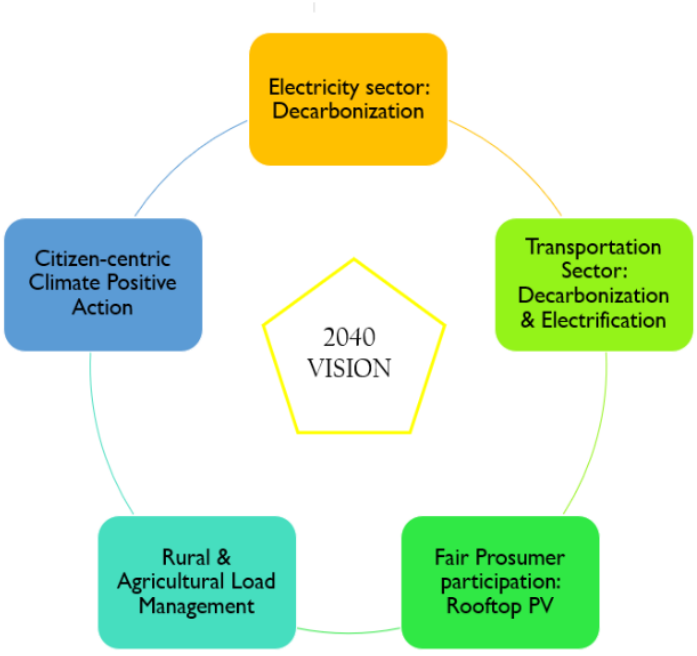
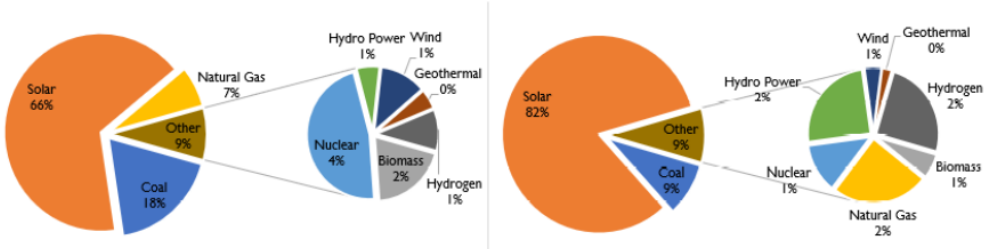
STRAPSETT

Strategic Transition Pathways towards Sustainable Energy Technologies for Telangana

A Participatory Backcasting Approach





Vamsi Krishna Nallacheruvu

Master of Science - Sustainable Energy Technologies

TU Delft Delft University of Technology

Strategic Transition Pathways towards Sustainable Energy Technologies for Telangana

A Participatory Backcasting Approach

By

Vamsi Krishna Nallacheruvu
Student number: 4728297

in partial fulfilment of the requirements for the degree of

Master of Science
in Sustainable Energy Technologies

of the
Faculty of Electrical Engineering, Mathematics and Computer Science

at the
Delft University of Technology

to be defended publicly on Tuesday September 24, 2019 at 11:30 AM.

Thesis committee:	Prof. dr. K. Blok,	TU Delft
	Dr. ir. J. N. Quist,	TU Delft
	Dr. S. T. H. Storm,	TU Delft

An electronic version of this thesis is available at http://repository.tudelft.nl/.

TU Delft

'If I have seen further it is by standing on the shoulders of Giants.'
– Isaac Newton, 1675

Acknowledgements

To the teachers, scientists, and engineers who
lit, sustained and encouraged the fire in me
towards the spirit of inquiry and science,

To the country that nourished and brought me up
with food for the body, mind, and soul,

To the numerous changemakers around the world
in the history and in the present
who inspired change,
taught and demonstrated commitment and patience,
led the way forward,
set the bar high,
and sown the seed that change begins from within you,

To the people who took the road less travelled and guided me,

To the gurus who taught that inward is *the* way forward,

To the social network that constantly supported me,

To the professional network that relentlessly taught,
tested and motivated me,

To the exams, assignments, night-outs, lots of coffee,
dark and cold winters, cloudy and clear summers, and
the challenges faced and surmounted,
To the professors who guided me in this journey,
Dr. Kornelis Blok, Dr. Jaco Quist and Dr. Servaas Storm,
and to my colleagues and fellow researchers, here at TU Delft,

And most importantly, to my parents,

I Thank you.

Summary

Global Green House Gas emissions have increased due to continued use of fossil fuels for energy in various sectors mainly in electricity, transport, and heating around the world. However efforts to replace fossil fuels through the adoption of sustainable energy technologies are rapidly increasing primarily driven by solar and wind, and other resources for electricity and electrified forms in transportation. As a part of its 2015 Paris Climate Agreement India has been getting more ambitious in its targets for reducing the emissions intensity of GDP, i.e., the emissions produced per unit of GDP. Both at the central as well as state governments in India action plans for energy transition are coming up through increasing Renewables penetration in electricity, electric mobility, and others.

Telangana is a state in the southern part of India which has relatively progressive policies for the promotion of Renewable Energy (RE). Year-on-year with the state GDP and electricity consumption growing at nearly 14% each, fuel consumption growing at more than 10%, and total number of vehicles growing at more than 9%, it is highly desirable that this increasing energy demand be met with cleaner energy sources or low carbon alternatives in addition to improving efficiency of the current systems. The availability of various RE sources was assessed and a tremendous potential for Solar PV was found, nearly 190,000 GWh, that could sufficiently cater to a large share of the total demand for electricity. Adding other RE sources, the total RE potential was nearly 194,000 GWh.

