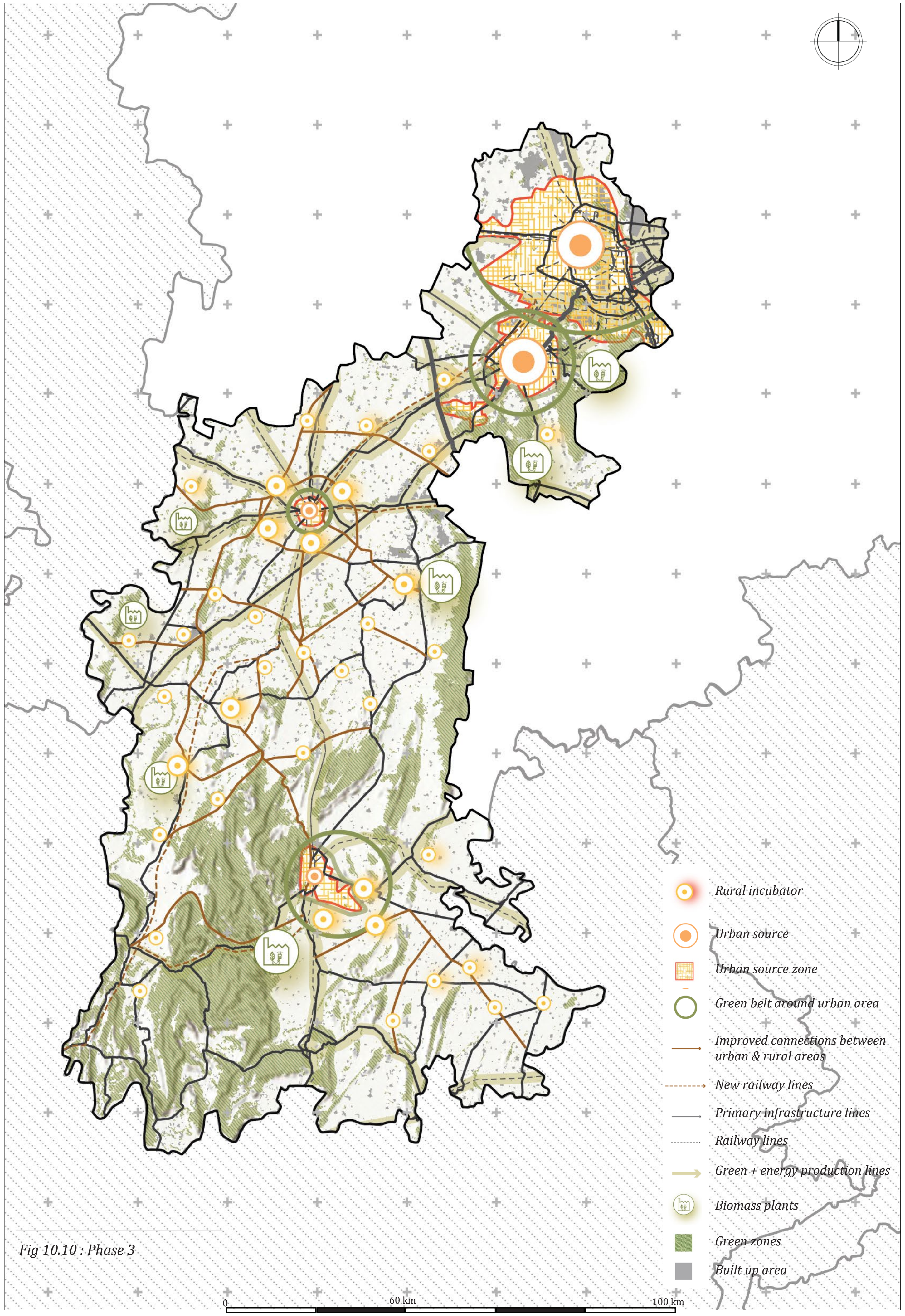


Fig 10.10 : Phase 3

11

Transferability on local scale

11.1 | Introduction

The addressal of transferability of the strategies is done by projecting them onto the previously mentioned locations of Gurgaon (urban context) and Alwar (rural context). The four strategies of (1) Shifting the role of dense urban areas: creating an urban source (2) Setting up open source rural incubators: Empowering the rural areas 3) Extending transit lines to improve urban-rural connectivity (4) Rethinking "vs energy" as "and energy": Cross-functional uses with technology are applied on the two locations. Through this process, the application, scope, and limitations of the strategies are identified. These inferences can be used to inform the development of energy systems in areas with similar contexts. This process is also essential in reflecting upon the strategies from a 'just transition' point of view.

Shifting the role of dense urban areas: creating an urban source

Setting up open source rural incubators: Empowering the rural areas

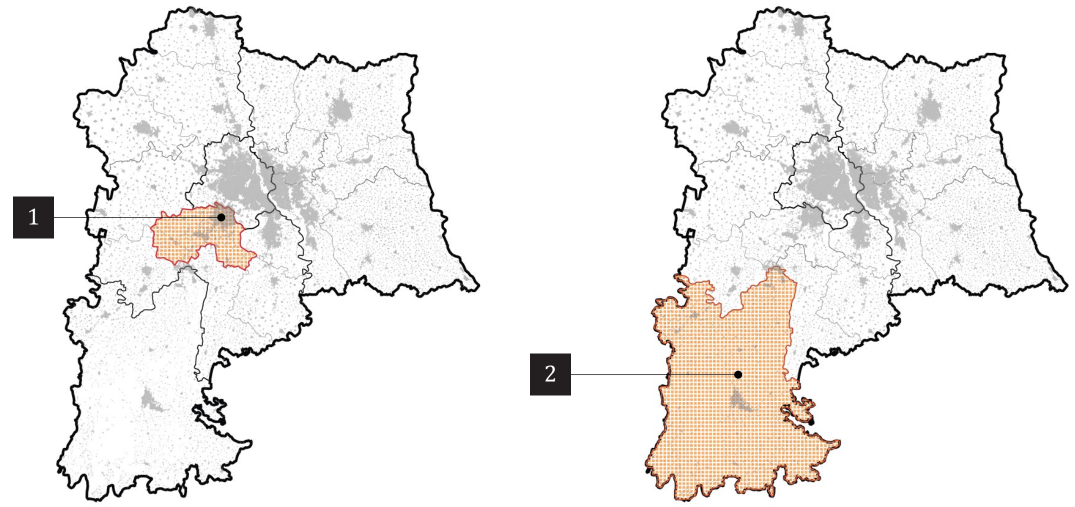
Strengthening transit support : improving urban-rural connectivity

Rethinking 'vs energy' as 'and energy' : Cross-functional uses with technology

| Zoom in locations

The three spatial systems previously identified are marked on the below maps that also highlight the energy potentials in the transect scale. The black boxes indicate the test locations. Both the locations have the potential for harnessing solar and biomass energy. The variations in ESH (peak sun hours) and arable land are taken into consideration in the energy calculations for the two locations.

Location 1: Gurgaon, DMA Haryana sub-region, NCR
Location 2: Alwar, Rajasthan susb-region, NCR



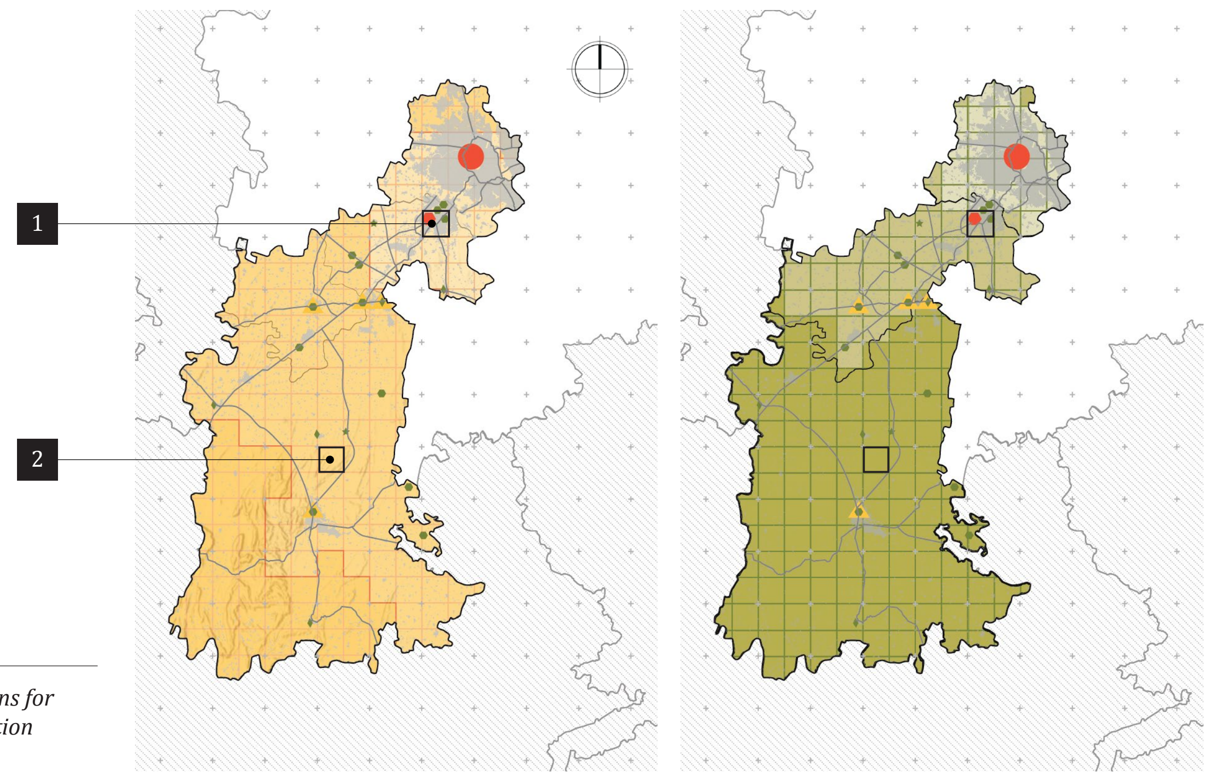


Fig 11.1 : Zoom locations for local scale implementation

11.2 | Zoom location 1 : Gurgaon, DMA Haryana sub-region

The actions explored in the urban area of Gurgaon is based on the main strategy of shifting the role of urban areas and creating urban sources. The other strategies like empowering rural areas, strengthening transit support and rethinking 'vs energy' as 'and energy' act as support structures to the development of the areas.

Considering a 10km x 10km location in the district of Gurgaon, the strategies are implemented in three phases, starting from 2021 up until 2051. The phasing takes into account the energy demands of the future and incorporating renewables like solar and biomass into the energy mix. The design explorations are illustrative of the transferability and feasibility of the strategies on other urban locations on the regional scale.

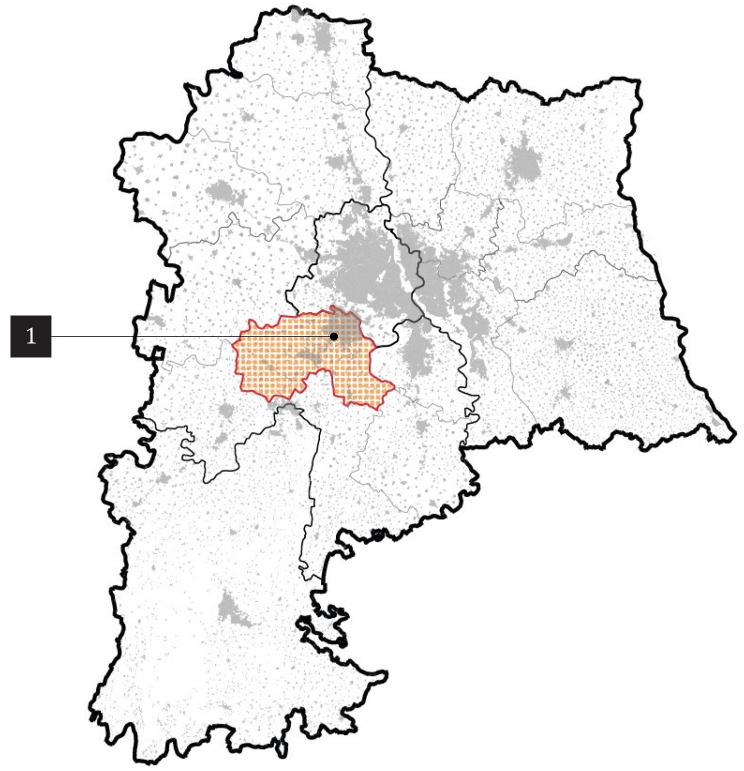
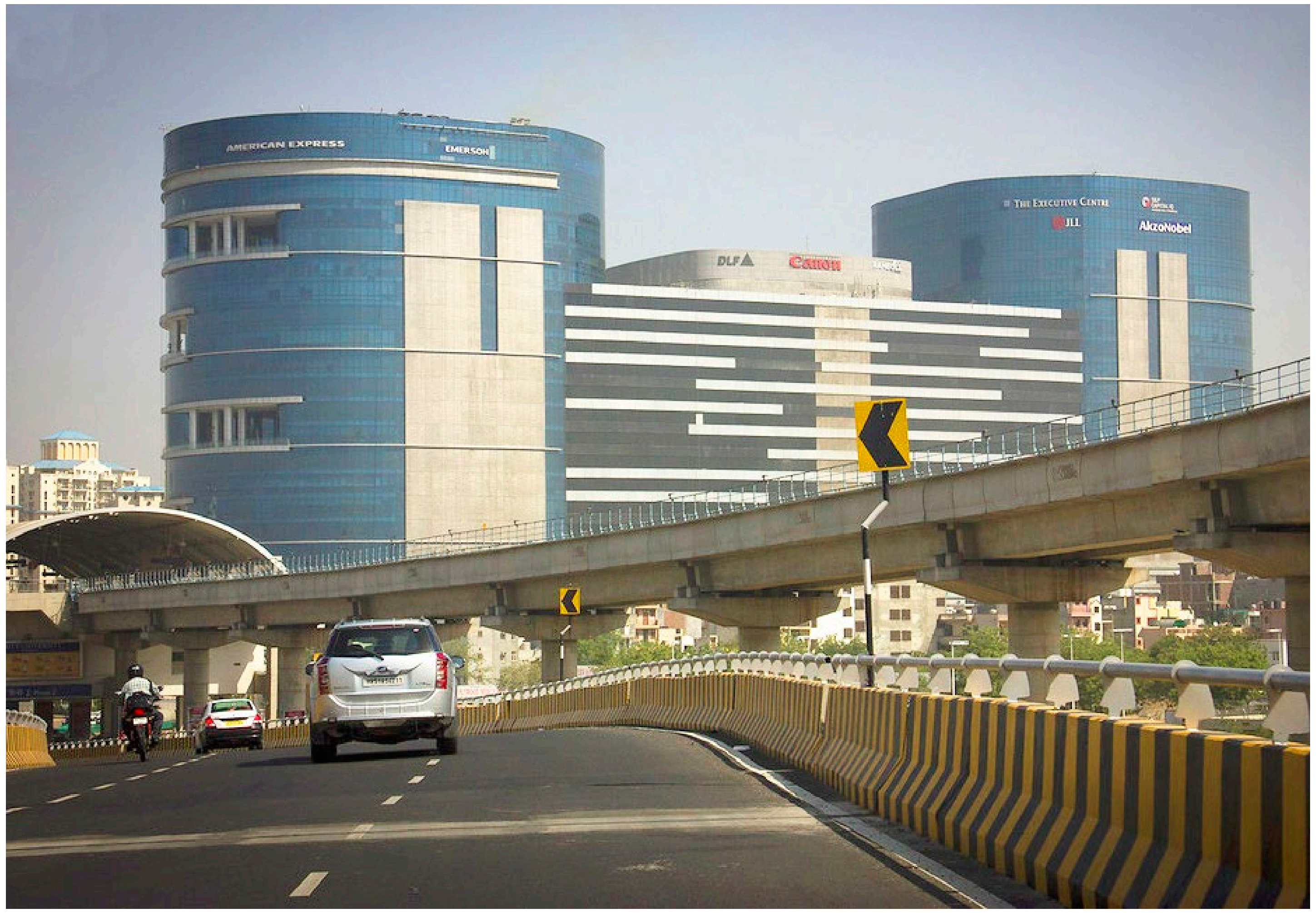


Fig 11.2 : Bird view of gurgaon urban area
Source: www. flickr.com



The public infrastructure lines in the urban area of Gurgaon is well connected with commercial and industrial development along it. The residential areas are also well linked to the city centre and cyber city area. The metro line connects a part of Gurgaon city to Delhi. The 100km^2 area considered has a built up area of 65km^2 and agricultural area on the outskits of 5km^2.