Currently only a tiny share of this potential is realised. And the future plans for decarbonization were found insufficient and this thesis attempts to design ambitious low carbon normative future scenarios for the year 2040 through Quist's participatory backcasting approach and develop the pathways required to achieve them. The Research question thus developed was

"What are the transition pathways that can be developed for the state of Telangana towards a sustainable energy system by 2040?"

The stakeholders, including state and non-state actors, who are a part of the system were interviewed and the outcomes from their interviews were used to define this future vision of a greater sustainable energy. A backcasting analysis was done to develop pathways to achieve this desired vision of the future.

Currently in a Business As Usual scenario the total demand is projected to increase by nearly 5 times for electricity and more than 4 times for fuel. But with a moderate growth, an alternative scenario suggests that the total demand could increase by 3 times for electricity and 2.5 times for fuel. From the outcomes of the interview and study of literature available, a desired vision was developed with 5 key elements.

1. Electricity Sector Decarbonization: Higher share of clean energy sources apart in addition to closure of fossil fuel facilities.
2. Transportation sector Decarbonization & Electrification: Shifting to low carbon alternatives as well as electrified forms of mobility for 2, 3, and 4 wheelers along with buses.
3. Fair Prosumer Participation: Major shifts in policy of setting the electricity tariffs that can usher in changes which improve the operations of Distribution Companies, allow roof-top PV to become a

successful economic endeavour and facilitate consumers to become prosumers.

4. Rural & Agricultural Load Management: The increasing demand from rural parts of the state and agricultural share of the demand like large irrigation projects need to be addressed through off-grid projects and more Solar PV systems.
5. Citizen-centric Climate Positive Action: The role of citizens in the form of a constructive initiative building role through greater climate literacy, awareness and action through changes in behaviour to drive a sustainable future.

Then 2 targets were set to achieve a high sustainable energy shares in the overall energy mix and consequently 2 pathways were developed for them, called A_C and A_M. A_C envisions 50% of electricity to come from non-fossil fuel sources and to have a 15% of total vehicles. And A_M on the other hand much more ambitiously targets 75% of non-fossil fuel energy in the electricity mix and 30% of electric vehicles. To facilitate an energy transition of a large scale, more than the addition of clean energy sources, significant changes in the existing system are needed to be made in addition to addressing the barriers in place that inhibit us from achieving the vision. In addition to lack of capital, one of the biggest barrier is the existing tariff structure of the electricity that weakens the system. Other barriers that were discussed include the lack of a coherent directed policy for uptake of electric vehicles, high losses in the grid and lack of robust energy efficiency measures, and a limited view of decarbonization that needs to be expanded. A brief discussion on the lack of push from citizens to drive changes in sustainability is also made.

The backcasting analysis discusses how the vision can be achieved through addressing the barriers and the right kind of interventions necessary and eventually recommendations were made. Raising capital through green funds and addressing barriers to access this capital due to lack of sufficient knowledge on the part of the financial institutions was discussed. Then, changes required in tariffs of electricity were discussed by detailing the benefits and the types of tariff changes that can be made. Low carbon transition in Transportation was discussed through emphasis on public transportation as well as diesel consuming taxi segment followed by others like 2 and 3 wheelers. But for this to happen, sufficient infrastructure is required both in terms of manufacturing capacity creation and then target realisation. Capacity creation for Solar PV and battery storage was explained. Yearly targets for GW of PV needed, GWh of storage required along with their total costs was presented. Additional transmission & distribution infrastructure needed was discussed as well. The pathway A_C would need atleast \$39 bn and A_M, atleast \$60 bn to realise the energy transition. It is possible to do so with the right policies in place and with a political willingness to facilitate the transition.

Contents

Summary vi

List of Abbreviations xiii

List of Figures xviii

List of Tables xx

1 Introduction 2
- 1.1 The Paradox of Economic Development and Environmental Responsibility . . . 3
- 1.2 Sustainable Development . . . 4
- 1.3 Transition to a Sustainable Energy future . . . 4
  - 1.3.1 The case of China . . . 5
  - 1.3.2 The case of India . . . 5
  - 1.3.3 The case of Indian Cities . . . 6
- 1.4 Problem Introduction: The case of Telangana . . . 6
- 1.5 Research Questions & Objectives . . . 8
- 1.6 Overview . . . 9

2 Literature Review & Research Methodology 10
- 2.1 Energy Transition . . . 11
- 2.2 Backcasting . . . 12
  - 2.2.1 Types of Scenarios . . . 12
  - 2.2.2 Why Backcasting? . . . 13
  - 2.2.3 Participatory Backcasting . . . 14
- 2.3 Literature Sources and Data Availability . . . 16
- 2.4 Understanding Research Methodology . . . 17
- 2.5 Outline of the methodology practiced . . . 20

I Strategic Problem Orientation 21

3 Location Survey 22
- 3.1 Geography . . . 23
- 3.2 Economy . . . 25
  - 3.2.1 Sectors in the Economy . . . 26
  - 3.2.2 Energy Balance Sheet . . . 30
- 3.3 PESTEL Analysis of factors affecting Telangana's Energy sector . . . 32
  - 3.3.1 Political . . . 32

3.3.2 Economic . . . 32
3.3.3 Social . . . 33
3.3.4 Technological . . . 33
3.3.5 Environmental . . . 33
3.3.6 Legal . . . 35

4 Renewable Energy Potentials 36
4.1 Solar PV . . . 37
4.1.1 Utility scale/ground mount . . . 39
4.1.2 Rooftop . . . 40
4.1.3 Others . . . 41
4.2 Wind Power . . . 41
4.3 Hydro-electric Power . . . 42
4.4 Bio-based sources . . . 43
4.5 Geothermal Power . . . 44

5 Understanding Stakeholders 46
5.1 Introduction . . . 47
5.1.1 Choosing the Stakeholders for interviews . . . 47
5.2 Power Supply Structure . . . 48
5.3 Power Sector of Telangana . . . 49
5.4 Other Stakeholders . . . 50

II Developing Future Visions 53

6 How does future demand look like? 54
6.1 Understanding Causality Factors . . . 55
6.2 Future Projections . . . 62
6.2.1 Scenarios: Electricity . . . 63
6.2.2 Scenarios: Transportation . . . 65
6.2.3 Scenarios: Fuel . . . 66

7 Developing Future Visions 69
7.1 Basis of Framing the Vision . . . 70
7.1.1 Major Interview Outcomes . . . 70
7.2 Desired Vision . . . 72
7.3 Elaborating the Vision: Defining Targets . . . 74

III Backcasting Analysis 79

8 Analysing Barriers 80
8.1 Nature of Barriers . . . 81
8.2 Limited view of Decarbonization . . . 81
8.3 Tariff Determination . . . 82
8.3.1 Problem with Low Tariffs . . . 83
8.3.2 Imapct on DISCOMs . . . 83
8.3.3 Case A - Computing Losses in procurement and sale of electricity . . . 84
8.3.4 Case B: Case for Roof top PV for a household consumer . . . 84

8.4 EV Policy Paralysis . . . 85
8.5 Losses & Efficiency . . . 86
8.6 Creation and making access to Financial capital . . . 87
8.7 People driving the change . . . 87

9 Backcasting Analysis: STRAPSETT 89
9.1 Financing the vision . . . 90
9.2 Tariff Management . . . 93
9.2.1 Time of Day Tariff . . . 93
9.2.2 Temporal Pricing . . . 93
9.2.3 Eliminating Cross subsidies . . . 93
9.2.4 Financial Health of DISCOMs . . . 94
9.2.5 Feed in Tariffs . . . 94
9.3 Low Carbon Transition in Transportation . . . 95
9.4 Creation of capacity . . . 96
9.5 Closure of Coal power . . . 97
9.6 Role of Citizens . . . 98
9.6.1 Climate Literacy & Action in Pune . . . 98
9.6.2 Rally for Rivers . . . 99
9.6.3 Project Drawdown . . . 99

10 Conclusions, Recommendations & Reflections 100
10.1 Conclusions . . . 101
10.2 Recommendations . . . 102
10.2.1 Restructuring Tariff Policy . . . 102
10.2.2 Raising and providing access to Capital . . . 102
10.2.3 Infrastructure . . . 103
10.2.4 Electrifying Transportation . . . 103
10.2.5 Efficiency Improvements . . . 104
10.3 Reflections . . . 104
10.3.1 Methodological Reflections . . . 104
10.3.2 Adopting a different approach . . . 106
10.3.3 Limitations . . . 107
10.3.4 Is STRAPSETT ambitious? . . . 108
10.3.5 Is STRAPSETT achievable? . . . 108

Bibliography 109

IV Appendices 119

A Equations used 120
A.1 Solar Energy Potential calculation . . . 120
A.2 PV system electricity cost calculation . . . 121

B Additional figures and tables 123
B.1 Growth Rates and Projections . . . 124
B.2 Yearly Installed Capacities projected . . . 127
B.3 Cost Assumptions . . . 128

C Stakeholders 131
C.1 Interviewees . . . 131
C.2 Interview Transcripts . . . 132
C.2.1 Electricity, Grids, and Finance . . . 133
C.2.2 Fuel, Transportation, and Storage Tech . . . 139
C.3 Other Major Stakeholders . . . 143

List of Abbreviations

AQI	Air Quality Index
ARAI	Automotive Research Association of India
AT&C	Aggregate Technical & Commercial
BEE	Bureau of Energy Efficiency
BHEL	Bharat Heavy Electricals Limited
CEA	Central Electricity Authority
CEEW	Council for Energy, Environment & Water
CERC	Central Electricity Regulatory Commission
CoP	Conference of Parties
CPFC	Central Power Finance Corporation
CPR	Centre for Policy Research
CTU	Central Transmission Utility
DISCOM	Distribution Companies
DSM	Demand Side Management
DeSM	Deviation Settlement Management
ECBC	Energy Conservation Building Code
FDI	Foreign Direct Investment
FiT	Feed in Tariff
GDP	Gross Domestic Product
GoI	Government of India
GW	Giga Watt
GWh	Giga Watt hour
IESA	India ENergy Storage Alliance
IEX	Indian Energy Exchange
IOC	Indian OIl Corporation
IPO	Initial Public Offering
IPP	Independant Power Producers
IREDA	Indian Renewable Energy Development Agency
ISGS	Inter State Generation Systems
kW	kilo watt
kWh	kilo watt hour
MNRE	Ministry of New & Renewable Energy
MoSPI	Ministry of Statistics & Programme Implementation
MT	Million tons
NBFC	Non Banking Finance Corporations
NGO	Non Governmental Organization
NIBE	National Institute of Bioenergy
NISE	National Institute of Solar Energy