Fig 11.3 : Infrastructure lines within the urban area of Gurgaon.
Source: www.flickr.com

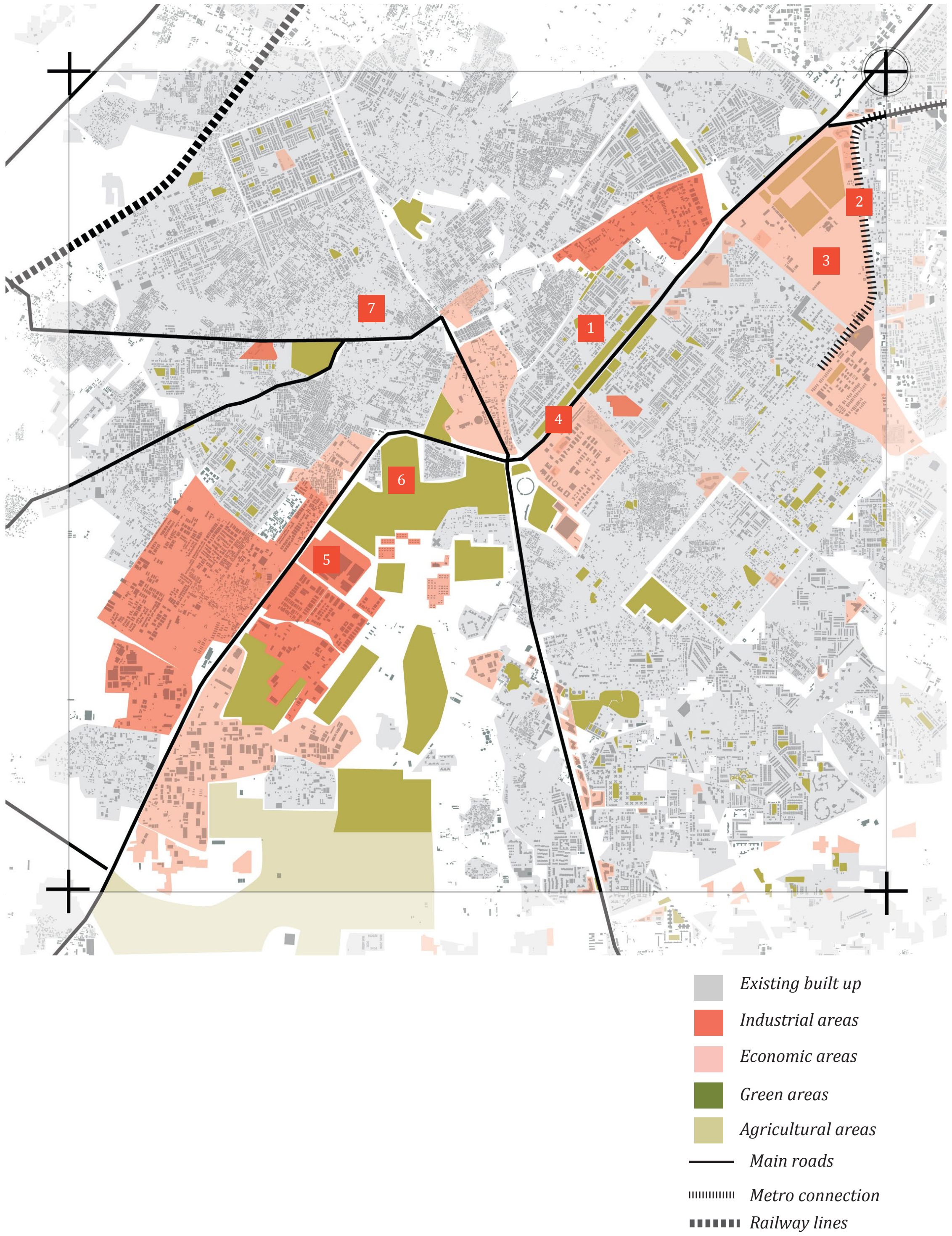


Fig 11.4: Existing status quo zoom location
Source: Author, based on GIS

Year	2011	2021	2031	2041	2051
Population	1514432	2369554	3292848	3999653	4158234
Growth Rate (GR) (%)	73.96	56.46	38.96	21.46	3.96
GR Decline (%)	17.5	17.5	17.5	17.5	17.5
Pop Density (p/km2)	2052.08	3210.78	4461.85	5419.58	5634.46

Per capita consumption (kWh/p/year)	Year	2017	2018	2019	2020	2021	2031	2041	2051
	Gurgaon (DMA)	1574	1653	1735	1822	1913	3116	5076	8269
	Growth Rate (%)	1.1	5.0	5.0	5.0	5.0	62.9	62.9	62.9

2051	Population Density (p/km2)	Population (p)	No. of households	Per Capita Consumption (kWh/p/year)	Total Energy Consumption (GWh/year)	Daily Energy Generation (kWh/day)
	5634.46	563446	112689	8269	4659.01	12764405

Fig 11.5: Data used for calculations
Source: Extrapolated based on data from www.citypopulation.de and www.tcpharyana.gov.in

The above tables shows the extrapolated data for population density, energy consumption and the daily power generation required for the year 2051. Population (p) in the 2051 projection stands for the population calculated within the 100 km^2. The extrapolated data has taken into account the growth rate and decline based on previous year's trends.

The total area required for power generation in the case of solar and biomass sources are calculated in the same manner as mentioned previously in section 9.9.

India's ambitious energy goal is to incorporate around 40% non-fossil based energy in the energy mix by 2030's conditional targets (Climate action tracker, 2020) . Energy mix in 2021 was taken based on the existing energy mix seen in Haryana. The energy mix includes 78% thermal, 3.6% renewable, 18.3% others (hydro power and nuclear). Nuclear power is supplied from outside the region. Due to the limitations in developing the hydro plants because of water scarcity issues and the vision to have a more decentralised energy production and consumption in the region, it is assumed that the contribution from hydro and nuclear remains the same throughout. Since the energy that can be harnessed from biomass is very less due to the limited agriculture fields in the urban context. It is more feasible to harness the solar energy.

Based on the energy calculations performed for the region (see appendix) and considering that 50% of the total arable land area of 5km^2 is cultivated with biomass crop, the region would require an additional 30.5km^2 area for solar energy generation to meet the energy demands of 2051. The next sections contain the strategies used and energy mix in phasing from 2021 to 2051.

Shifting the role of dense urban areas: creating an urban source

- City level Energy Biennale
- Green Belt
- Neighbourhood assembly (Mohalla sabha)
- Work groups from rural areas
- Subsidies and incentives
- Upgrading transmission lines
- Retroffited with solar panels
- Surplus energy
- Landscape and energy

Strengthening transit support : improving urban-rural connectivity

- Primary transit lines linked to renewable energy source
- Strengthen secondary transit lines

Rethinking 'vs energy' as 'and energy' : Cross-functional uses with technology

- Agrivoltaic farming
- Water harvesting
- Technology updates
- CCS technology
- Downsizing and fuel switching

Setting up open source rural incubators: Empowering the rural areas

- Women based work groups
- Biomass plants

**Actions of the strategies are elaborated in chapter 10*

| Phase 1

The first phase is about creating awareness in the society, bringing the communities together for promoting the transition towards renewable sources and starting the journey towards sustainable energy production and consumption. This can be initiated through strategic actions like energy biennales and organising neighbourhood assemblies. Involving work groups from rural areas also boost the work force participation in the rural areas. Stakeholders in phase one (from national, state, and local level), will help create a more accountable involvement in energy production, distribution, and consumption.

Over the initial span of 10 years (2021 to 2031) the thermal power contribution must be reduced by incorporating renewables. First, the current energy demands of the location is analysed along with the existing energy mix. The energy demands for 2021 and 2031 are extrapolated based on the population growth and the per capita consumption growth. The goal is to achieve 35% renewable energy contribution by 2031 from 3.6% in 2021 and phase out thermal contribution to 57% in 2031 from 78% in 2021. During this phase, the existing thermal plants will be implemented with CCS technology to reduce the CO_2 emissions. Also, in order to reduce the transmission losses that are at their peak in India due to outdated energy infrastructure, transmission lines will be upgraded.

Stakeholders involved

Public Sector

- *National govt.*
- *State energy department*
- *State power generation and distribution bodies*
- *Municipal corporation*
- *Village*

Private Sector

- *Energy companies*
- *O&M companies*
- *Discoms*

Civil Society

- *Landowners*
- *Residents*
- *Community corporatives*

Legend

- *Regional level*
- *Sub-regional level*
- *Local level*

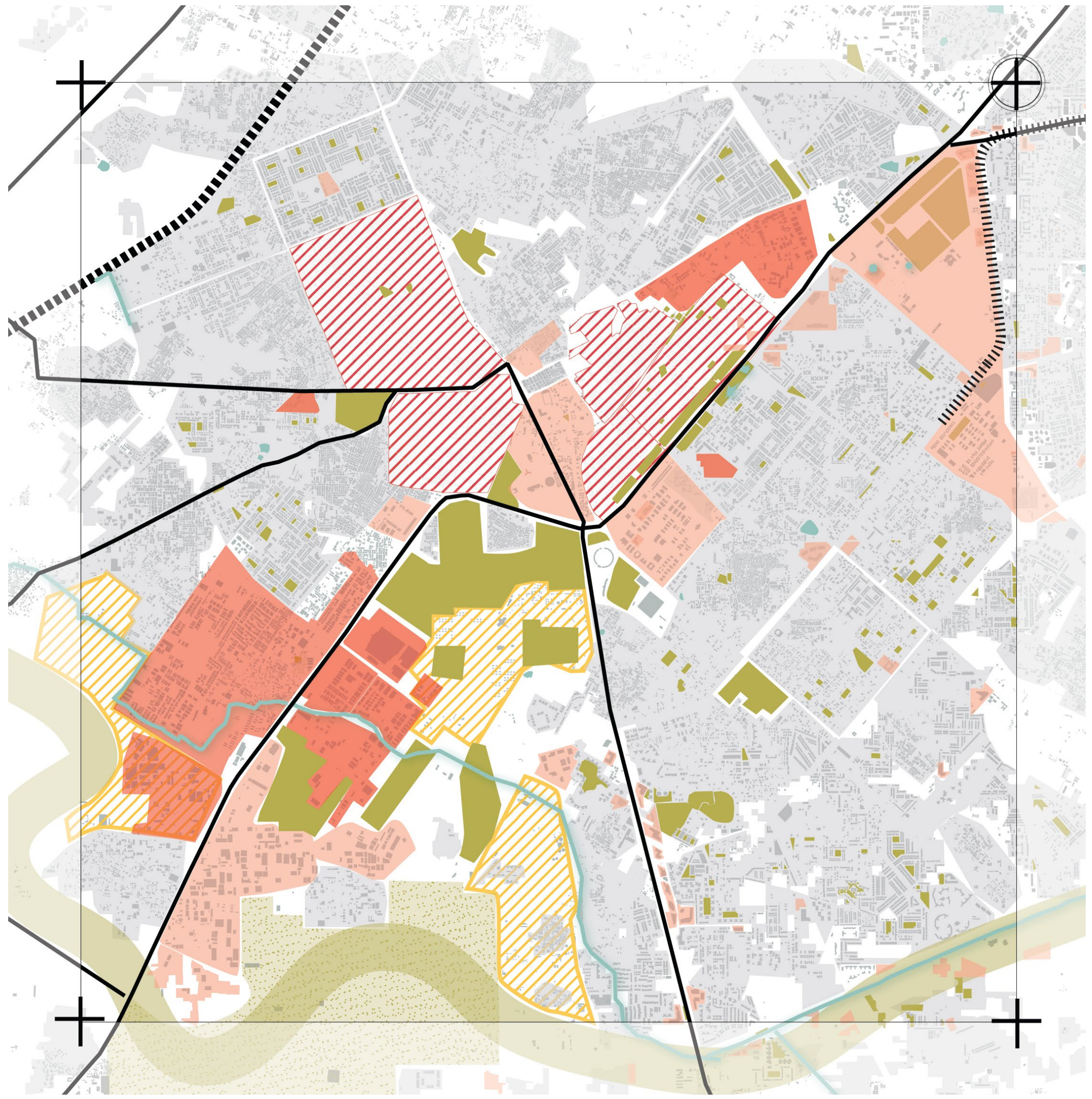


Fig 11.6: Phase 1
Source: Author, based on GIS

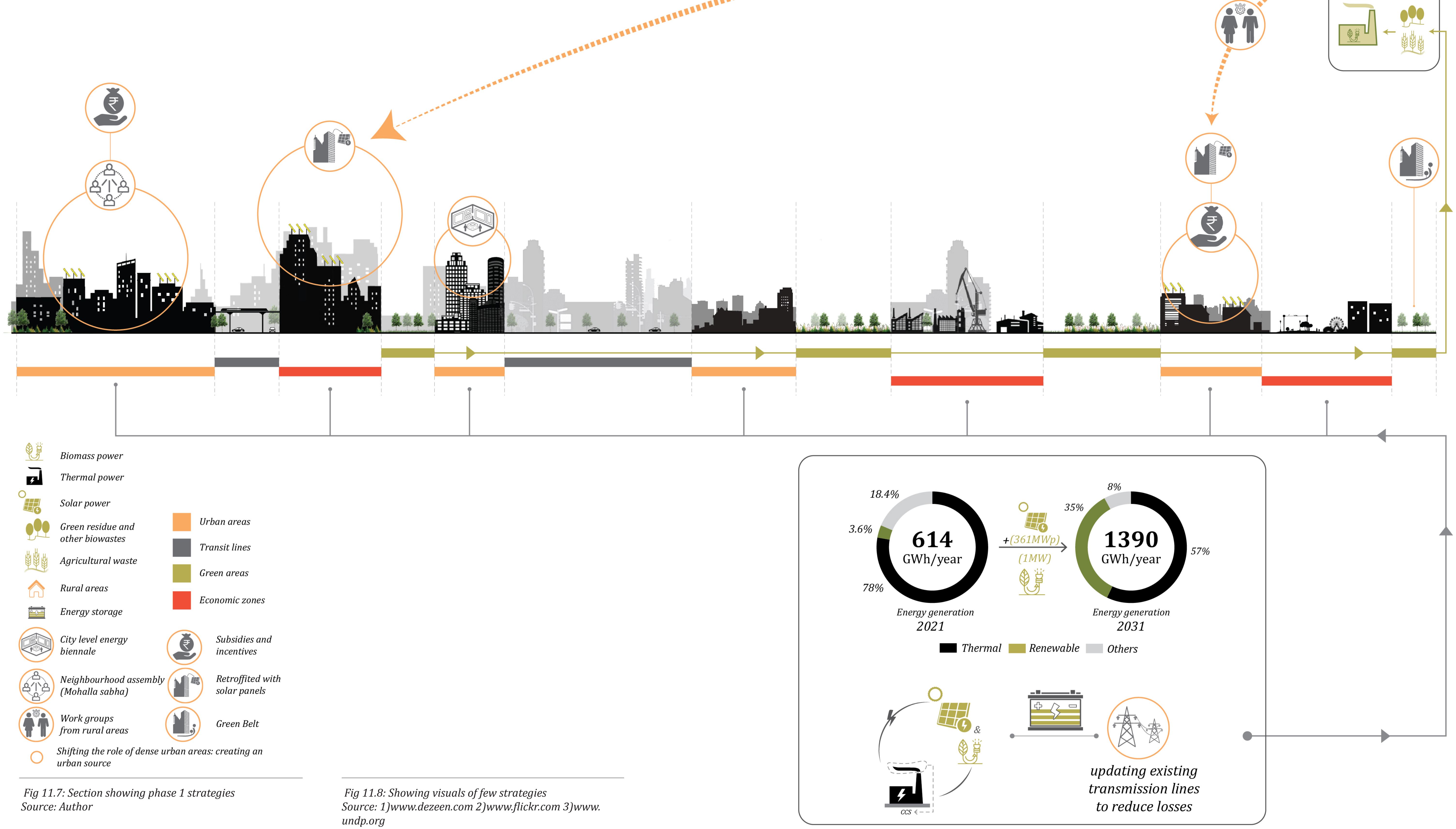


Fig 11.7: Section showing phase 1 strategies
Source: Author

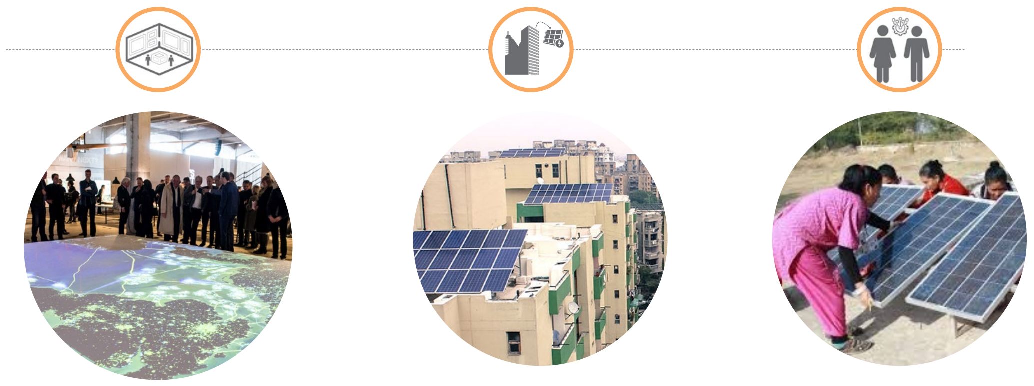


Fig 11.8: Showing visuals of few strategies
Source: 1)www.dezeen.com 2)www.flickr.com 3)www.undp.org

| Phase 2

Phase 2 continues with the extension of phase 1 strategies along with addressing transition lines and new farming methods. Strategic actions like agri-voltaic farming in the urban areas, water harvesting methods and extending primary transit lines like metro connections towards rural areas will be incorporated. The infrastructural lines must be supported by energy production that can be used for streetlighting, metro stations and other energy demanding works. The extensive infrastructural connections will promote easier transportation from urban to rural areas and vice versa. This will also promote economic activities that were completely based in urban areas to expand towards rural areas as well. This will bring a more symbiotic relationship between the two systems.

Over the second span of 10 years (2031 to 2041) the thermal power contribution must be reduced even further. The 2031 energy demand of the location is analysed along with the respective energy mix. The energy demands for 2031 and 2041 are extrapolated based on the population growth and the per capita consumption growth. The goal is to achieve 70% renewable energy contribution by 2041 from 35% in 2031 and phase out thermal contribution to around 26% in 2041 from 57% in 2031. During this phase, the thermal plants continue to be implemented with CCS technology and other upgraded technologies to reduce the CO2 emissions. Along with this, transmission lines will also be upgraded.

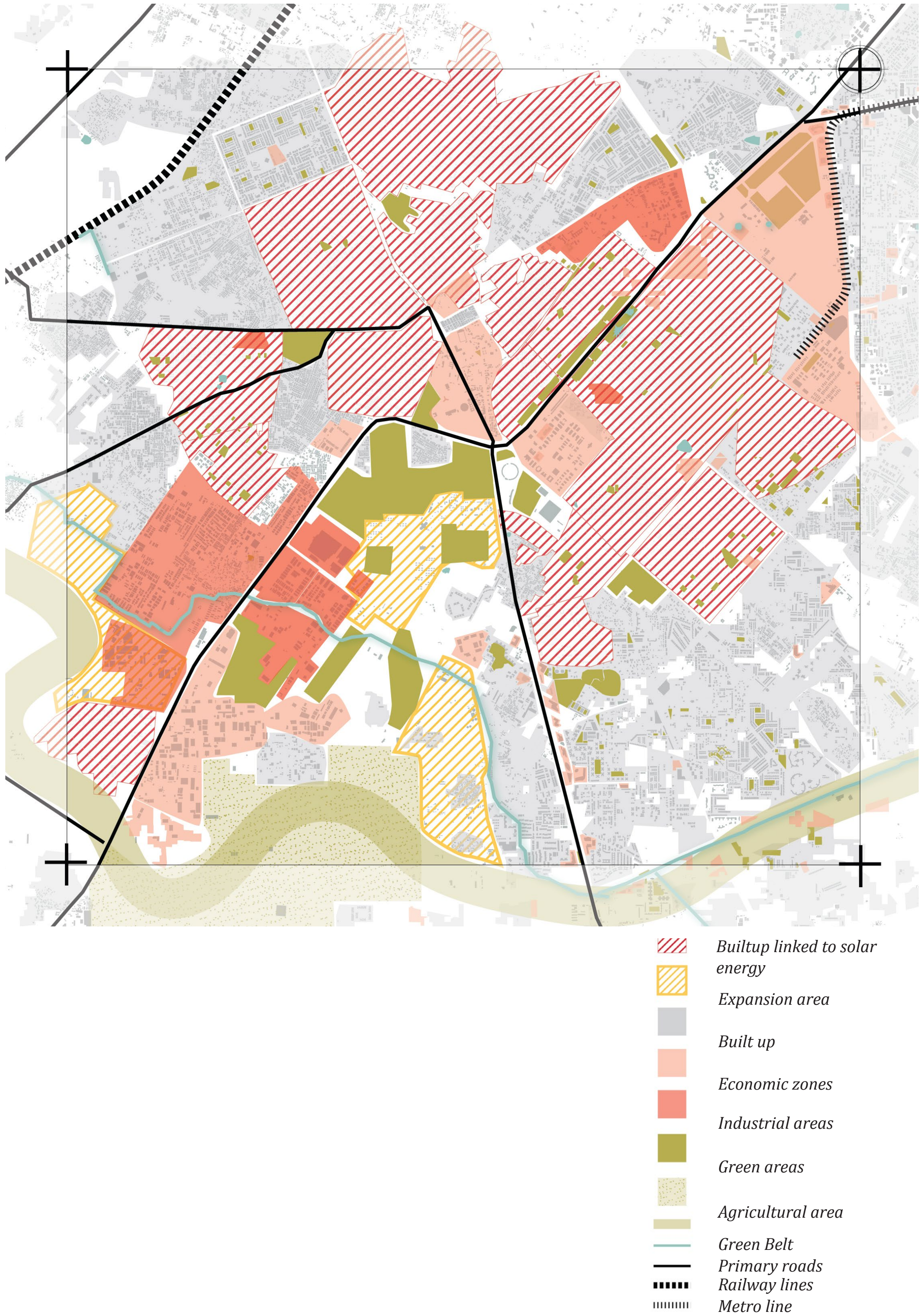


Fig 11.9: Phase 2
Source: Author, based on GIS

Stakeholders involved

Public Sector

- *National govt.*
- *NCR planning board*
- *State energy department*
- *State power generation and distribution bodies*
- *Municipal corporation*
- *Block*
- *Village*