NITI Aayog	National Institute for Transforming of India
NIWE	National Institute of Wind Energy
NLDC	National Load Dispatch Centre
NSEFI	National Solar Energy Federation of India
NTPC	National Thermal Power Corporation
PPA	Power Purchase Agreement
PPAC	Petroleum Planning Analysis Cell
PV	Photo voltaic
RBI	Reserve Bank of India
RE	Renewable Energy
REC	Rural Electrification Corporation
SCCL	Singareni Colleries Company Limited
SECI	Solar Energy Corporation of India
SFN	Shakti Foundation
SIAM	Society of Indian Automotive Manufacturers
SRLDC	Southern Regional Load Dispatch Centre
TERI	The Energy Research Institute
TS	Telangana State Government
TSGENCO	Telangana State Generation Corporation
TSNPDCL	Telangana State Northern Power Distribution Company Limited
TSPFC	Telangana State Power Finance Corporation
TSREDCO	Telangana State Renewable Energy Development Corporation
TSRTC	Telangana State Road Transport Corporation
TSSPDCL	Telangana State Southern Power Distribution Company Limited
TSTRANSCO	Telangana State Transmission Corporation Ltd
TW	Tera Watt
TWh	Tera Watt hour
UNFCCC	United Nations Framework Convention on Climate Change
WHO	World Health Organization

List of Figures

2.1 This succinctly explains the placement of this thesis and the fields of perspectives it influences and is also influenced by (wrt Energy Transitions). Source: (Cherp et al., 2018). 11
2.2 Scenario typology with three categories and six types (Börjeson et al., 2006). 13
2.3 An example of the PESTEL Framework Analysis that will be used. 18
2.4 Division of a long-term vision into multiple short-term visions in Time periods (TP) . . . 19

3.1 Location of the state of Telangana in India (shown in green) 23
3.2 Map of Telangana (with 31 separated districts) showing the location of the city of Hyderabad 23
3.3 The decadal population growth rates for Telangana are compared to that of India from 1941. While the growth rates nearly increased closely, TS has seen a sharp fall since 1992 and this trend is expected to continue. The bars in red project TS's future rates. Source: Directorate of Economics & Statistics (2017) and Office of the Registrar General & Census Commissioner (2011). 24
3.4 Average monthly Radiation. Annual Irradiation received: 1972 $\frac{kWh}{(m^2).yr}$ 24
3.5 Average monthly sunshine hours. Equivalent Sun Hours (ESH) Annually = 5.4 24
3.6 Month-wise Ambient Temperatures range. 25
3.7 Average Monthly Precipitation. 25
3.8 Sectorwise GDP share (2018) 25
3.9 Sector-wise growth rates (at current prices) 25
3.10 An overview of major industries and category wise breakdown. Source: Annual Survey of Industries, 2015 26
3.11 GDP growth rates (at constant prices) comparison of Telangana and its neighboring states vis-a-vis India over a 12 year period starting from 2005. The dotted and dashed vertical red line: To the left of it, the base year used for calculation was 2004-05 and to the right of it, the base year used was 2011-12. Source: Reserve Bank of India Statewise GDP Report 28
3.12 Comparison of Inflation measured using Consumer Price Index (CPI) for Telangana and India. Source: Directorate of Economics & Statistics (2017). 28
3.13 Sector wise electricity consumption. 29
3.14 Sector wise energy Consumption. 29
3.15 Sector-wise load profile on a given work day. The load is represented as a percentage of the total energy consumption of the day. Compiled with inputs from Interview #1. 30
3.16 Source-wise share of total installed capacities (2017). 31
3.17 Source-wise Share of Electricity generation (2017). 31
3.18 The share of PV among other RE in the electricity mix for Telangana in 2017. Source: Prayas Energy Group 31
3.19 The US Air Quality Index for the month of April 2019 for Hyderabad. Source: IQ Air Visual app. 34
3.20 PM 2.5 levels in $\frac{\mu g}{m^3}$ for the month of April 2019 for Hyderabad. Source: IQ Air Visual app. 34

3.21 PM 2.5 levels in $\frac{\mu g}{m^3}$ for the month of April 2019 for Hyderabad. Source: IQ Air Visual app. 34
3.22 General pollutants levels. Source: IQ Air Visual app. 34

4.1 Telangana (highlighted in yellow) compared with other states int erms of RE share in total energy mix. 37
4.2 The increasing share of PV (in orange) in the energy mix of Telangana from 2016 to 2019 March. The rest of the sources contributed to 1-2% each or lower. 37
4.3 Annual Irradiation received for Telangana (the scale in the figure corresponds to kWh per acre). Region with highest value at $2,150\frac{kWh}{m^2.year}$ and that of lowest value at $2,000\frac{kWh}{m^2.year}$. Source: Harinarayana and Kashyap (2014). 38
4.4 Annual Wind energy generation potential (at 75m hub height; per km^2) for Telangana state. Average Capacity factor $C_f = .06$ 42
4.5 Geothermal Energy Locations in India. Total potential: 10,600MW. 44
4.6 Location of 150+ MW geothermal potential in Khammam district (in red). 44
4.7 RE source-wise potentials available in TS 45