Private Sector

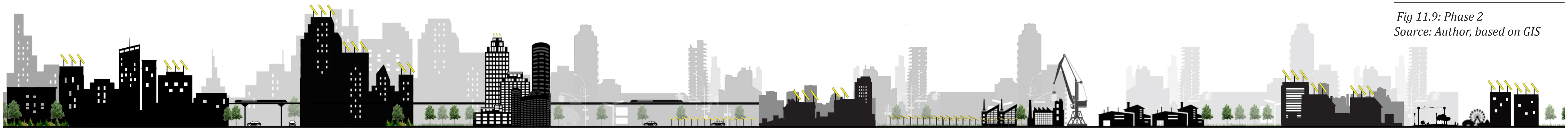
- *Energy companies*
- *O&M companies*
- *Discoms*
- *Enterprises*
- *Industries*

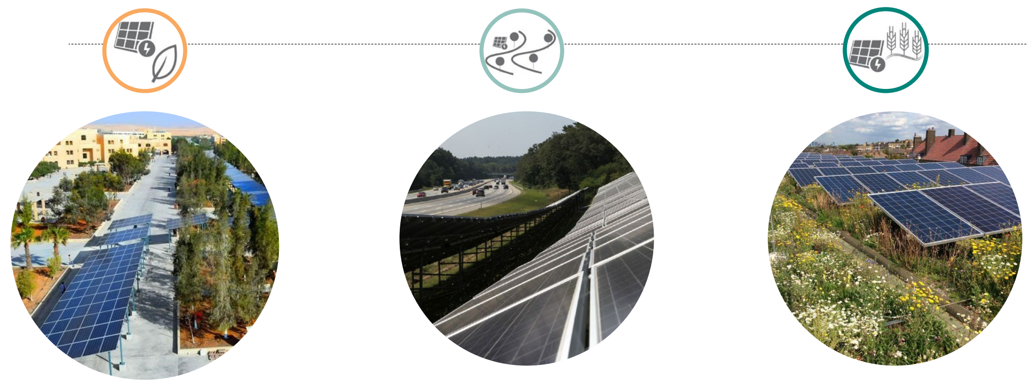
Civil Society

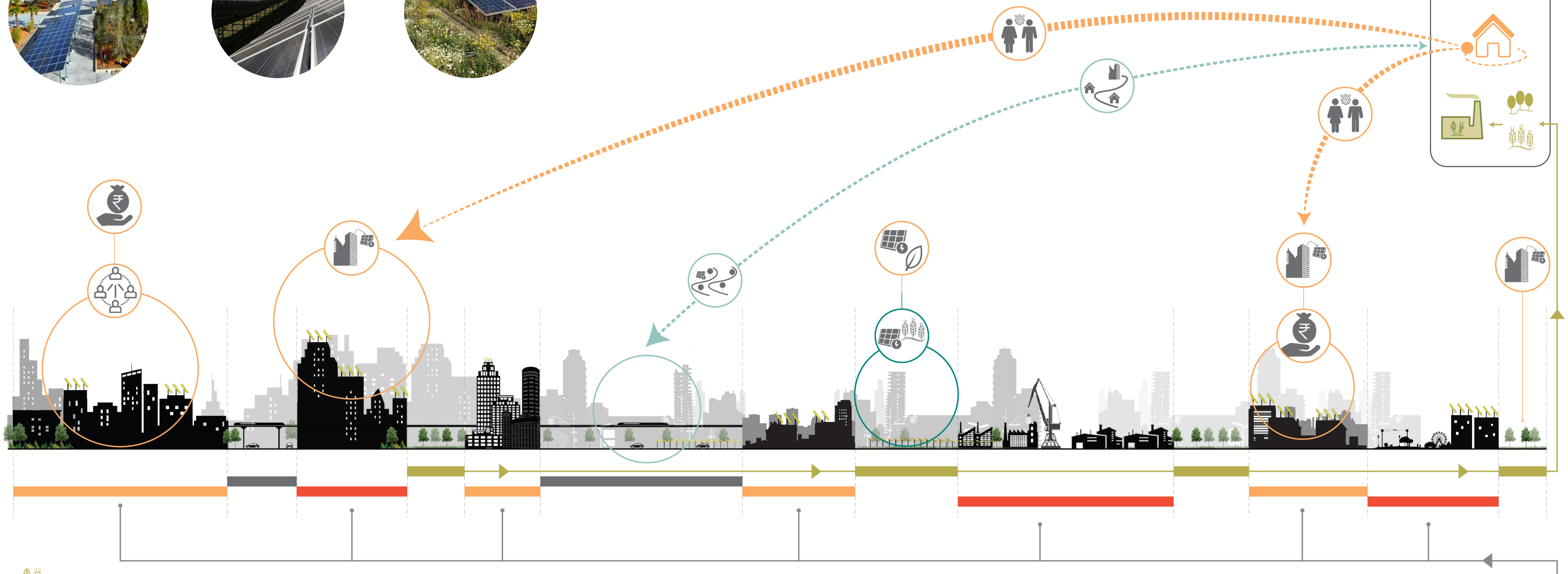
- *Landowners*
- *Residents*
- *Community corporatives*

Legend

- *Regional level*
- *Sub-regional level*
- *Local level*







Biomass power
Thermal power
Solar power
Green residue and other biowastes
Agricultural waste
Rural areas
Energy storage

Urban areas
Transit lines
Green areas
Economic zones

City level energy biennale
Neighbourhood assembly (Mohalla sabha)
Work groups from rural areas
Subsidies and incentives
Retroffited with solar panels
Green Belt
Agrivoltaic farming
Landscape and energy
Primary transit lines linked to renewable energy source
Strengthen secondary transit lines

Shifting the role of dense urban areas: creating an urban source
Strengthening transit support : improving urban-rural connectivity
Rethinking 'vs energy' as 'and energy' : Cross-functional uses with technology

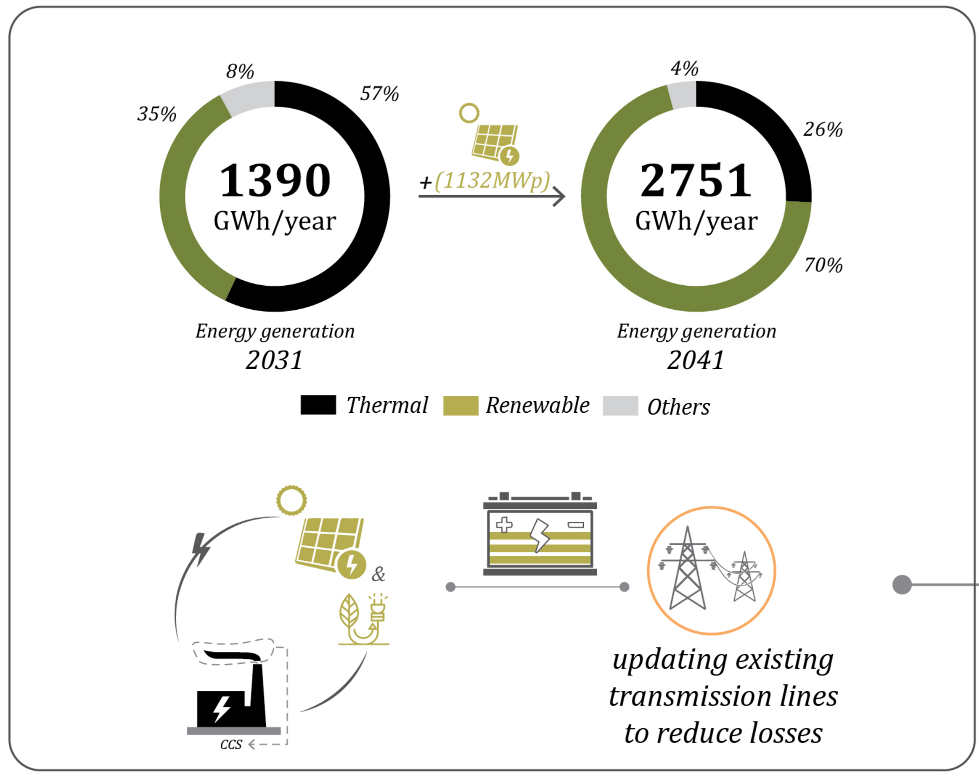


Fig 11.10: Section showing phase 2 strategies
Source: Author

Fig 11.11: Showing visuals of few strategies
Source: 1)www.ecomena.org 2)www.bostonglobe.com 3)www.greenrooftechnology.com

Phase 3 is extended from phase 2 strategies to incorporate technology upgradation and supply the surplus energy produced towards energy intensive industries. This will ensure that the products generated in the economy is based on renewable source of power. By the end of this phase, the shift towards a completely renewable based society would be achieved in a just manner. The ecological, social, and economic aspects that are linked to just transition are combined and put through the three phases. From creating awareness to switching to an environmentally positive society to promote equity in access to energy and development, the phasing depicts a scenario where the actions take place in an optimistic way to complete the transition by 2051.

Over the last span of 10 years (2041 to 2051) the thermal power contribution must be made nil for a completely positive transition by 2051. The 2041 energy demand of the location is analysed along with the respective energy mix. The energy demands for 2041 and 2051 are extrapolated based on the population growth and the per capita energy consumption growth. The goal is to achieve 97.6% renewable energy contribution by 2051 from 70% in 2041 and phase out thermal contribution completely in 2051 from 60% in 2041. During the final phase, thermal plants can be downsized, fuel change must be introduced to utilise the existing power plants in alternative ways.

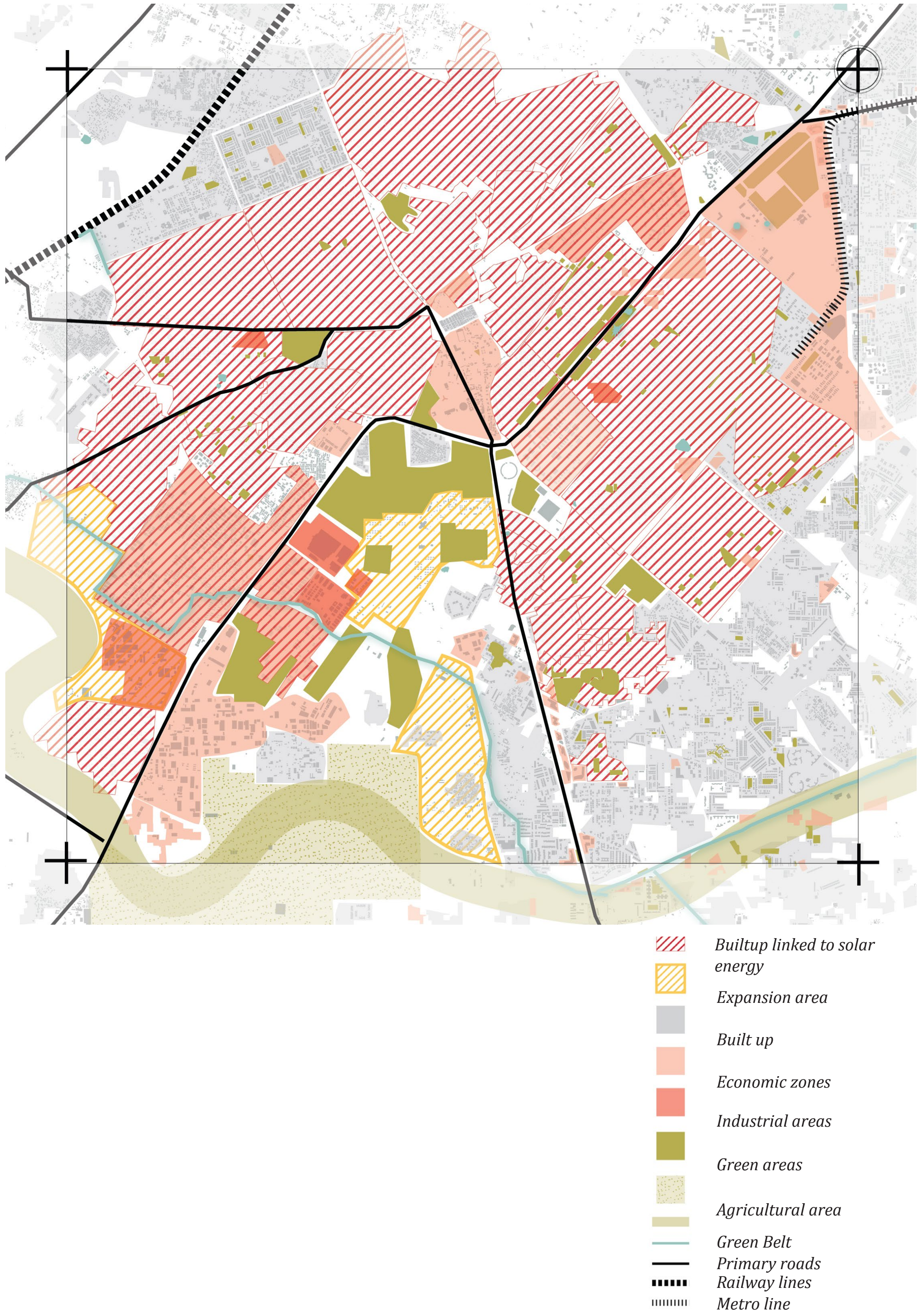


Fig 11.12: Phase 3
Source: Author, based on GIS

Stakeholders involved

Public Sector

- *National govt.*
- *NCR planning board*
- *State energy department*
- *State power generation and distribution bodies*
- *Municipal corporation*
- *Block*
- *Village*

Private Sector

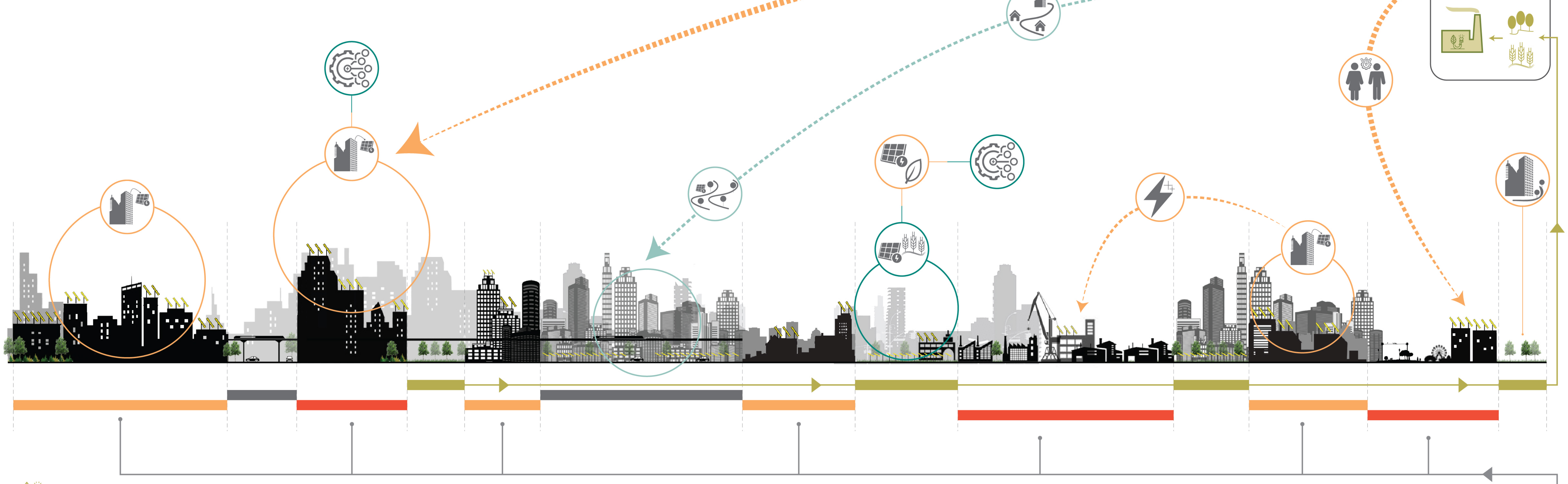
- *Energy companies*
- *O&M companies*
- *Discoms*
- *Enterprises*
- *Industries*