5.1 Power Supply Structure system operation 48
5.2 Brief overview of stakeholders and institutions at the state level. 49
5.3 An overview of the major stakeholders (non-exhaustive list) who will be discussed throughout this thesis. The actors interviewed are shown in green those with red dots are exclusively in transport sector. 51

6.1 The relationship between (i) GDP and Electricity demand rates, (ii) services sector growth rate and electricity demand can be seen. Compiled from Directorate of Economics & Statistics (2017) and Reserve Bank of India State Wise GSDP Report, 2018. 55
6.2 The figure compares the year-on-year changes in the GDP of Telangana and its neighboring states vis-a-vis India over a 12 year period starting from 2005 (at constant prices). The dotted and dashed vertical red line: To the left of it, the base year used for calculation was 2004-05 and to the right of it, the base year used was 2011-12. Source: Reserve Bank of India Statewise GSDP Report, 2018. 56
6.3 Decadal Population Growth Rates and Electricity-Population Elasticity Index. Compiled from: Directorate of Economics & Statistics (2017), Andhra Pradesh State Electricity Board (1998), Government of India (GoI) (2002). (Blue: Historic, Red: Projected) 57
6.4 Cumulative increase in the total number of vehicles in the state over the period of 2005-2020. Due to lack of availability of data, 2017 & 2018 are approximately estimated and the numbers for 2019 & 2020 are projections. It can be seen that the year-on year growth has gradually fallen from 15.6% in 2005 to less than 10% in 2016. Compiled from EPTRI and MoEFCC (2016) data. 59
6.5 Share of the major vehicle segments (as of 2016): 2 Wheelers (2W) are the largest segment followed by cars and then 3 Wheelers (3W). Compiled from EPTRI and MoEFCC (2016) data. 60
6.6 Year-on-year cumulative growth (in billion liters) of fuel consumption along with y-o-y growth rates. Compiled from EPTRI and MoEFCC (2016) data. 60
6.7 Percentage deviation from expected rainfall (905 mm per year) over the last two decades. The (red) curve above 0% corresponds to excess rainfall and below 0% correspond to deficit. A comparison with electricity consumption shows an inverse relationship in most of the years, i.e., an year of deficit rainfall warrants additional electrical power for pumping water. But a more mature and stabilised relationship from the 2016 is seen due to improved irrigation and agricultural infrastructure. 61

6.8 Projections of GDP growth rate year-on-year till 2040 calculated through above mentioned factors and semi quantitative methods (subject matter expert discussion). 62
6.9 Total Energy Demand (electricty and transportation, in terms of final consumption) in both the scenarios shown in bars (left-hand axis) and the gradually falling growth rate curves (right-hand axis). The total demand in Sc_{ALT} stays above zero in 2040. The per-capita energy would increase from 3,000 kWh to 7,320 kWh. 63
6.10 The 2 scenarios of electricity consumption. E_{BAU} represents a business as usual scenario growth and E_{ALT} represents an moderate growth scenario. E_{BAU} follows a growth rate equal to that of the GDP growth rate and E_{ALT} follows a rate that is determined from $e_{E\text{-}gdp}$. 64
6.11 The bars in red compare and project the future 20-year per capita electricity consumption changes to that of the historic (blue) data. The orange curve shows the increasing percapita consumption over time. 2018: 1,727 kWh; 2040: 4,400 kWh 64
6.12 The falling growth rate in the overall vehicles and cumulative rise in total number of vehicles. 65
6.13 Projected fuel demand by 2040 for BAU and ALT scenarios (Fuel includes Gasoline/Petrol, Diesel, and other alternative fuels like CNG predominantly, LPG and Compressed Bio-gas (CBG). 66
6.14 The F_{ALT} Scenario is broken down to explain its constituents. 67

7.1 Key Elements of the vision for 2040 enabling STRAPSETT 72
7.2 Left: Source-wise share of energy mix. Right: Source wise share of Installed Capacity. The share of RES is nearly 50% in this scenario by 2040. (While nuclear is not a RES, it is a clean and non-polluting source of energy.) 75
7.3 Left: Source-wise share of energy mix. Right: Source wise share of Installed Capacity. The share of RES is nearly 75% in this scenario by 2040. (While nuclear is not a RES, it is a clean and non-polluting source of energy.) 75
7.4 The share of transportation in final electricity consumption in A_C and A_M with 15% and 30% of the total vehicles becoming electric is 7% (14,000 GWh) and 14% (27,500 GWh) respectively. 76
7.5 A supply-demand profile of a typical day in 2040 for A_M where the total energy from PV is more than 70% in the mix. 77
7.6 The share of total electricity consumed of the the 5 major sectors is given for a 24 hour period in 2040. On the left hand axis, the % of the load from the respective sector in that hour of day is shown. The right hand axis (for the black curve) gives the % of total load for an hour of the day. 77
7.7 Comparing sector-wise electricity shares in 2017 and 2040. 78