Civil Society

- *Landowners*
- *Residents*
- *Community corporatives*

Legend

- *Regional level*
- *Sub-regional level*
- *Local level*



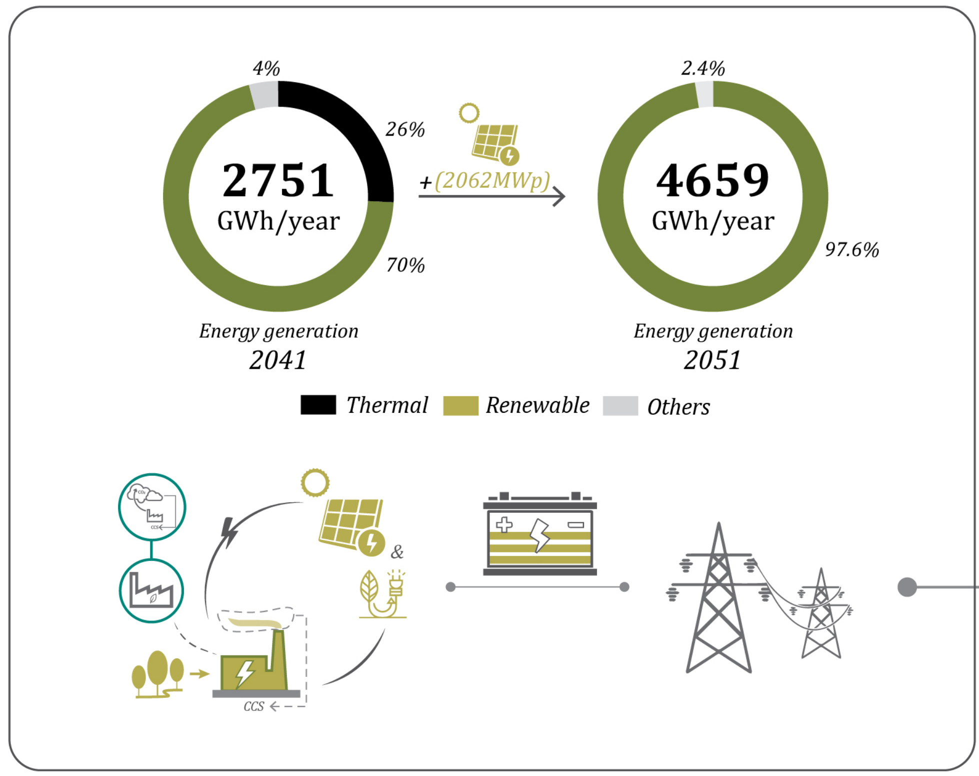
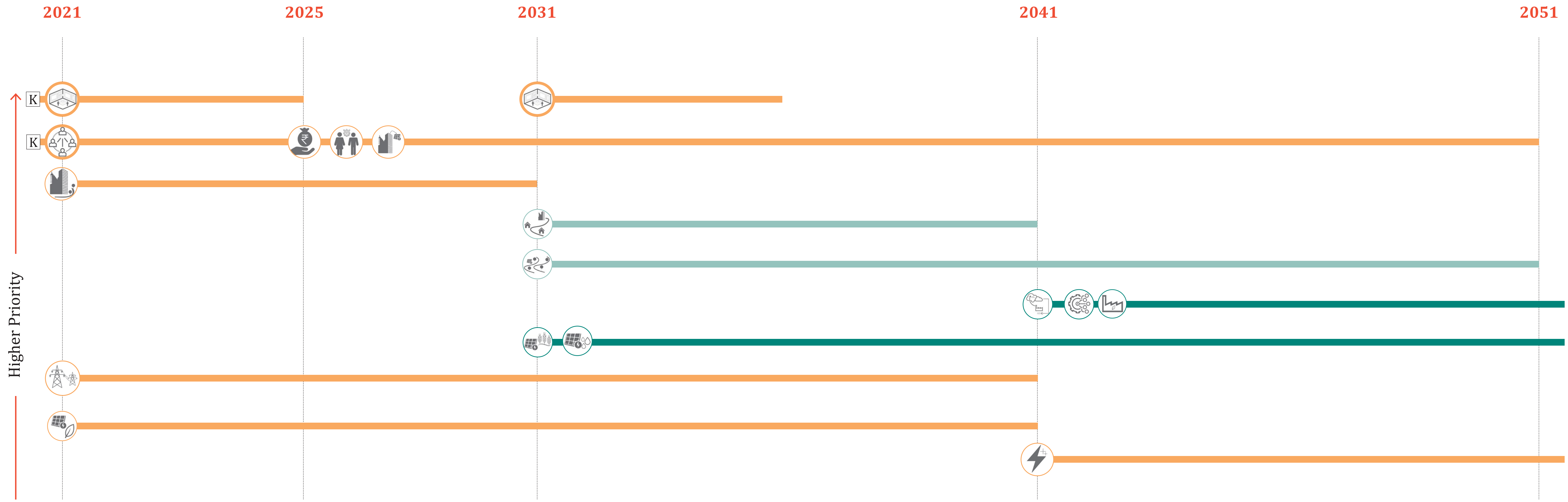


Fig 11.13: Section showing phase 3 strategies
Source: Author

Fig 11.14: Showing visuals of few strategies
Source: 1)www.energypedia.info 2)www.inhabitat.com 3)www.energynews.us

Phasing of urban context

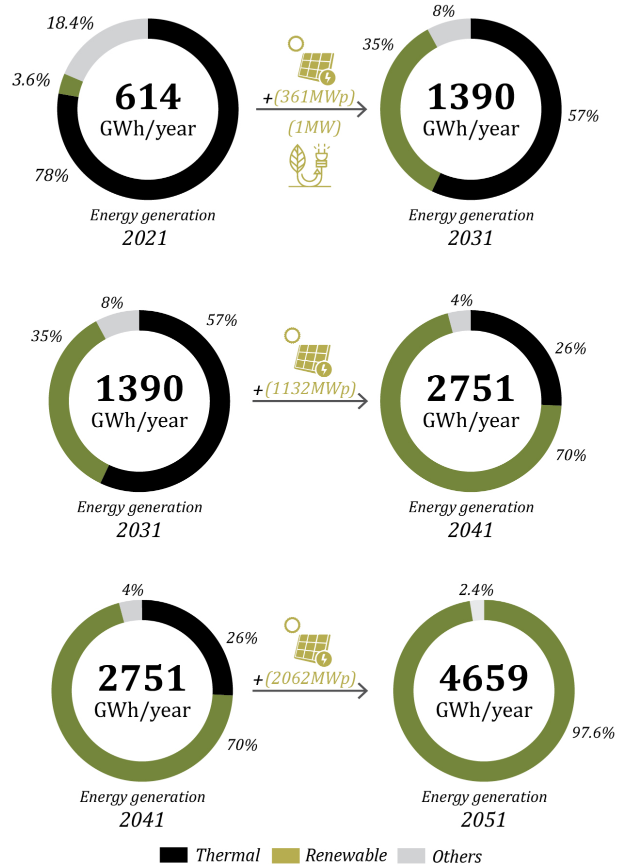


K key projects/trigger projects

Fig 11.15: Phasing of strategic action in the area
Source:Author

The above diagram shows the phasing of strategies for the urban area. The strategies shown in the same lines horizontally are dependent on each other and the priorities of strategies increase vertically from bottom to top. When looking into the urban contexts of the region, the main strategy is to create urban sources. The urban areas have higher energy demand, and as the population continues to grow, it is important to create awareness towards a more responsible societal development. Changing the attitude of people and bringing communities together are high in the priority order of phasing. The next strategy in line is improving connectivity between the urban and rural areas. This allows for more people to commute as well as promotes increased accessibility and ease of motion. Having surplus electricity is lower on the priority list as it is not a necessity in the initial phases of the transition. When looking at the regional scale, with all urban areas developing in a sustainable manner, surplus energy can be used when there are energy fluctuations or during the maintenance period of the energy sources.

The energy mix in the electricity supplied to the urban areas of Gurgaon, has very less percentage of renewable energy contribution. In order to meet the demands of the future along with the phasing out of fossil-based thermal plants by 2051, it is imperative to start as soon as possible. If not, India would find it difficult to meet its energy goals and would slow the process of sustainable development of the region.



K key projects/trigger projects

Fig 11.16: Pie charts showing the energy demands from 2021-2051.
Source: Author

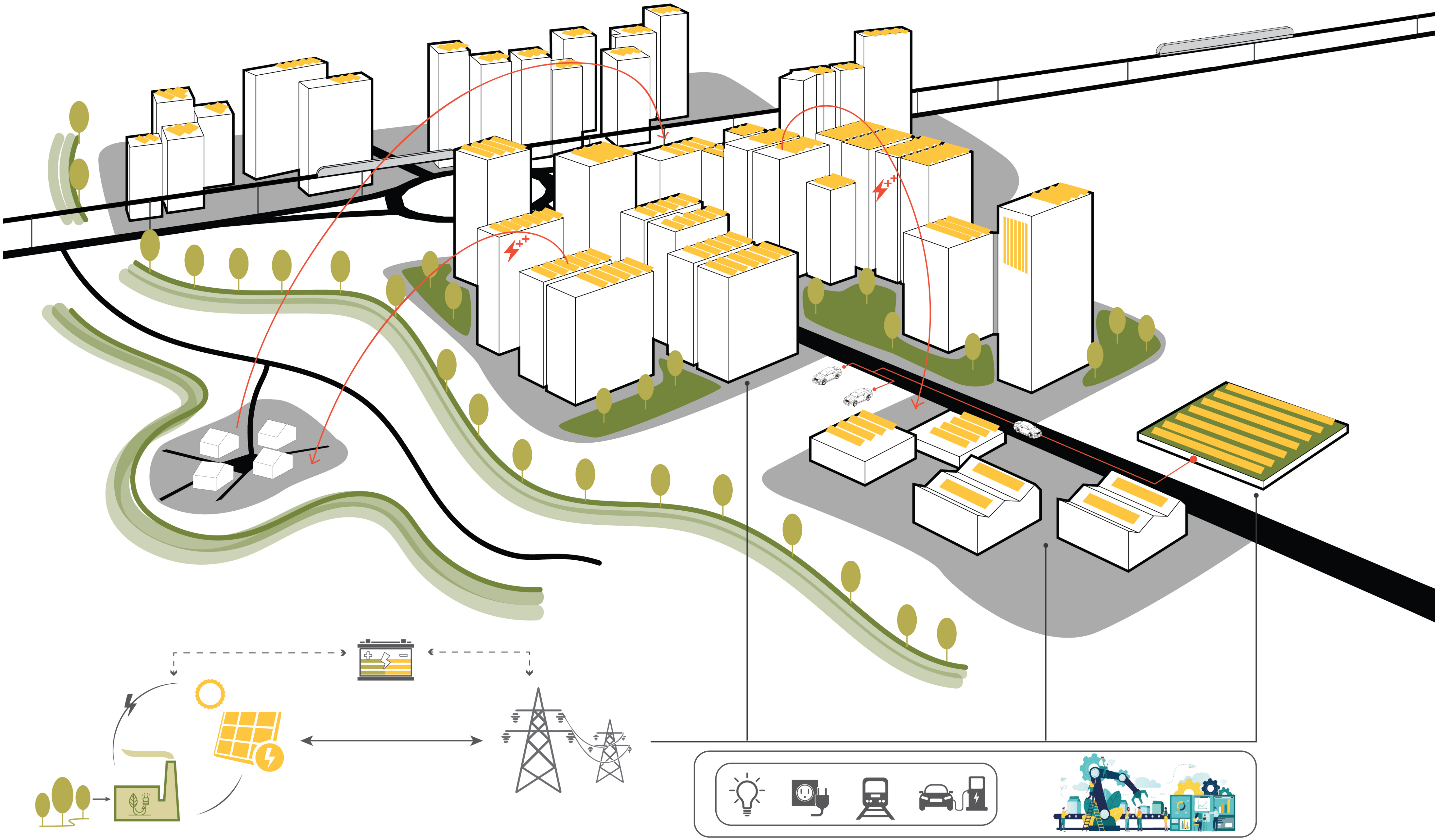


Fig 11.17: 3D representation of the urban context
Source: Author

Fig 11.18: Rooftop view within gurgaon urban area
Source: www.flickr.com

Fig 11.19: Impression of development of the urban area after incorporating the strategies
Source: Author

11.3 | Zoom location 2 : Alwar, Rajasthan sub-region

The actions explored in the rural area of Alwar is based on the main strategy of setting up open source rural incubators by empowering the rural areas. The other strategies like strengthening transit support and rethinking 'vs energy' as 'and energy' act as support structures to the development of the areas.

Considering a 10km x 10km location in the district of Alwar, the strategies are implemented in three phases, starting from 2021 up until 2051. The phasing takes into account the energy demands of the future and incorporating renewables like solar and biomass into the energy mix. The design explorations are illustrative of the transferability and feasibility of the strategies on other rural locations on the regional scale.

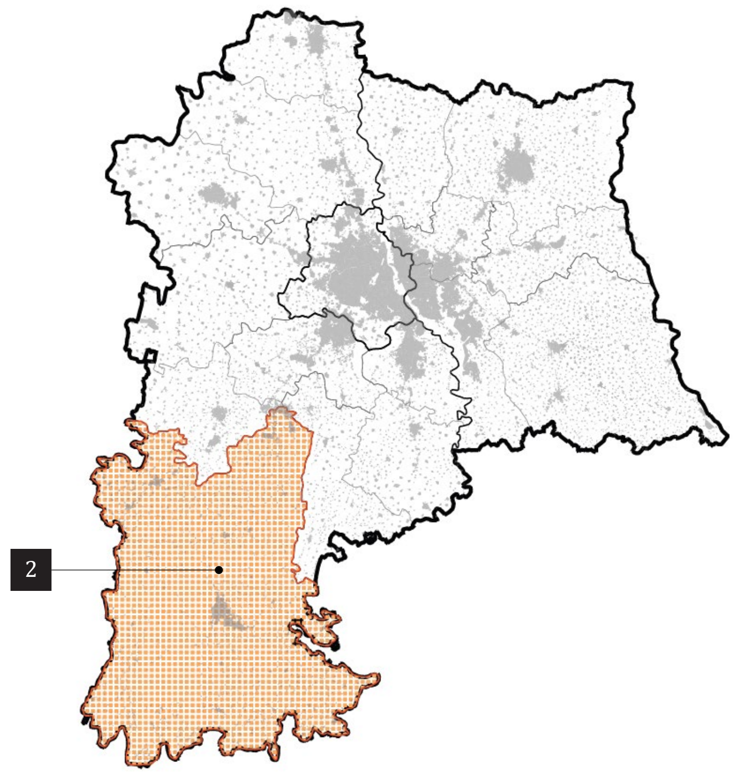
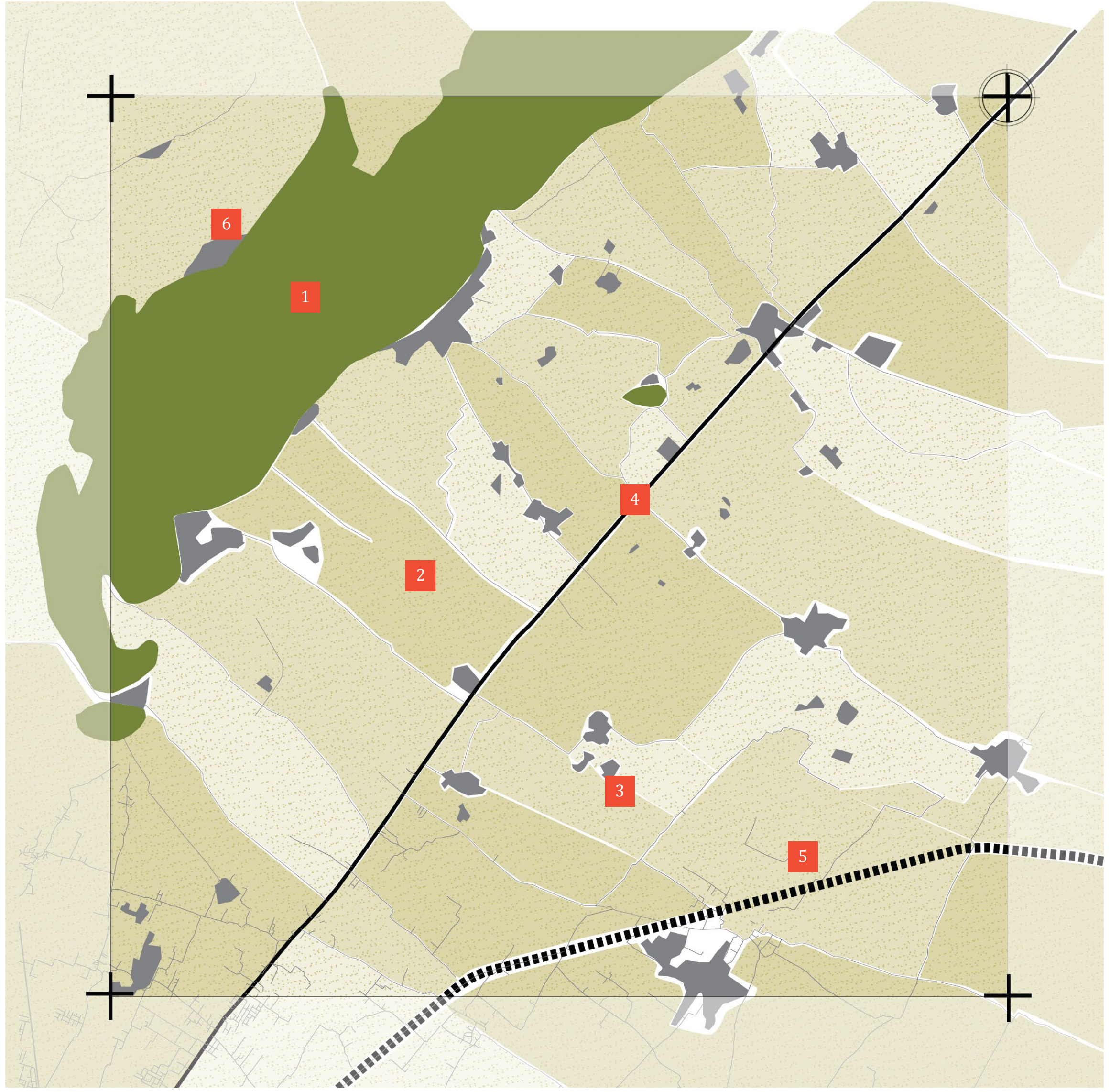


Fig 11.20: Bird view of village bhatana in Alwar, Rajasthan Source: www. mapio.net

| Existing Status quo

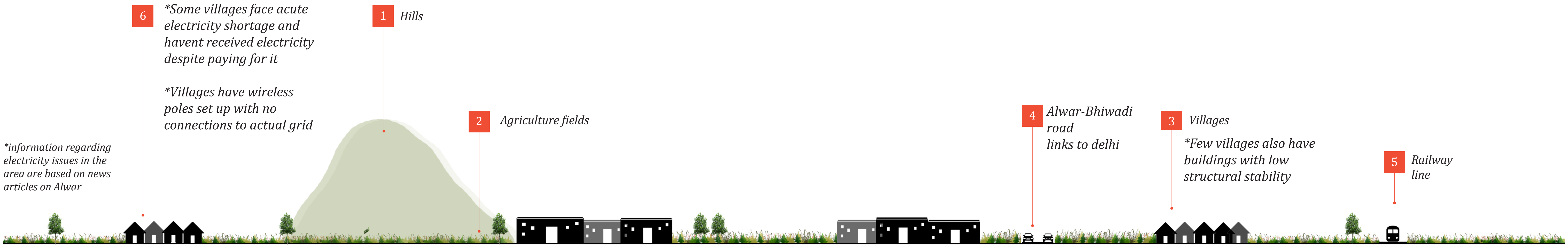
The villages move outward starting from the foothills of the Alwar hills and towards the Alwar-Bhiwadi road. The road is a state highway that links Alwar to the other districts. With a population density of around 400 people per km^2, the area consists of mainly agricultural fields.

Fig X : Roads near villages of Alwar with agriculture fields on either sides.
Source: Google earth, 2019



Existing built up
Hilly terrain
Agricultural fields
Roads connecting villages
Roads connecting to city
Exisiting railway lines

Fig 11.21: Exisiting situation
Source: Author



Year	2011	2021	2031	2041	2051
Population	3674179	4345665	4944315	5402941	5660975
Growth Rate (GR) (%)	22.78	18.28	13.78	9.28	4.78
GR Decline (%)	4.5	4.5	4.5	4.5	4.5
Pop Density (p/km2)	438.45	518.58	590.01	644.74	675.53

Per capita consumption (kWh/p/year)	Year	2017	2018	2019	2020	2021	2031	2041	2051
	Rajasthan	1166	1224	1286	1350	1417	2309	3760	6125
	Growth Rate (%)	0.2	5.0	5.0	5.0	5.0	62.9	62.9	62.9

	Population Density (p/km2)	Population (p)	No. of households	Per Capita Consumption (kWh/p/year)	Total Energy Consumption (GWh/year)	Daily Energy Generation (kWh/day)
2051	675.53	67553	13511	6125	413.79	1133676

Fig 11.22: Data used for calculations
Source: Extrapolated based on data from www.citypopulation.de and www.tcprajasthan.gov.in

The above tables shows the extrapolated data for population density, energy consumption and the daily power generation required for the year of 2051. Population (p) in the 2051 projection stands for the population calculated within the 100 km^2. The extrapolated data has taken into account the growth rate and decline based on previous year's trends.