9.1 The cumulative total shares of installed capacities year-by-year in A_C. 90
9.2 The cumulative total shares of installed capacities year-by-year in A_M. 90
9.3 Showing the GW of PV needed in both cases and comparing their costs in A_C and A_M. . . 91
9.4 It would cost around 39 billion US$ over a 21 year timeline for A_C that amounts to less than 1% of the state's GDP in terms of capital needed per year. The share of PV in the total capital is more than 75%. 92
9.5 The capital needed in A_M is 60 billion US$ and the share of PV is the nearly same as in A_C in the total capital. 92
9.6 Cumulative Storage Capacities needed in GWh in A_M and A_C. 97

A.1 PV Module Datasheet 122

B.1 Day wise peak demand. Max value = 9.191 GW (2017) [GW] 123
B.2 Installed Capacities as on 1 July 2019. Source: TSTRANSCO. 123

B.3 Total energy demand in both scenarios including electricity and fuel. 128
B.4 Historical Percapita Electricity Consumption taken for 20-year periods observed till 2018. The trends shows a very slow but gradually falling percentages. 128
B.5 Scenarios for projected increase in the total number of vehicles 128
B.6 What if 100% of the vehicles go electric by 2040? Share of electricity from transportation in a 100% EV scenario. 129
B.7 Share in the total capital for PV, Storage and Transmission and Distribution Infrastructure. The % values are the same for both A_C and A_M. 130

C.1 Possible contributions of actor analysis to policy analysis activities. Source: Hermans et al. (2010). 131
C.2 Direct and indirect, uni- and bi-directional Powerflows among the stakeholders interviewed. 132

List of Tables

3.1 A comparison of Socio-Economic Indicators of Telangana and India (2016). Source: Directorate of Economics & Statistics (2017) and NITI State Statistics Portal. 23
3.2 Energy Balance Sheet of Telangana (2017). All values are approximated and are in GWh. . . 31

4.1 Assumptions made in the calculations. (Value of albedo is taken from PVSYST Directory (2014) and SVF is calculated from the tilt angle.) 39
4.2 The potential of Solar PV that can be exploited on wastelands. 39
4.3 Assumptions made in the calculations for Rooftop PV potential. (Value of albedo is taken from PVSYST Directory (2014) and SVF is calculated from the tilt angle.) 41
4.4 Total Solar PV potential of Telangana. 41
4.5 Comparison of various Biofuels (bio-diesel feedstocks) adapted from Mata et al. (2010). Last 2 columns refer to the diesel consumption in Telangana. 43
4.6 Details of the Geothermal energy location in Telangana shown in figure 4.6. Source: (Sharan and David, 2017) 44

6.1 An example to show the additional Energy demand from rural households by the end of 2030 through increased standard of living. 58
6.2 Approximate Savings in fuel and oil imports possible by switching to electric vehicles. ($ calculation include crude oil prices that India paid to import as of 2018. Source: Ministry of Petroleum & Natural Gas). 68

8.1 Example to demonstrate the costs incurred, revenues generated and profit/loss made by DISCOMs for 1000 kWh of electricity purchased and sold. All values in INR. (15% of Distribution losses are accounted in the last column, so purchase of 1000 units implies a sale of 850 units.) 84
8.2 Calculations to show and compare the Pay back Periods for a Rooftop PV system and battery for a house. (All values in INR) 85

B.1 Year-wise projected values for Electricity (E), Fuel in transportation (F), total energy for the scenario (Sc) and the per-capita energy consumption. 124
B.2 Growth in the consumption of Gasoline, Diesel and Alternate Fuels as percentage and TWh values year-on-year. G: Gasoline; D: Diesel; AF: Alternate Fuels (CNG, CBG, HCNG); α: Efficiency improvements in fuel use; β: growth rate; F: Total (fuel) energy use. 125
B.3 ALT Scenario: Quantum of fuel use in billion litres and thousand tonnes of CNG (assumed as an alternate fuel). Total Vehicles in millions. 126
B.4 The ratio of change in energy consumption to the change in GDP considered as a multiplier to calculate future energy growth. 127
B.5 Scenario A_C: Yearly Installed Capacity in GW for all sources. 127
B.6 Scenario A_M: Yearly Installed Capacity in GW for all sources. 129

C.1 List of Interviewees 132

1 Introduction

> We are the first generation to be able to end poverty, and the last generation that can take steps to avoid the worst impacts of climate change.
> Future generations will judge us harshly if we fail to uphold our moral and historical responsibilities.
>
> Ban Ki-moon, former UN General Secretary

Chapter Summary

This chapter initially introduces the landscape in which this thesis is placed by discussing the global climate change problem and the challenges in the Indian geographical, socio-economic and political context. Then the topic of this thesis is introduced. Then, the relevant research questions which were developed, that this thesis attempts to answer, are discussed.
Finally an overview of all the chapters is briefly mentioned.

1.1 The Paradox of Economic Development and Environmental Responsibility

The Intergovernmental Panel on Climate Change[1] (IPCC) released the 5th Assessment Report (AR5) in 2014 in which it clearly mentions the role of humans in the changing climate landscape in the following way: "Anthropogenic greenhouse gas emissions have increased since the pre-industrial era, driven largely by economic and population growth, and are now higher than ever. This has led to atmospheric concentrations of carbon dioxide, methane and nitrous oxide that are unprecedented in at least the last 800,000 years. Their effects, together with those of other anthropogenic drivers, have been detected throughout the climate system and are extremely likely to have been the dominant cause of the observed warming since the mid-20th century. Since the 1950s, many of the observed changes are unprecedented over decades to millennia. The atmosphere and ocean have warmed, the amounts of snow and ice have diminished, and sea level has risen" (IPCC (2014)). This called for an action on a global scale at an unprecedented level.