The total area required for power generation in the case of solar and biomass sources are calculated in the same manner as mentioned previously in section 9.9.

Energy mix in 2021 was taken based on the existing energy mix seen in Rajathan. The energy mix includes 56% thermal, 32% renewable, 12% others(hydro power and nuclear). The state of Rajasthan is one of the leading states in harnessing solar power through centralised solar farms. The strategies in the project is aiming towards more decentralised energy systems in the future. Since the energy that can be harnessed from biomass is high due to the large amount of agriculture fields in the rural context. It is easier to harness the biomass energy intially and then add in solar energy to the energy mix as well.

Based on the energy calculations performed for the region (see appendix) and considering that 50% of the total arable land area of 70km^2 is cultivated with biomass crop, the region would require only an additional 2km^2 area for solar energy generation to meet the energy demands of 2051. The next sections contain the strategies used and energy mix in phasing from 2021 to 2051.

Setting up open source rural incubators: Empowering the rural areas

- Primary building
- Community organisations
- Participatory budgeting
- Financial aid groups
- Gender separation to addressing issues
- Women based work groups
- Biomass plants
- Decentralised grids
- Rural incubator
- Knowledge & resource exchange

Strengthening transit support : improving urban-rural connectivity

- Strengthen secondary transit lines
- Rural incubators linked to transit lines

Rethinking 'vs energy' as 'and energy' : Cross-functional uses with technology

- Agrivoltaic farming
- Water harvesting
- Technology updates
- CCS technology
- Downsizing and fuel switching

Shifting the role of dense urban areas: creating an urban source

- Work groups from rural areas
- Updating transmission lines

**Actions of the strategies are elaborated in chapter 10*

| Phase 1

The first phase is about bringing the people in the rural communities together, creating awareness in the society and involving the people in addressing their issues in a way that initiates positive conversations. Strategies like starting community organisations where issues regarding energy can be addressed, increasing the participation of women in various jobs and activities, and improving local accountability through participatory budgeting should be made mandatory. Stakeholders in phase one (from national, state and local level) will help create a more accountable involvement in energy production, distribution, and consumption.

Over the initial span of 10 years (2021 to 2031) the thermal power contribution must be reduced by incorporating renewables. First, the current energy demands of the location is analysed along with the existing energy mix. The energy demands for 2021 and 2031 are extrapolated based on the population growth and the per capita energy consumption growth. The goal is to achieve 60.5% renewable energy contribution by 2031 from 32% in 2021 and phase out thermal contribution to 33% in 2031 from 56% in 2021. During this phase, the existing thermal plants will be implemented with CCS technology to reduce the CO_2 emissions. In order to reduce the transmission losses that are at their peak in India due to outdated energy infrastructure, transmission lines will also be upgraded. The villages without existing connections will also be linked to the biomass plant set up in the area.

Stakeholders involved

Public Sector

- *National govt.*
- *State energy department*
- *State power generation and distribution bodies*
- *Municipal corporation*
- *Village*

Private Sector

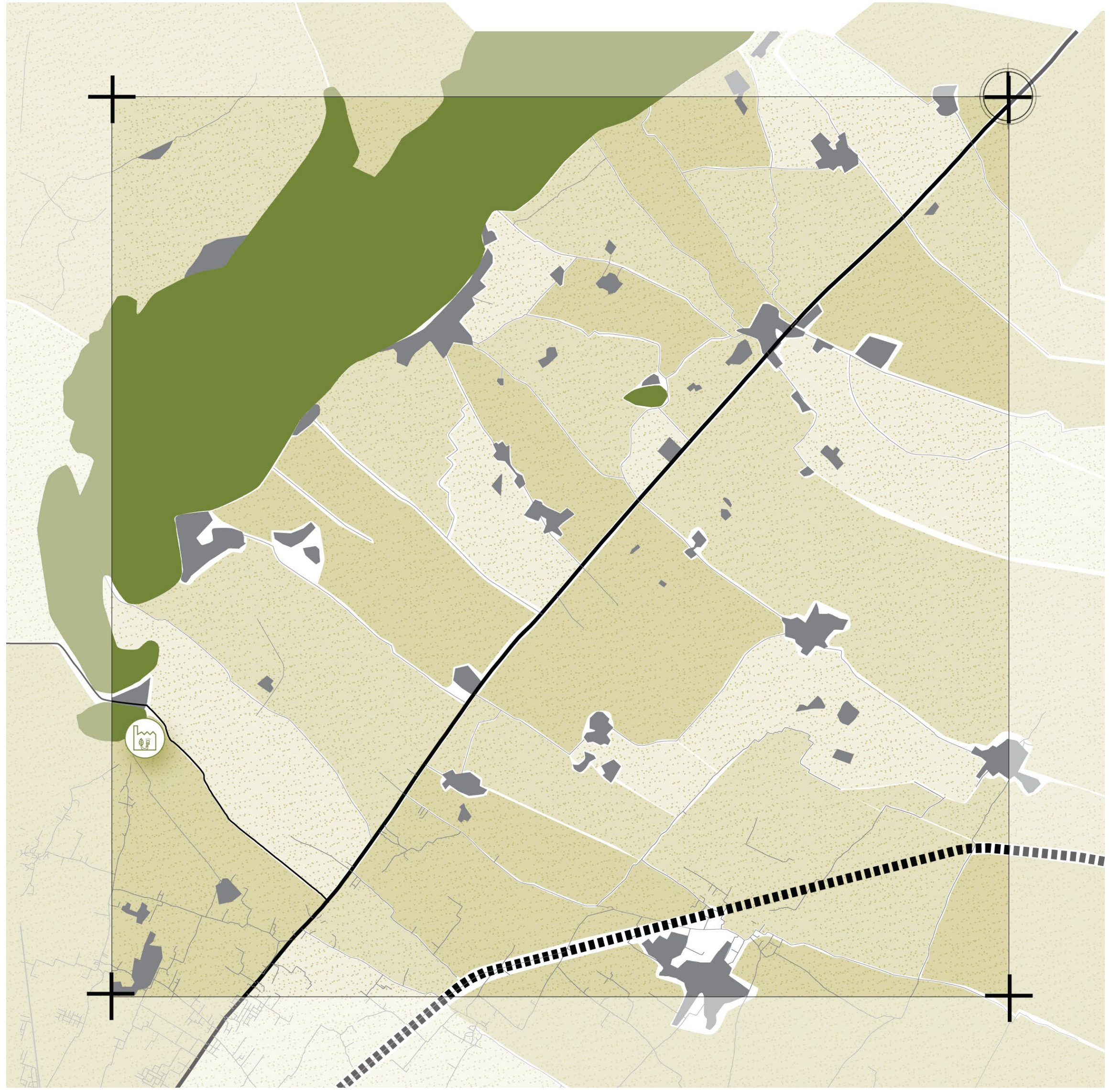
- *Energy companies*
- *O&M companies*
- *Discoms*

Civil Society

- *Landowners*
- *Residents*
- *Community corporatives*

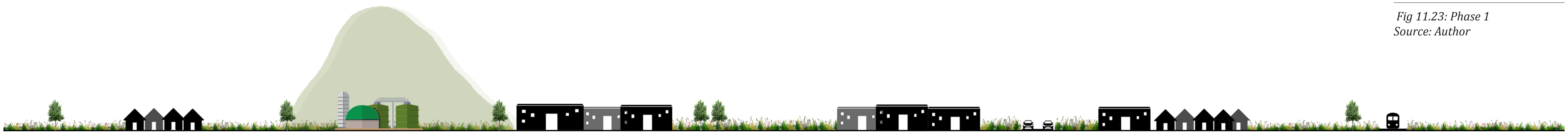
Legend

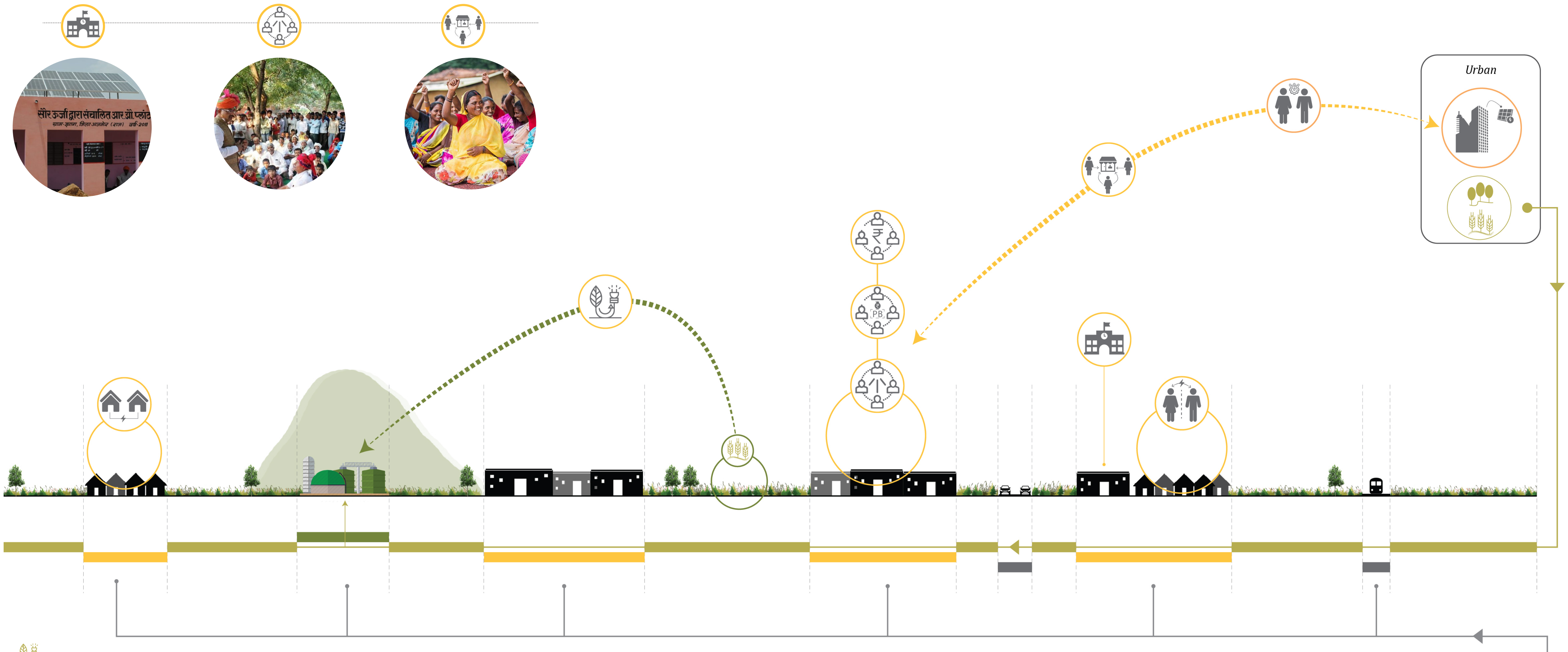
- *Regional level*
- *Sub-regional level*
- *Local level*



Existing built up
Hilly terrain
Agricultural fields
Biomass plant
Road connecting to biomass plant
Roads connecting villages
Roads connecting to city
Exisiting railway lines

Fig 11.23: Phase 1
Source: Author





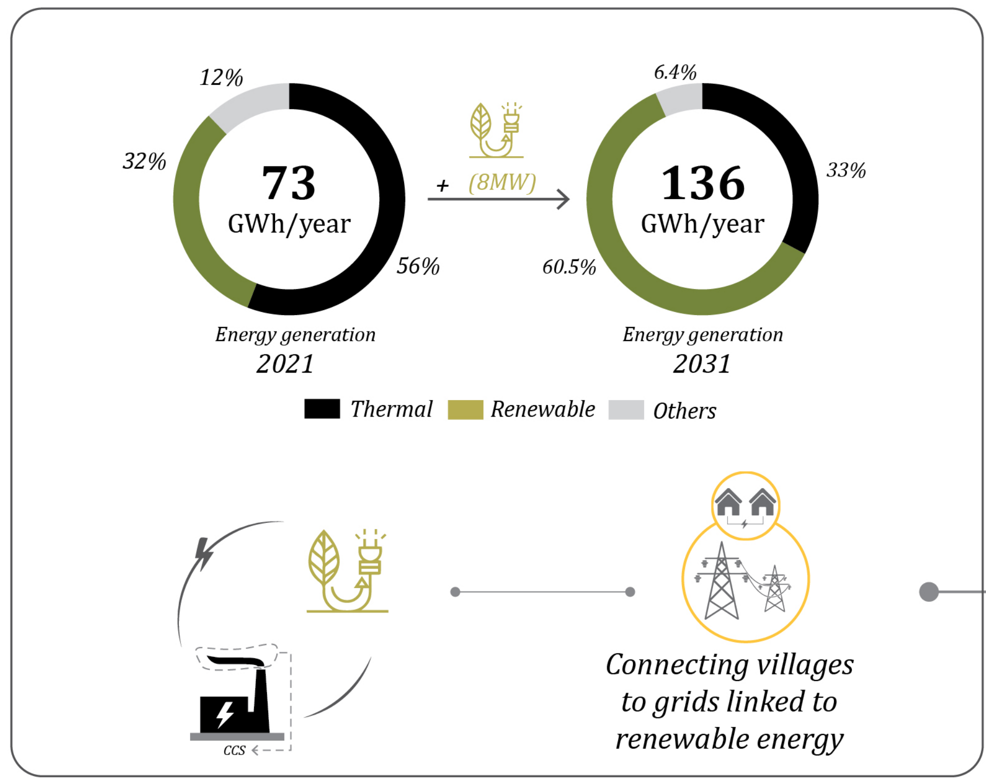


Fig 11.24: Section showing phase 1 strategies
Source: Author

Fig 11.25: Showing visuals of few strategies
Source: 1)www. grinity.in 2)www.jagranjosh.com 3)www.undp.org

| Phase 2

Phase 2 continues with the extension of phase 1 strategies along with addressing transition lines and new farming methods. Strategic actions like agri-voltaic farming in the rural areas, water harvesting methods and extending primary transit lines like road connections towards rural areas will be incorporated. The new farming methods will be informed through the community organisations and financial aid groups will help people in implementing the agri-voltaic method of farming. The solar panels will also be linked to water collectors that will store water for later use or reused in the agricultural fields. The extensive infrastructural connections will promote easier transportation from urban to rural areas and vice versa. This will also promote economic activities that were completely based in urban areas to expand towards rural areas as well. This will bring a more symbiotic relationship between the two systems.

Over the second span of 10 years (2031 to 2041) the thermal power contribution must be reduced even further. The 2031 energy demand of the location is analysed along with the respective energy mix. The energy demands for 2031 and 2041 are extrapolated based on the population growth and the per capita energy consumption growth. In the second phase, the remaining percentage of biomass potential, in its entirety, is harnessed along with solar power. This would bring the renewable energy contribution to 80% in 2041 from 60.5% in 2031. The thermal contribution is hence reduced further down to 16.4% in 2041 from 33% in 2031.

Stakeholders involved

Public Sector

- *National govt.*
- *NCR planning board*
- *State energy department*
- *State power generation and distribution bodies*
- *Municipal corporation*
- *Block*
- *Village*

Private Sector

- *Energy companies*
- *O&M companies*
- *Discoms*
- *Enterprises*
- *Industries*

Civil Society

- *Landowners*
- *Residents*
- *Community corporatives*

Legend

- *Regional level*
- *Sub-regional level*
- *Local level*

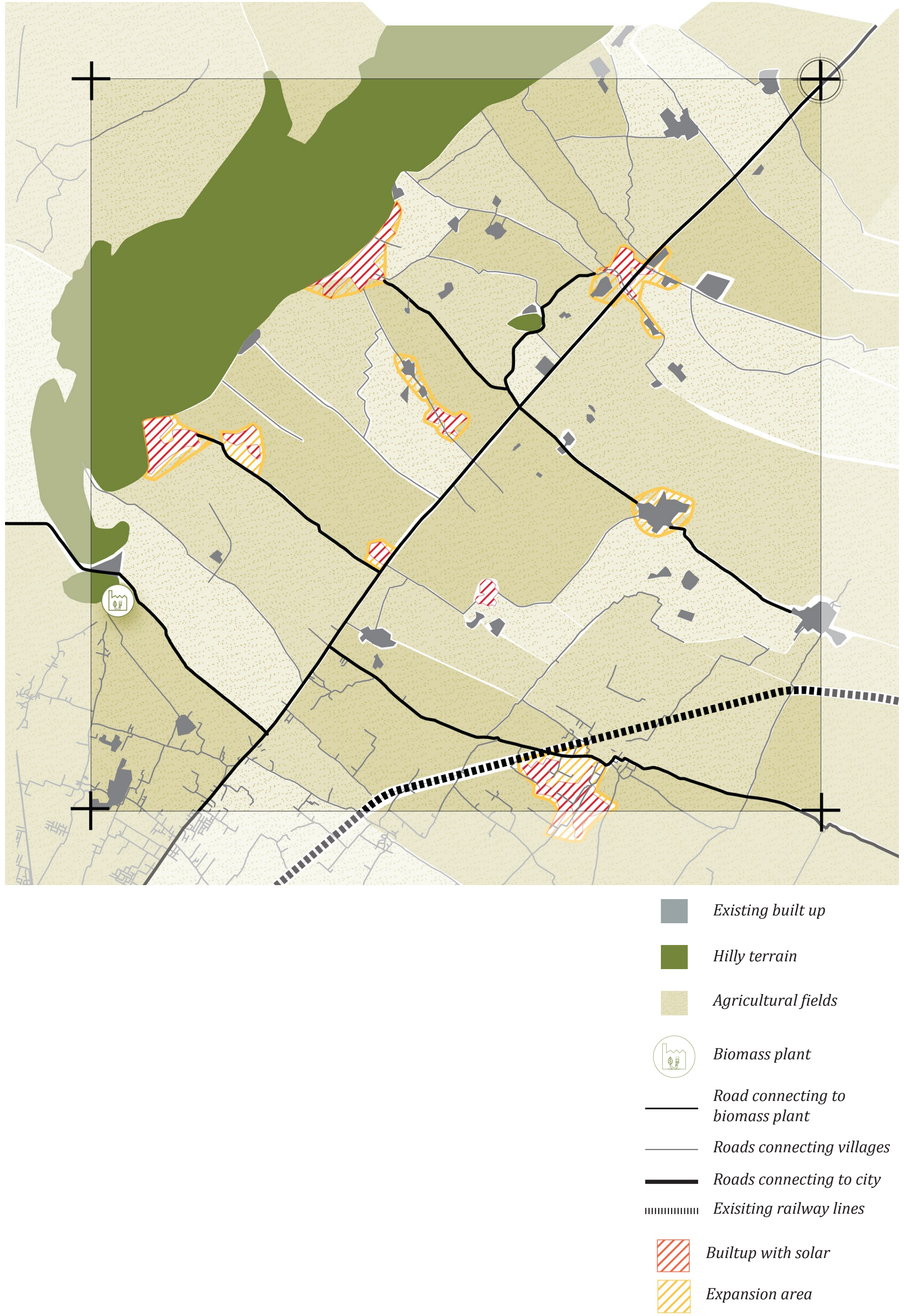
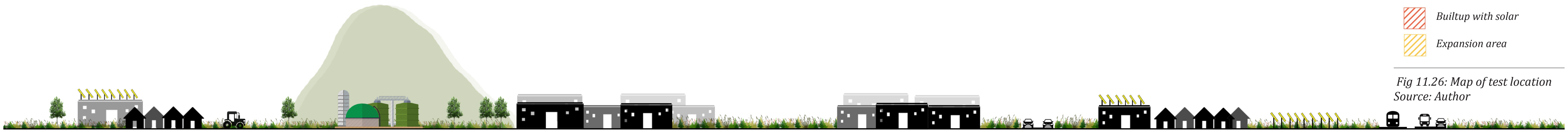


Fig 11.26: Map of test location
Source: Author



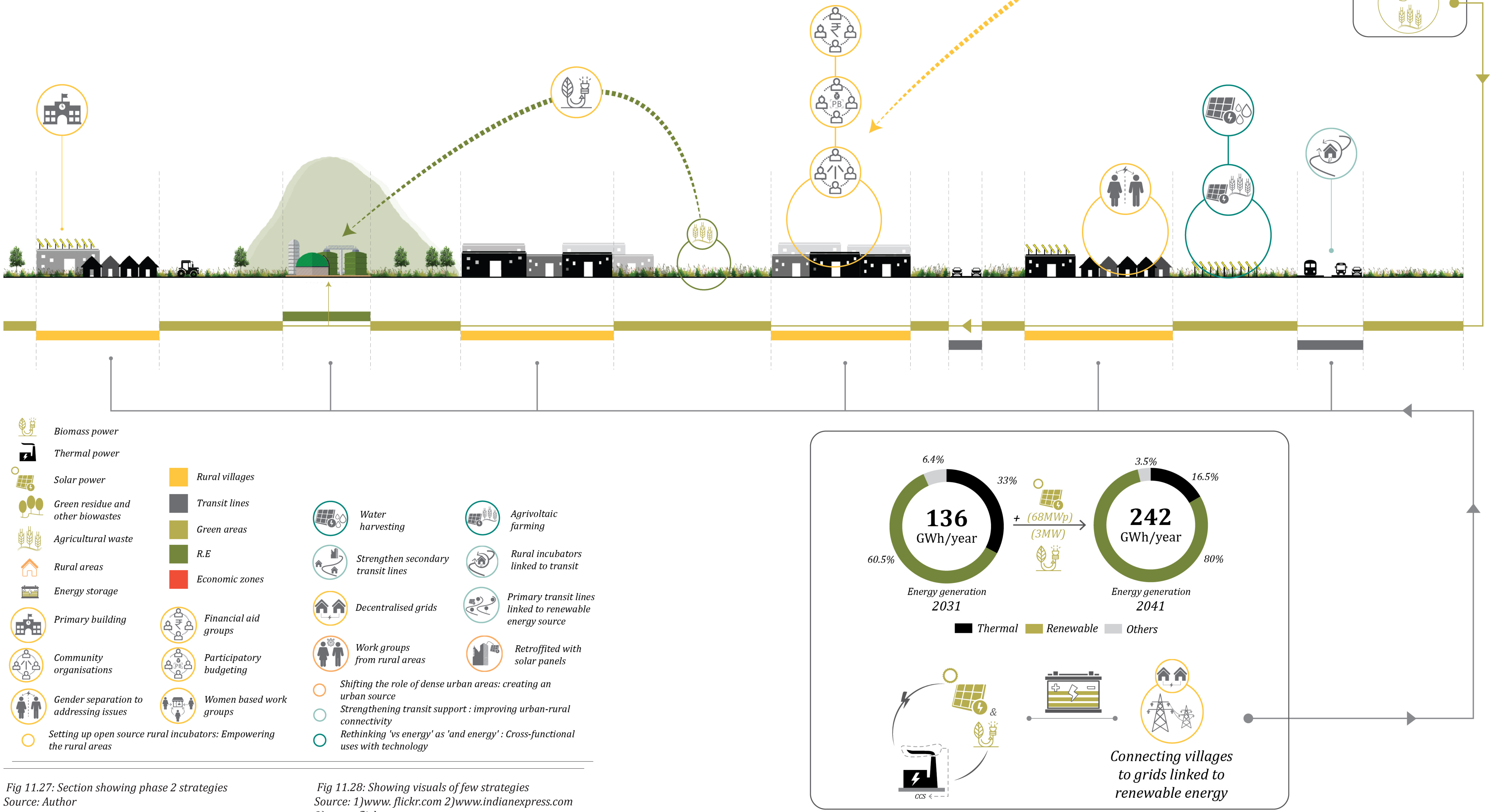


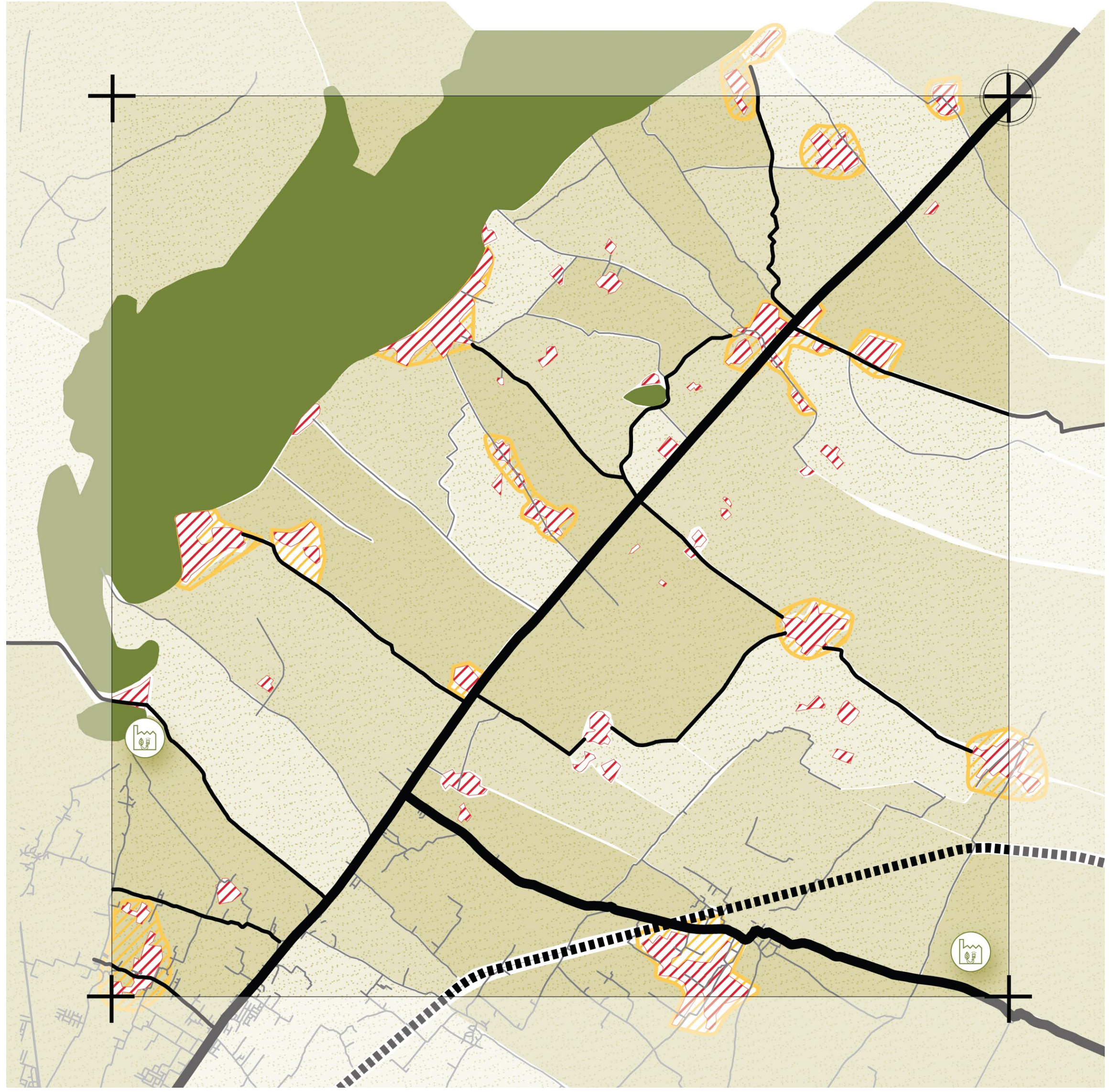
Fig 11.27: Section showing phase 2 strategies
Source: Author

Fig 11.28: Showing visuals of few strategies
Source: 1)www. flickr.com 2)www.indianexpress.com 3) www. flickr.com

| Phase 3

Phase 3 is extended from phase 2 strategies to incorporate technology upgradation and the overall development of the rural incubators. The phasing is about shifting to a completely renewable based society in a just manner. The ecological, social, and economic aspects that are linked to just transition are combined and put through the three phases. From creating awareness to switching to an environmentally positive society to promote equity in access to energy and development, the phasing depicts a scenario where the actions take place in an optimistic way to complete the transition by 2051.

Over the last span of 10 years (2041 to 2051) the thermal power contribution must be made nil for a completely positive transition by 2051. The 2041 energy demand of the location is analysed along with the respective energy mix. The energy demands for 2041 and 2051 are extrapolated based on the population growth and the per capita energy consumption growth. In the last phase, the solar energy is harnessed further to reach the goal of 98% renewable energy contribution by 2051 from 80% in 2041. Thermal power contribution will be phased out to nil by 2051 from around 16% in 2041. During the final phase, thermal plants can be downsized and fuel change must be introduced to utilise the existing power plants in alternative ways.



Existing built up
Hilly terrain
Agricultural fields
Biomass plant
Road connecting to biomass plant
Roads connecting villages
Roads connecting to city
Exisiting railway lines
Builtup with solar
Expansion area

Fig 11.29: Phase 3
Source: Author

Stakeholders involved

Public Sector

- *National govt.*
- *NCR planning board*
- *State energy department*
- *State power generation and distribution bodies*
- *Municipal corporation*
- *Block*
- *Village*

Private Sector

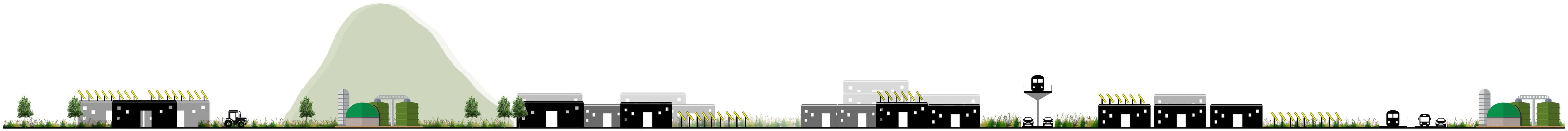
- *Energy companies*
- *O&M companies*
- *Discoms*
- *Enterprises*
- *Industries*

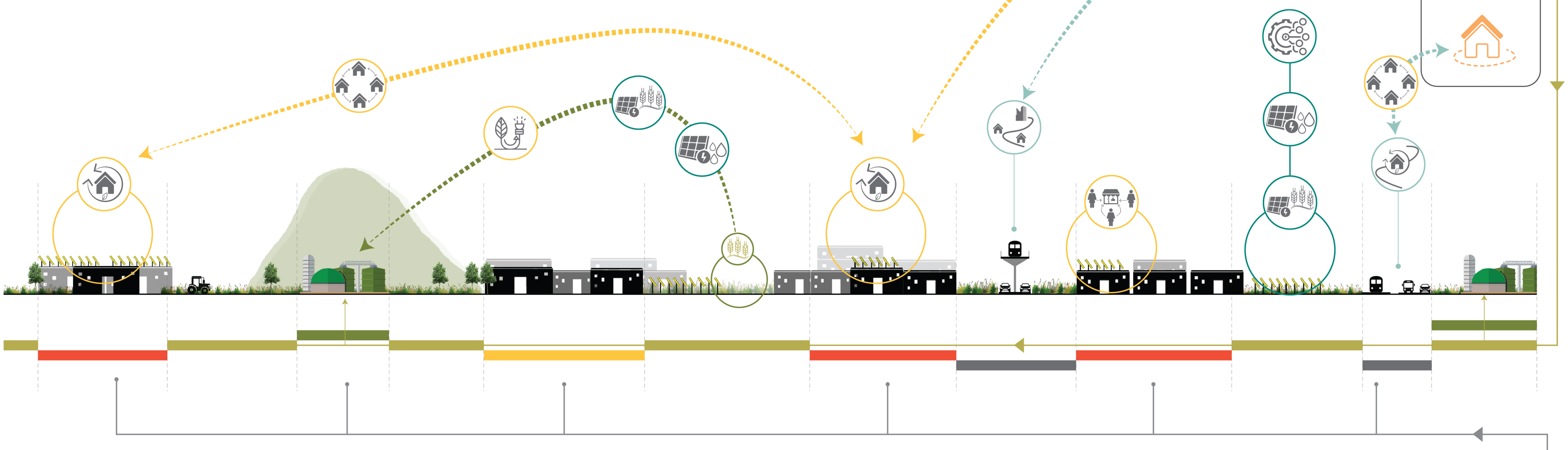
Civil Society

- *Landowners*
- *Residents*
- *Community corporatives*

Legend

- *Regional level*
- *Sub-regional level*
- *Local level*





Biomass power
Thermal power
Solar power
Green residue and other biowastes
Agricultural waste
Rural areas
Energy storage
Primary building
Community organisations
Gender separation to addressing issues

CCS technology
Rural villages
Transit lines
Green areas
R.E
Economic zones
Financial aid groups
Participatory budgeting
Women based work groups

Technology updates
Water harvesting
Strengthen secondary transit lines
Work groups from rural areas
Knowledge & resource exchange
Decentralised grids

Downsizing and fuel switching
Agrivoltaic farming
Rural incubators linked to transit
Primary transit lines linked to renewable energy source
Retroffited with solar panels
Rural incubator

Setting up open source rural incubators: Empowering the rural areas

Shifting the role of dense urban areas: creating an urban source
Strengthening transit support : improving urban-rural connectivity
Rethinking 'vs energy' as 'and energy' : Cross-functional uses with technology

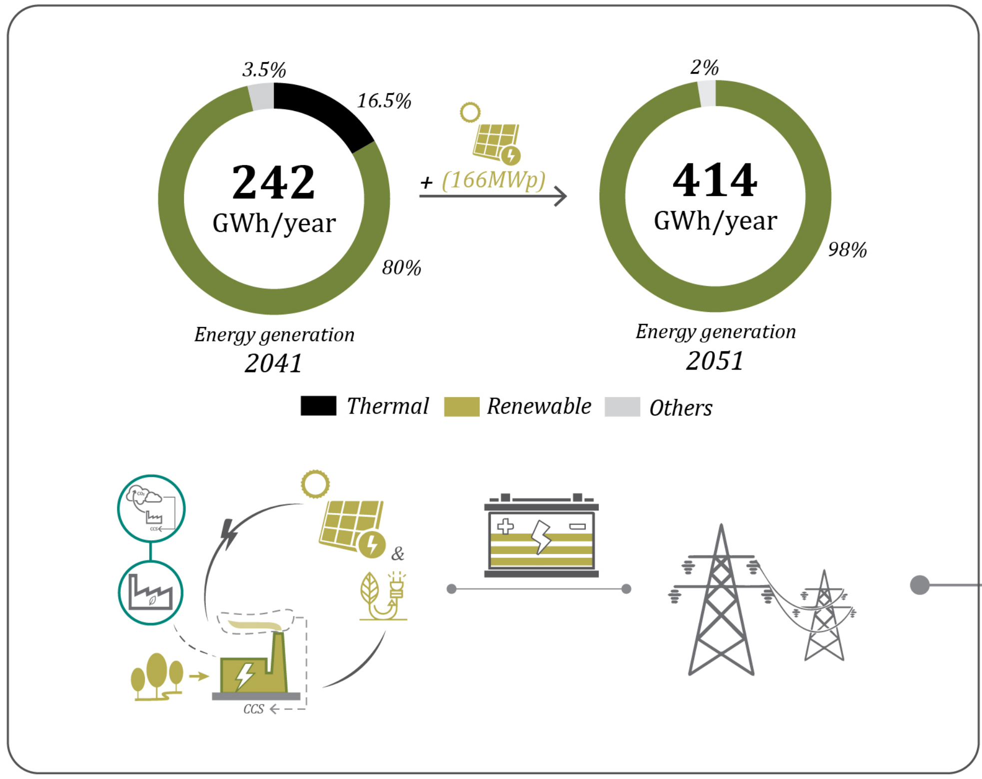


Fig 11.30: Section showing phase 3 strategies
Source: Author

Fig 11.31: Showing visuals of few strategies
Source: 1)www.visualstock.com 2)www.nirdpr.org.in 3)www.thetimes.com

Phasing of strategies for rural system

The above diagram shows the phasing of strategies for the rural area. The strategies shown in the same lines horizontally are dependent on each other and the priorities of strategies increase vertically from bottom to top. When looking into the rural contexts of the region, the main strategy is to empower the rural areas. The rural areas have a much lower energy demand and as the population continues to grow, it is important to create awareness towards a more responsible societal development. Changing the attitude of people and bringing communities together through community organisations is of higher priority. Prior to this, linking the rural areas to biomass plants will help harness energy from biowastes and also encourage waste collection rather than allowing stubble burning. The construction of primary buildings in villages with weak poor building conditions is also necessary to facilitate this transition. The next strategy in line is improving connectivity between the urban and rural areas. This allows for more people to commute as well as promotes increased accessibility and ease of motion. Having resource and knowledge information exchange between rural areas is lower on the priority list as it is not a necessity in the initial phases of the transition. When looking at the regional scale with rural incubators developing in a sustainable manner, surplus energy can be used when there are energy fluctuations or during the maintenance period of the energy sources.

The energy mix in the electricity supplied to the areas of Rajasthan has a higher percentage of renewable energy contribution. This would make phasing out fossil-based thermal plants relatively easier compared to urban context.