The 12th of December 2015 became a landmark date in the world history, at the 21st Conference of Parties (COP [2] 21) that was held, where 195 nations came together to unite and agree on a common framework "to strengthen the global response to the threat of climate change by keeping a global temperature rise this century well below 2 degrees Celsius above pre-industrial levels and to pursue efforts to limit the temperature increase even further to 1.5 degrees Celsius" (UNFCCC (2015)). The IPCC's AR5 was a critical scientific input into this agreement (Schleussner et al. (2016)). Also commonly known as the Paris Climate Agreement, it binds the signed parties into a common cause to initiate, mobilize and strengthen efforts to combat climate change and adapt to its effects, with special support to assist developing countries as well. Before and during the CoP 21, countries submitted their respective comprehensive national climate action plans called Intended Nationally Determined Contribution (INDC) which, among other things, specifies the quantum of reduction they plan to achieve in the emissions intensity per GDP. This means that the economic development and growth which was hitherto allowed to grow unsustainably must now be attained sustainably through lowered emissions as the CO2 emissions are accordingly higher (or lower) as economic growth increases (or decreases) (Mardani et al. (2019)).

In her book Financial Whirlpools, Higgins (2013) explains that in the short term, while the benefits of economic growth are many: the more that businesses and nations grow and profit, the more individuals have jobs, resources and quality of life making the consumers demand more and more. Yet in order to grow, the economy also feeds on natural resources and emits waste that pollutes the air and threatens the delicate climate on which life relies. The unlimited use of natural resources such as coal, oil, gas, land, forests that facilitate economic growth by technological advances undermine the foundational principle upon which economic growth is built and, over the long term, create a sinkhole which will swallow up the economy, environment and society. The economic principle in question is that 'the use of the environment and natural resources should not take place if the costs are greater than the benefits', however globally environmental degradation and resource depletion went too far in violating this principle (Salih (2003)). Therefore, this continued emphasis on the economic growth is diametrically opposed to the idea of sustainable development that nurtures environmental responsibility (Higgins (2013)).

[1] The IPCC is an intergovernmental body of the United Nations, dedicated to providing the world with an objective, scientific view of climate change, its natural, political and economic impacts and risks, and possible response options (IPCC (1998)).

[2] The United Nations Framework Convention on Climate Change (UNFCCC) is an international environmental treaty adopted on 9 May 1992 whose objective is to "stabilize greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system".

The COP is the supreme decision-making body of the convention (UNFCCC). All States that are Parties to the Convention are represented at the COP, at which they review the implementation of the Convention and any other legal instruments that the COP adopts and take decisions necessary to promote the effective implementation of the Convention, including institutional and administrative arrangements (United Nations (n.d.)).

1.2 Sustainable Development

The agenda for Sustainable Development started gaining mass globally after the Brudntland Report published in 1987. As a matter of fact, while the UNFCCC signed much earlier in 1992, it has to be noted that it was expected of all the countries in the world, the developed and developing, to take climate positive action. While this may seem like an equal treatment, there is a lack of equity in the fact that the developed parts of the world had greater role in causing larger anthropomorphic changes than the rest of the world. i.e., industrialisation proceeded in developed countries much earlier than it did in developing countries. This implies the placement of onus on former more than that of the latter. Identifying this, the principle of Common But Differentiated Responsibilities (CBDR) was formalized in the UNFCCC (UNFCCC (1992)).

CBDR acknowledges the economic developmental disparity between the developed and developing regions of the world and therefore denies equal responsibility of all States with regard to environmental protection. Eventually, the States came to an agreement that developed countries contributed more to environmental degradation and should have greater responsibility than developing countries and thus CBDR can therefore be said to be based on the 'polluter-pays principle' where historical contribution to climate change and respective ability become measures of responsibility for environmental protection (Rajamani (2000)).

Over time the United Nations further called for a much larger and participatory agenda for global sustainable development and as a result the United Nations Sustainable Development Goals (UNSDG) was established. They are a blueprint to achieve a better and a more sustainable future for all as they address the challenges faced globally including those related to poverty, inequality, climate, environmental degradation, prosperity, and peace and justice (United Nations (2015)). One of the challenges mentioned above, that is also the primary aspect covered in this thesis, is fighting climate change and environmental degradation through clean energy from renewables.

1.3 Transition to a Sustainable Energy future

The current energy system is dominated by fossil fuels around the world. Electricity & heat production contributes to nearly a quarter, industry contributes to one fifth and transportation sector to one sixth of total emissions of Green house gases (GHGs) (IPCC, 2014). Put together these 3 sectors contribute to nearly 60% of global emissions. The shift to cleaner technologies to lower the emissions and consequently their harmful effects is therefore necessary. Energy security from clean energy technologies is taking centre stage among the discussions at global level for the past few years. And expectations from rapidly emerging economies like China and India are on the rise.