K *key projects/trigger projects*

Fig 11.32: Phasing of strategic action in the region
Source: Author

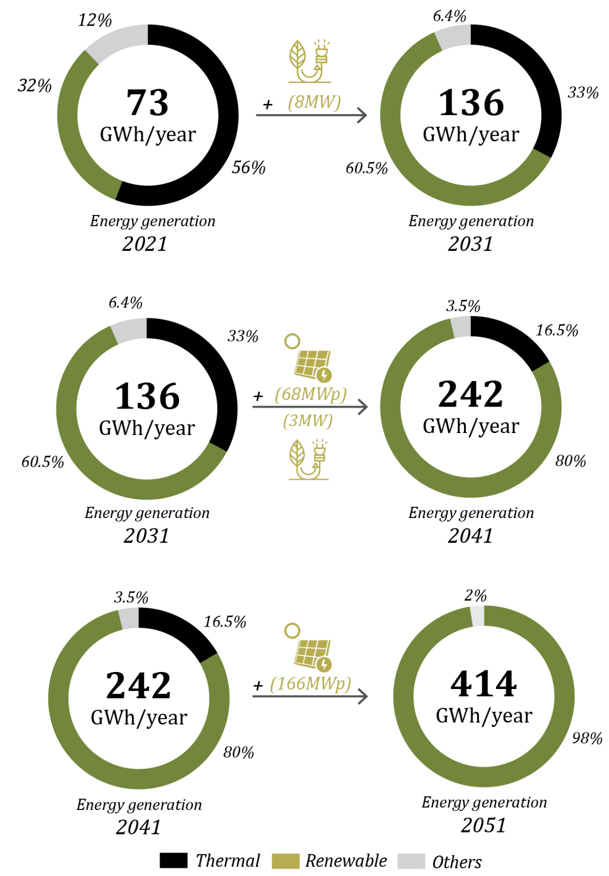


Fig 11.33: Pie charts showing the energy demands from 2021-2051 in the rural context.
Source: Author

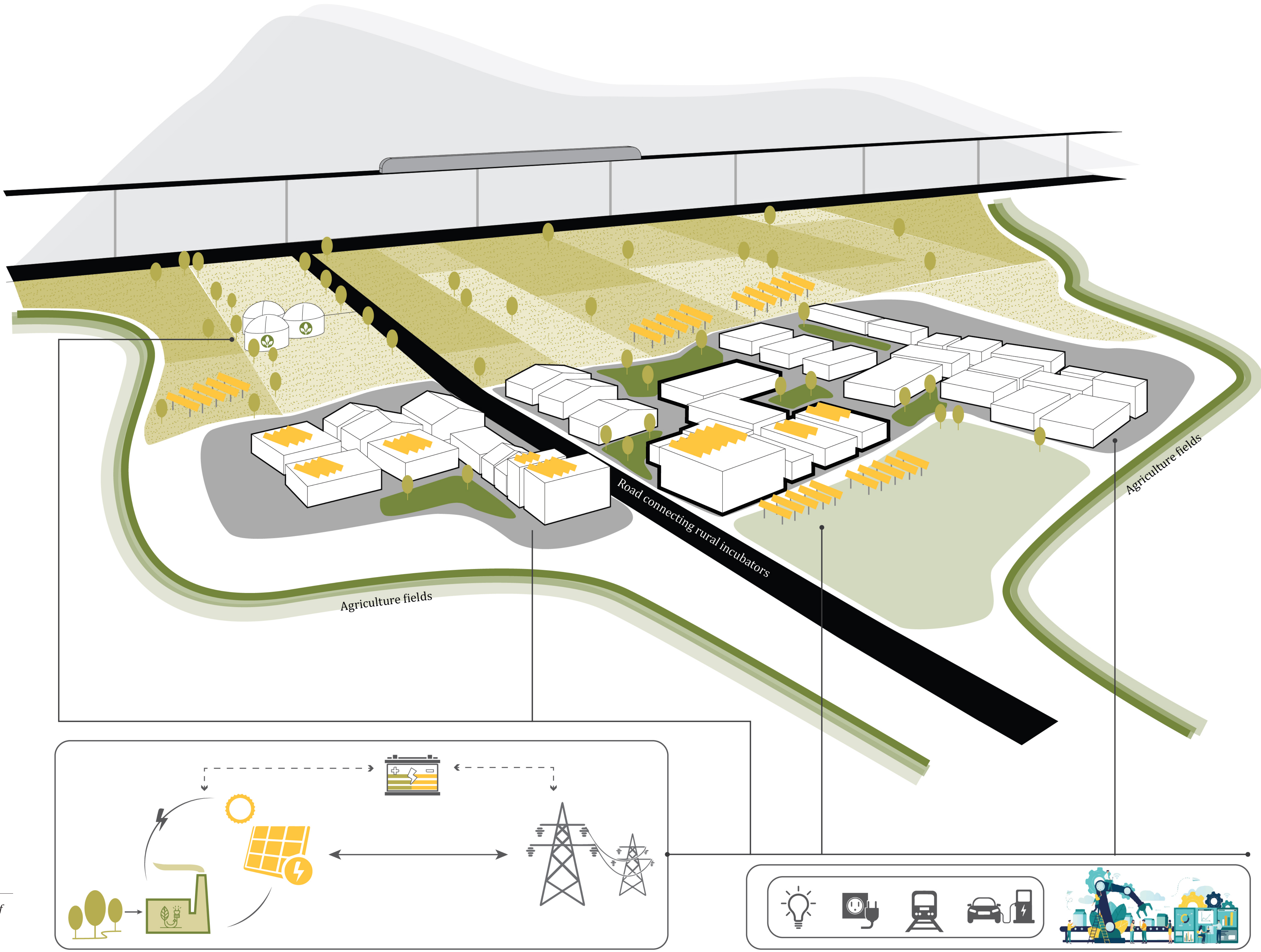


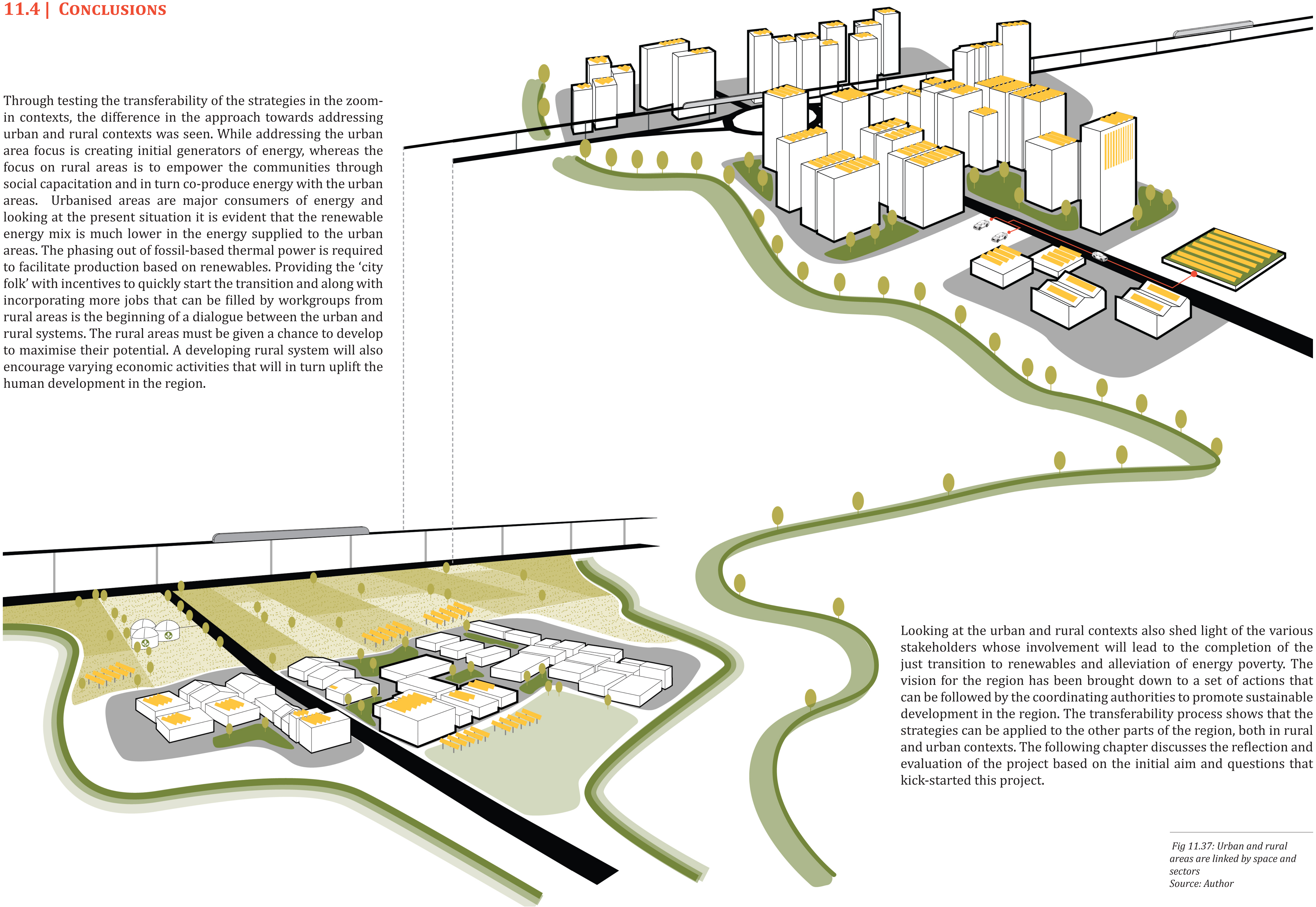
Fig 11.34: 3D representation of rural area
Source: Author

Fig 11.35: View of a village in the strategic zoom location, Alwar
Source: Google earth,2019

Fig 11.36: Impression of the developed rural village
Source: Author

11.4 | Conclusions

Through testing the transferability of the strategies in the zoom-in contexts, the difference in the approach towards addressing urban and rural contexts was seen. While addressing the urban area focus is creating initial generators of energy, whereas the focus on rural areas is to empower the communities through social capacitation and in turn co-produce energy with the urban areas. Urbanised areas are major consumers of energy and looking at the present situation it is evident that the renewable energy mix is much lower in the energy supplied to the urban areas. The phasing out of fossil-based thermal power is required to facilitate production based on renewables. Providing the 'city folk' with incentives to quickly start the transition and along with incorporating more jobs that can be filled by workgroups from rural areas is the beginning of a dialogue between the urban and rural systems. The rural areas must be given a chance to develop to maximise their potential. A developing rural system will also encourage varying economic activities that will in turn uplift the human development in the region.



Looking at the urban and rural contexts also shed light of the various stakeholders whose involvement will lead to the completion of the just transition to renewables and alleviation of energy poverty. The vision for the region has been brought down to a set of actions that can be followed by the coordinating authorities to promote sustainable development in the region. The transferability process shows that the strategies can be applied to the other parts of the region, both in rural and urban contexts. The following chapter discusses the reflection and evaluation of the project based on the initial aim and questions that kick-started this project.

Fig 11.37: Urban and rural areas are linked by space and sectors
Source: Author

12

Evaluation and conclusions

12.1 | Evaluation & Conclusions

What are the reasons behind energy poverty and urban-rural divide in NC region?

What are the barriers that prevent renewable energy transition in the region?

What are the spatial implications of energy systems in the urban-rural context?

How can a regional energy system between urban and rural areas be designed for a just energy transition in NC region, India ?

What are the scenarios that can help develop the urban-rural areas with resilient energy systems?

What are the ways of designing energy systems to reduce impacts on the FEW nexus?

What governance initiatives can enable inclusive participation to reduce energy poverty?

The aim of this project was to illustrate the scope and application of energy systems that can be adapted into the urban and rural areas to alleviate energy poverty and promote a just renewable energy transition in NCR. The way to do this was to test out different energy systems in the local scale through scenario planning and by identifing the ecological, social and economic impacts of the energy systems in the rural areas.

How can a regional energy system between urban and rural areas be designed for a just energy transition in NC region, India ?

Through the study of theories related to the research question, the word 'just' was translated as a concept that focuses on transitions that are environmentally sound, socially fair and economically viable. The methods that followed were taken accordingly. Taking into consideration the potentials of an area, the local resources are harnessed to be able to address the problem of energy poverty in areas facing energy vulnerability. The comparative analysis of the three scenarios gave rise to ways of having a deeper understanding on the present fossil dependency and the benefits of local circles of decentralised energy generation. The local circles create better development in the rural areas and also reduce the divide between the urban and rural areas by making urban system contribute to the development of the rural system.

Looking back at the initial definition of energy poverty that kick started this project, "the absence of sufficient choice in accessing adequate, affordable, reliable, high-quality, safe and environmentally benign energy services to support economic and human development"(Sueyoshi & Goto, 2018), this project definitely addresses the need for collaborative approaches to help give the communities a choice towards clean, renewable energy system. This is to be implemented though initiatives like participatory budgeting, forming financial aid groups and educational empowerment to promote to the economic and human development within different areas of the urban-rural systems.

The sub-questions are a derivative for getting to answer the main research question. A quick brief on the findings are written below.

What are the reasons behind energy poverty and urban-rural divide in NC region?

The reason behind energy poverty is four fold: (1) the access to energy is limited; (2) the focus is more towards supplying energy to the urban areas as the region is dependent on them; (3) the growing urban-rural divide seen across the region has lead multitude of problems, energy poverty being one of them (4) the difference in policies that support mainly the urban growth and has low accountability on the implementation in the local level of the rural areas. Urban-rural divide is the root cause of the problems faced. This happened due to years of neglect and focus on urban development to uplift the nation. And though attempts have been made to improve the rural areas, it was not seen as a pressing need until recently. Thus, the project focuses on combining the folds of the issue and addressing them together.

What are the barriers that prevent renewable energy transition in the region?

The barriers preventing the complete transition is a series of promises made by the government without understanding the consequences on the need for meeting the energy demands. Free electricity and highly subsidised electricity make the distribution companies to run into losses. On top of this, the people are now reluctant to take up and pay for renewable energy sources as they get free wood and hope that some day the government will give them free electricity. Poverty is another factor. The project looks into ways of developing a collaborative system that can help improve the communities' awareness to the situation and urge them to see the positive aspects of renewable energy transition.

What are the scenarios that can help develop the urban-rural area with resilient energy systems?

The determinants for scenarios were based on the various energy systems seen implemented in India and organisation of the energy systems. The first pathway for the scenario is the energy mix (non-renewable or renewable) and the second pathway is for the organisation (centralised or decentralised). The method followed was a research by design approach, where three types of energy systems (1) 100% centralised non-renewable, (2) 100% centralised renewable energy, (3) 100% decentralised renewable energy has been taken as scenarios to draw out plausible futures. A comparative analysis of the difference in impacts between renewables and non-renewables, centralised and decentralised energy systems helped in drawing wholistic conclusions.

What are the spatial implications of energy systems in the urban-rural context?

As mentioned previously, three types of energy systems- (1) 100% centralised non-renewable, (2)100% centralised renewable energy and (3) 100% decentralised renewable energy)- have been taken as scenarios to draw out plausible futures. The conclusions drawn from the comparison of the three scenarios are three-fold- the ecological impacts, social impacts and economic impacts. The spatial implications lean towards the ecological impacts and social impacts. Positive ecological and social impacts are seen in the decentralised energy system as it urges for changes to be made in the society. Higher levels of positive changes in aspects of circular economy and sustainability were noted when creating local flows of resource and people.

What are the ways of designing energy systems to reduce impacts on the FEW nexus?

From the problem field, it was evident that implementation of energy systems will have an impact on the food and water network. Understanding these issues, helped at looking into alternative methods of implementing the energy system. To reduce the impacts on the FEW nexus, the energy systems like Agri-voltaic systems (where solar farms or microgrids and agriculture go hand-in- hand), CCS (carbon capture technology), and installed water channels along solar grids can be utilised. Technological advancements will keep happening. It is important that the knowledge and technology is shared to the local communities. This project has taken this insight and included it under the strategy of rethinking "vs energy" as "and energy".

What governance initiatives can enable inclusive participation to reduce energy poverty?

Through the conclusions of scenario planning and inferences from the interviews conducted, it is evident that there is need for empowerment of the rural areas. The 73rd CAA gives power to the village scale. However, empowering the communities on local area planning, inclusion in participatory budgeting processes, and initiating financial aid groups among community co-operatives are the initiatives that the project has included in the strategies towards the implementation of the regional vision. Emphasis has also been given towards the need for creating educational camps regarding renewable energy transition, energy production and local area planning to all levels of governance to improve the relations between the public, private and civil society.

Conclusions

The evaluation section takes a look back into the research questions that started the project. The section evaluates and concludes the findings and how the ways in which the project has answered the questions. The next section shall look into the reflections, limitations and scope for further research.

13

Reflection

India got independence 72 years ago and since then the country has been developing step by step. As India took the giant leap into an industrialised world, one part of India was left behind in the process- the rural community of India. Mahatma Gandhi, the father of the nation, once said the future of India lies in its villages. However, along the way towards development, these villages were left behind. Currently, the development gap between the urban and rural areas is huge. One of the by-products of this gap is lack of rural energy access or energy poverty in the rural areas. Despite, a large number of attempts to bridge the energy gap, "more than 250 million people in India still remain without basic electricity access and 870 million continue to use biomass as their primary cooking fuel" (Aklin, Bayer, Harish, & Urpelainen, 2018). Providing clean energy access to all is a development goal for the nation.

And my area of focus for investigating the problem was the National capital region (NCR) of India. which is the world's fourth-largest agglomeration and includes New Delhi and surrounding regions (Bansal, 2017). The region covers parts of Haryana, Uttar Pradesh, Rajasthan (3 other states of India) with Delhi (the capital of India or the NCT) at its centre. I superimposed my questions on this area.

"How can a regional energy system between urban and rural areas be designed for a just renewable energy transition in NCR, India?"

"What are the reasons behind energy poverty and urban-rural divide in NC region?"

What are the scenarios that can help create a develop the urban-rural area with resilient energy systems?

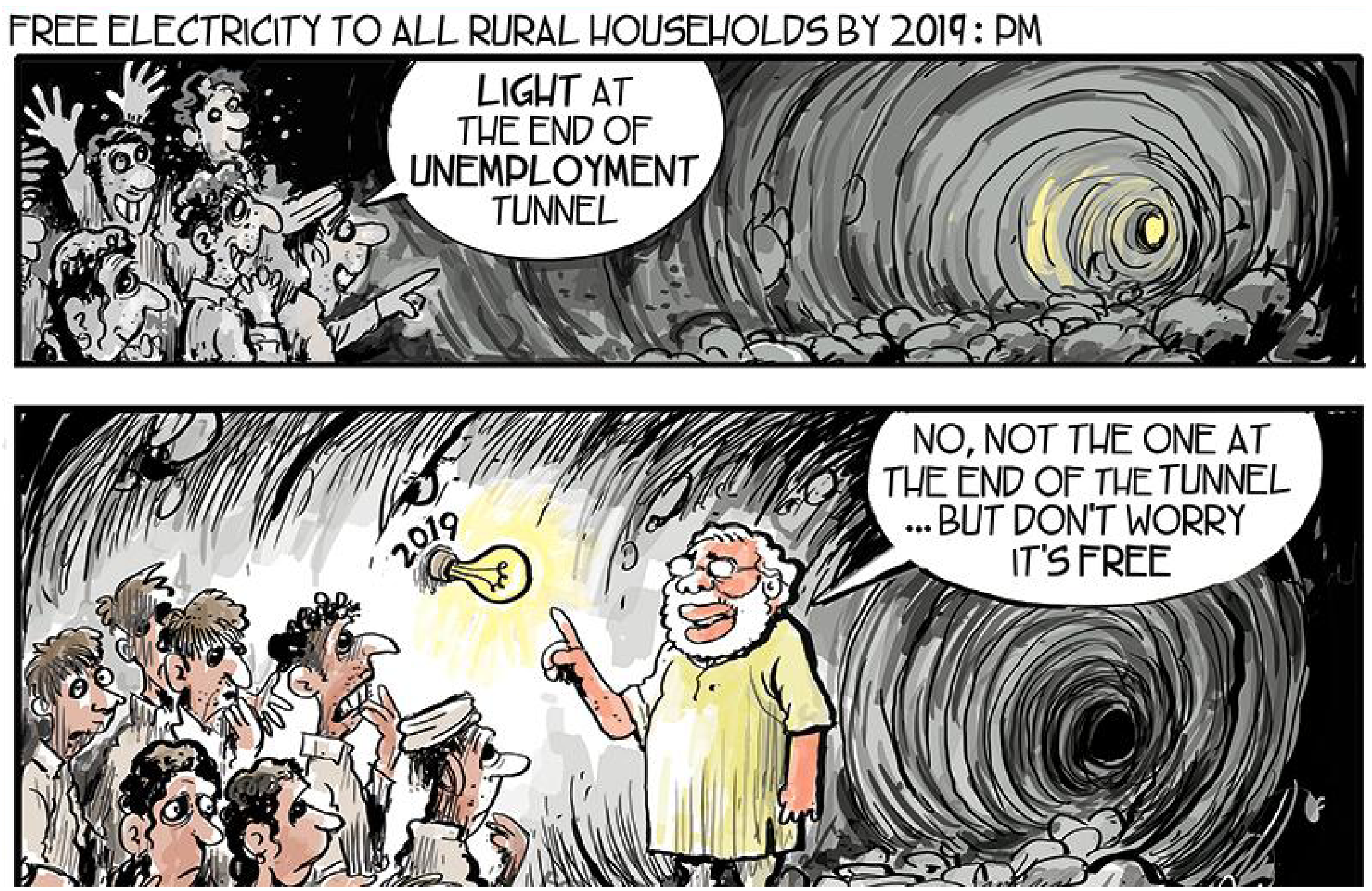
As I reflect on my questions, findings, methodology, and goals, I came to understand the importance between environment, social and economic perspectives in addressing a disparity like energy poverty. And this project is just a small step. There are many layers to the problem of energy poverty like the government policies that are governed by corruption, false promises for gaining votes, suppressed rural communities by the whims and fancies of powerful village leaders, cultural blocks generated by age old traditions and superstitions. All of the above make clean energy transition more difficult in India. Despite this, I am hopeful as I have heard many success stories of community participation being a strength and support for rural energy access and development.

Energy poverty, "**the absence of sufficient choice in accessing adequate, affordable, reliable, high-quality, safe and environmentally benign energy services to support economic and human development**" (Sueyoshi & Goto, 2018).

The problem of energy poverty is a multi-faceted issue with strong connection between the disparities in development of areas combined with poverty. With globalisation and the countries pushing for quick economic development in urban areas, the rural areas get left behind. Years of uneven development has led to day and night differences between the urban and rural areas. Energy poverty is just one of the effects seen. India being 60% rural and 40% urban has realised that its strength lies in harnessing the powers of the rural areas as well. However, the government started to overcompensate for the negligence that has been shown over the years by trying to extend connections and give out free or subsidised 24x7 electricity, which the government could not profit from. This led to false promises, lack of access to 24x7 electricity and most importantly more disparities.

During my interviews with various institutions, I came to realise that people still depended on coal or other biomass sources for their daily needs until at least till the recent future . The rural community does not consider electricity as a commodity or even a priority. They are hoping the free electricity policies would eventually become available. Why spend money on something when you might have a chance of getting it for free? Why spend money on resources when

Fig 13.1: Comical drawing howing the dilemma between having electricity access and lack of human and economic development.
Source: www.timesofindia.indiatimes.com



firewood or kerosene is available? Why spend money when you can use it to meet other daily needs? The increased health risks, lack of proper development and living in poverty has become the 'normal' in rural areas of India. They have been living like this for years.

There is a real dilemma between energy poverty and poverty alleviation. Providing access to electricity is not enough as it does not guarantee the development of the region. This shows there is a need for rethinking the approach to energy poverty in rural areas. Providing clean and environmentally kind energy access is the base upon which ways of generating economic and human development is linked. The outcomes of the project aim at solving this dilemma by analysing the clean energy production capacity of a rural area and connecting into development strategies that are based on community organisations. The intend of the project is to show the possibilities of how the rural system can be developed by societal co-operation and have a self-sufficient development process. It illustrates a different route on how the individual energy nodes can form clustered developments and in turn have an impact on a regional scale.

| The sustainability standpoint

The underpinning of the project was addressing energy poverty and just transition. From UN discussions on climate change to (Stremke, Sven ; Dobbelsteen, 2013) on sustainable energy landscape, the word 'just' is linked to being equitable, sustainable, legitimate, environmentally sound, economically viable. It is not attained by viewing one element over the other. Yes, the economy must be favoured to improve the social benefits of the people suffering from energy poverty and poverty in general. At the same time, environment must be kept in mind to fuel the responsible use of resources and promote sustainable development. From the outcomes of the scenario planning, it was evident that a more decentralised approach with societal, ecological and environmental sustainability is the core of just transition. So an overlap between societal, environmental and economic benefits is the way forward. This is the reason the project threads through the weak sustainability standpoint where the sustainability venn diagram shows sustainable development at the overlap of ecology, social and economic sustainability.

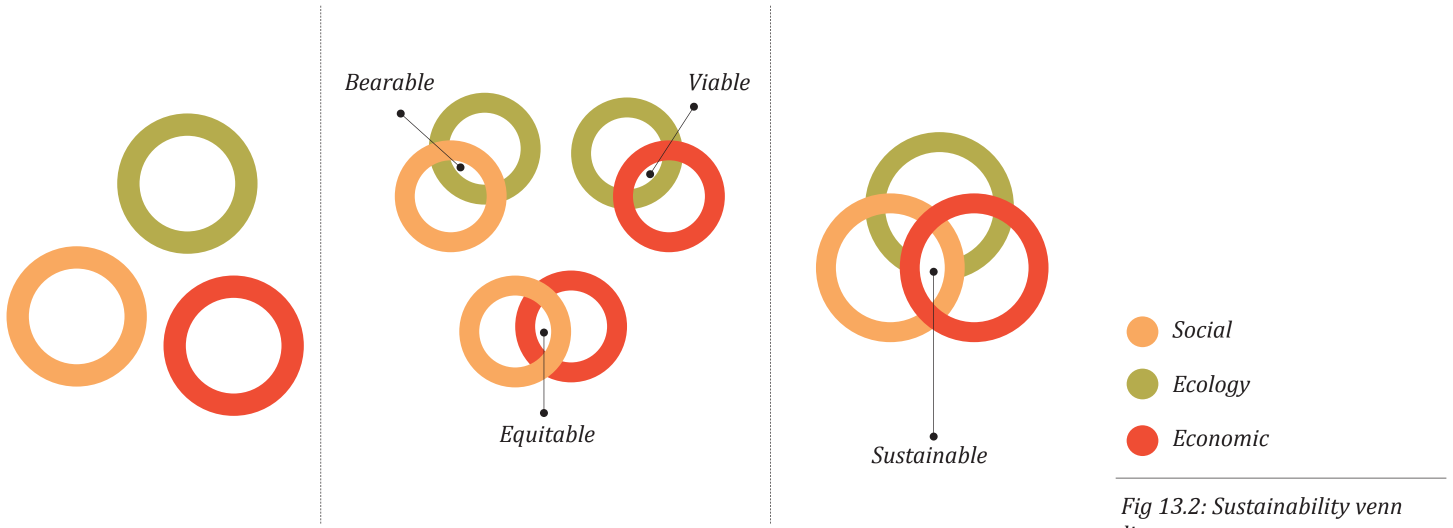


Fig 13.2: Sustainability venn diagram
Source: Author

| Methodology

The methodology chosen first went through works of literature. This was done hand-in-hand with documentary research to understand the problem of energy poverty and energy transition. This study included going through government reports, websites, news articles and reports published by academicians. The study also provided insight on context-specific information that was valuable in the three components of energy poverty- spatial needs, resource, and policy aspect.

The field work initially included interviews and field visits with NGO's. These institutions were working with the government and independently on clean energy access and societal development in the rural areas of the NC region. I had gone to Delhi, India in the month of December, 2019 and one day into my field work, a new law was passed in India which spurred riots across the nation. This prevented my travel to the rural areas of the region. To compensate for this, I had more detailed interviews with the NGO's and even had a deeper look at their projects to understand which methods proved to help the local communities in the areas affected by energy poverty. This was followed by interviews with women empowerment groups as well. This gave a clear picture on the reasons behind energy poverty, the barriers faced and how they are implementing renewable energy in the rural context of NCR.

From the transcalar analysis to formulating the final strategy, the methodology moves through scales. The scenario planning took extreme situations and perhaps it would have been interesting to look at different types of energy mixes like combinations of renewable and fossil or even upcoming new types of technogical innovations that can play a role in spatial development. However, looking at extreme scenarios definitely pushes towards looking into immediate energy transition methods that can be done in a just manner.

The results of the research can be taken as a step towards addressing the issue of energy poverty in a wholistic manner. The strategies can be used to address the issues in regions with similar contexts in the global south.

| Limitations

1. Limited access to accurate logistical data of the rural areas made it difficult to accurately analyse the areas with energy vulnerability.

2. Energy poverty has both electricity and fuel based poverty in its umbrella. This project considers only electricity production and consumption.

3. The project does not take into consideration whether the production of the energy resources like solar panels are made in a sustainable manner.

4. This project looks only at the impacts of energy on the food and water system and not at the inter-relations between the FEW systems.

| Further research

The next steps could include the complete understanding of the FEW nexus when it comes to tackling issues of energy poverty. The inter-relations between the food, energy and water to have a deeper understanding of energy systems from an urban metabolism point of view. Future research can also address energy poverty from a fuel based point of view, which can act as an extension to the study done in this project. It can also include regions with other types of renewable energy potential like wind and geothermal.

| Studio and course

The master's urbanism programme has taught me so much about the different ways of approaching the broad study of urbanism. It was in the third quarter of the master track where the study of flows was brought to my attention. It included a design course where we discussed about the balanced and reciprocal development in the AMA region through the understanding flows (in-boundary and trans-boundary) of the region. Personally, I see the urban metabolism studio is an extension of this.

When it came to the problem of addressing energy poverty, it seemed more like a social problem. Being in the urban metabolism studio allowed me to access this issue in a more dynamic way that broadened my perspective as an urbanist. For me, this graduation project is a platform where I was be able to take the learnings of the urbanism master track and apply it in a context of the global south.

Fig 13.3: Indicating that people use kerosene lamps to bring light to their homes.
Source: www.topyaps.com

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Appendix

| Solar energy calculations for 2051

2051	Location	Population Density (p/km2)	Population (p)	No. of households	Per Capita Consumption (kWh/p/year	Total Energy Consumption (GWh/year)	Daily Energy Generation (kWh/day)	Peak Sun Hours (ESH) (kWh/m2/day)	Reqd. Power Generation (kWp)	Oversized Power Reqd. (kWp)	Total Panel Area Reqd. (km2)	Total Land Area Reqd. (km2)
	Rewari	791.93	79193	15839	10375	821.66	2251115	4.9	459411	633182	3.17	5.3
	Alwar	675.53	67553	13511	6125	413.79	1133676	5	226735	312497	1.56	2.6
	Gurgaon-DMA	5634.46	563446	112689	8269	4659.01	12764405	4.8	2659251	3665101	18.33	30.5

2011	Location	Population Density (p/km2)	Population (p)	No. of households
	Rewari	564.83	56483	11297
	Alwar	438.45	43845	8769
	Gurgaon-DMA	2052.08	205208	41042

Area (km2)	100
People/household	5
Inverter Efficiency (%)	80
Battery Efficiency (%)	85
Cable Efficiency (%)	97
Oversizing factor	1.5
Standard Insolation (kW/m2)	1
Panel Efficiency (%)	20
Panel Spacing Efficiency (%)	60
Overall Eff. Improvement (%)	10

*Modern commercial panels have a panel efficiency of 24% conversion efficiency.
* Assuming a panel spacing efficiency of 60%.
* Overall efficiency improvement of 10% by 2051.

| Biomass energy calculations for 2051

Annual yield in India (Tons/hectare/year)	Year	2014	2015	2016	2017	2018	2019	2020	2021	2031	2041	2051
	Wheat	3.15	2.75	3.03	3.20	3.37	3.51	3.65	3.79	6	8.31	12.30
	Growth Rate (%)		-12.6	10.3	5.5	5.3	4.0	4.0	4.0	48.0	48.0	48.0
	Rice	2.42	2.39	2.40	2.50	2.58	2.67	2.77	2.88	4	6.32	9.35
	Growth Rate (%)		-1.0	0.4	4.0	3.2	3.4	4.0	4.0	48.0	48.0	48.0

Calorific value (dry basis) (GJ/Ton)	Crop	Part	%w/w	GJ/Ton
	Wheat	Straw	50	15.59
	Rice	Straw	29	12.61
		Husk	22	13.07

CHP eff. (%)	90

Crop	GJ/Ton	GWh/Ton
Wheat	7.02	0.0019488
Rice	5.88	0.0016331

Location	Population Density (p/km2)	Population (p)	No. of households	Per Capita Consumption (kWh/p/year)	Total Energy Consumption (GWh/year)	Reqd. Crop Production (Ton/year)	Reqd. Crop Area (hectare)	Total Area Reqd. (km2)
Rewari	791.93	79193	15839	10375	821.66	421632.82	34282.74	342.83
Alwar	675.53	67553	13511	6125	413.79	212337.05	17265.01	172.65
Gurgaon-DMA	5634.46	563446	112689	8269	4659.01	2390767.24	194391.98	1943.92

Total CO2 Emissions (kTon/year)
324.19
163.27
1838.26

Area (km2)	100
People/house	5

*Assumed 4% Annual Increase in production
*Hence assuming an improved efficiency of 90% in 2051
*Chosen crop is wheat

| Biomass and solar energy calculations for decentralised system

General Data	Location	Population Density (p/km2)	Population (p)	No. of households	Per Capita Consumption (kWh/p/year)	Total Energy Consumption (GWh/year)
	Rewari	791.93	79193	15839	10375	821.66
	Alwar	675.53	67553	13511	6125	413.79
	Gurgaon-DMA	5634.46	563446	112689	8269	4659.01

Biomass Data	Location	Total Arable Area (km2)	Biomass Crop Share (%)	Biomass Crop Area (km2)	Annual Crop Production (Ton/year)	Total Energy Generation (GWh/year)	Total CO2 Emissions (kTon/year)
	Rewari	60.00	50.00	30.00	36896	71.90	28.37
	Alwar	70.00	50.00	35.00	43045	83.88	33.10
	Gurgaon-DMA	5.00	50.00	2.50	3075	5.99	2.36

Solar Data	Location	Reqd. Energy Generation (GWh/year)	Daily Energy Generation (kWh/day)	Peak Sun Hours (ESH) (kWh/m2/day)	Reqd. Power Generation (kWp)	Oversized Power Reqd. (kWp)	Total Panel Area Reqd. (km2)	Total Land Area Reqd. (km2)
	Rewari	749.76	2054125	4.9	419209	577773	2.89	4.8
	Alwar	329.91	903855	5	180771	249147	1.25	2.1
	Gurgaon-DMA	4653.02	12747989	4.8	2655831	3660388	18.30	30.5

CO2 Emission Factor	Fuel Type	CO2 Emission (kg/GJ)	CO2 Emission (Ton/GWh)
	Coal (Bituminous)	94.7	340.92
	Biomass (Solid)	109.6	394.56

Area (km2)	100
People/house	5
Wheat (GWh/Ton)	0.001949
Rice (GWh/Ton)	0.001633
Inverter Efficiency (%)	80
Battery Efficiency (%)	85
Cable Efficiency (%)	97
Oversizing factor	1.5
Standard Insolation (kW/m2)	1
Panel Efficiency (%)	20
Panel Spacing Efficiency (%)	60
Overall Eff. Improvement (%)	10

| Phasing calculations for urban context : Gurgaon

	Total Energy Consumption (GWh/year)	Energy Source	Energy Share (%)	Energy Share (GWh/year)
Existing 2021	614	Thermal	78.1	480
		Solar	3.6	22
		Biomass	0.0	0
		Hydro + Nuclear	18.3	112

	Total Energy Consumption (GWh/year)	Energy Source	Energy Share (%)	Energy Share (GWh/year)	Energy Addition (GWh/year)	Power Addition (MW)
Phase I 2031	1390	Thermal	56.9	791	312	41
		Solar	34.6	481	459	361
		Biomass	0.4	6	6	1
		Hydro + Nuclear	8.1	112	0	0

	Total Energy Consumption (GWh/year)	Energy Source	Energy Share (%)	Energy Share (GWh/year)	Energy Addition (GWh/year)	Power Addition (MW)
Phase II 2041	2751	Thermal	25.9	713	-78	-10
		Solar	69.8	1920	1439	1132
		Biomass	0.2	6	0	0
		Hydro + Nuclear	4.1	112	0	0

	Total Energy Consumption (GWh/year)	Energy Source	Energy Share (%)	Energy Share (GWh/year)	Energy Addition (GWh/year)	Power Addition (MW)
Phase III 2051	4659	Thermal	0.0	0	-713	-94
		Solar	97.5	4541	2621	2062
		Biomass	0.1	6	0	0
		Hydro + Nuclear	2.4	112	0	0

Energy Source	Operating hours/day	Operating days/year	Energy Efficiency
Thermal	24	350	0.9
Solar	4.8	365	0.72556
Biomass	24	350	0.9
Hydro + Nuclear	24	350	0.8

| Phasing calculations for rural context : Alwar

	Total Energy Consumption (GWh/year)	Energy Source	Energy Share (%)	Energy Share (GWh/year)
Existing 2021	73	Thermal	55.9	41
		Solar	32.2	24
		Biomass	0.0	0
		Hydro + Nuclear	11.9	9

	Total Energy Consumption (GWh/year)	Energy Source	Energy Share (%)	Energy Share (GWh/year)	Energy Addition (GWh/year)	Power Addition (MW)
Phase I 2031	136	Thermal	33.1	45	4	1
		Solar	17.4	24	0	0
		Biomass	43.1	59	59	8
		Hydro + Nuclear	6.4	9	0	0

	Total Energy Consumption (GWh/year)	Energy Source	Energy Share (%)	Energy Share (GWh/year)	Energy Addition (GWh/year)	Power Addition (MW)
Phase II 2041	242	Thermal	16.4	40	-5	-1
		Solar	45.4	110	86	68
		Biomass	34.6	84	25	3
		Hydro + Nuclear	3.6	9	0	0

	Total Energy Consumption (GWh/year)	Energy Source	Energy Share (%)	Energy Share (GWh/year)	Energy Addition (GWh/year)	Power Addition (MW)
Phase III 2051	414	Thermal	0.0	0	-40	-5
		Solar	77.6	321	211	166
		Biomass	20.3	84	0	0
		Hydro + Nuclear	2.1	9	0	0

CHP Efficiency (%)	90
Inverter Efficiency (%)	80
Battery Efficiency (%)	85
Cable Efficiency (%)	97
Oversizing factor	1.5
Overall Eff. Improvement (%)	10

Decoding the vector of energy poverty : Understanding the components of energy systems in the urban-rural context of NCR, India

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