China is the largest polluter in the world and India comes 4th after the US and the EU. China and India combined contribute to a third of all global emissions (Friedrich et al., 2017). However, things are changing in both the countries on this front. With China and India becoming the largest economies in the future, it is imperative that this growth is fuelled by non-polluting clean energy sources. While factors like younger population & skilled workforce, investment hungry climate, growing digitalization across multiple sectors, and increasing renewables deployment favour India, China's advantages are in leveraging economies of scale, favourable Renewables policies, increasing electric vehicle adoption and fast establishing global presence, geopolitically (Alok Medikepura, 2017).

1.3.1 The case of China

China's growth rate is unparalleled in terms of capacity addition for solar PV and wind energy technologies (Nicholas, 2018). It is currently the world's largest producer of wind and solar energy. The Chinese government places a priority on investing in renewable energy primarily because it enables the country to tackle problems of air and water pollution, and mitigate risks of socioeconomic instability (Chiu, 2018). Further, its cities like Shenzhen, Beijing and Guangzhou are implementing electric mobility friendly initiatives to cut down on local air pollution. The city of Shenzhen has electrified its entire fleet of public transportation (of 16,384 buses) and more than 60% of its taxis, both supported through generous subsidies from the Chinese government (Lu et al., 2018). Out of almost 425,000 e-buses worldwide at the end of December 2018, nearly 421,000 were in China. In contrast, Europe had only 2,250 and the US had 300 (Eckhouse, 2019).

Further, in its INDC, China intends to lower carbon dioxide emissions intensity per unit of GDP by 60% to 65% from the 2005 level and increase the share of non-fossil fuels in primary energy consumption to around 20% by 2030, among others (Govt. of China, 2015).

1.3.2 The case of India

In its INDC submitted to the UNFCCC, India mentions that "given the development agenda in a democratic polity, the infrastructure deficit represented by different indicators, the pressures of urbanization and industrialization and the imperative of sustainable growth, India faces a formidable and complex challenge in working for economic progress towards a secure future for its citizens" (Government of India, 2015). Keeping in view its development agenda, particularly the eradication of poverty coupled with its commitment to following the low carbon path to progress, India intends to reduce the emissions intensity of its GDP by 33 to 35 percent by 2030 from 2005 levels and also achieve about 40% cumulative electric power installed capacity from non-fossil fuel based energy resources by 2030, among others.

India's transition to Renewables has begun more than a decade ago with wind power driving the adoption and currently having 35GW of installed capacity. Solar power grew exponentially from 3MW installed capacity in 2008 to nearly 32GW as of April 2019 (Central Electricity Authority, 2019). In 2018, India became the world's lowest cost solar power producer where the average for the total installed costs of utility scale solar PV in 2018 were around $793 per Kilowatt (kW) (International Renewable Energy Agency, 2018)(p.21).

Some of the important reasons why many developing economies like India are embracing Renewable Energy Technologies (RET) like solar and wind primarily because of energy independence and security, reduction in imports and saving foreign exchange dollars, catering to the ever growing energy demand as millions come out of poverty with increasing standards of living, and most importantly enabling energy access to the masses through decentralized energy supply for lighting and cooking (Thapar et al., 2016). Especially in rural parts of the country, enabling energy accessibility through decentralised energy sources primarily driven by Solar PV, India has got millions of its citizens out of energy poverty. Armed with this new confidence, India set a target of achieving 175GW of installed capacity of Renewables by 2022 with a split of 100GW from Solar PV (60GW from utility scale and 40GW from rooftop PV), 60GW from wind power, 10GW from bio-power, and 5GW from small hydro power (Ministry of New & Renewable Energy, 2018).

How far is India from achieving this target? As of April 2019, nearly 78GW of installed capacity comes from the above mentioned RE sources (Central Electricity Authority, 2019).
How big is the 175GW target? Currently the total installed capacity in India is 350GW. 175GW of RE in 2022 implies a nearly 40% of installed power. The Government of India (GoI) in conjunction with its respective state governments has set ambitious targets. Certain states like Andhra Pradesh, Gujarat, Karnataka, Maharastra, Rajasthan, Telangana and Tamilnadu have themselves set ambitious targets of adding more RETs

especially through solar and wind. The Telangana state (TS), in the southern part of India, has progressive solar power policies and has a potential of achieving significant decarbonization levels in the coming decades. For this state, this thesis intends to design and suggest transition pathways for a sustainable energy future by 2040.

1.3.3 The case of Indian Cities

The largest Indian cities are Mumbai, New Delhi, Kolkata, Bangalore, Hyderabad and Chennai, with a population greater than 10 million. There are more than 35 Indian cities with a population greater than 1 million. The top 10 largest cities contribute to approximately 40% of the country's GDP and they are continuously growing (IIHS, 2015). However and this growth is unsustainable. India has 13 out of 15 most polluted cities in South Asia and New Delhi stands as the most polluted capital city in the world for 2018 (Air Quality Index, 2018). The rate of growth of installed RE power is not growing faster than the rate of growth of the cities. As economic engines of a country, city administrations and state governments thus have a responsibility to adopt measures to make their energy sectors more sustainable and cities, more liveable.

While the central government is pursuing ambitious RE targets, some of its cities are still being choked due to pollution from electricity, transportation and industry sectors. New Delhi has made multiple headlines globally in the last one year due to its pollution problem. India still opens new coal plants every year and there are no plans to stop new coal power plant construction at least by 2022 (UNFCCC Report, 2017). In reality, this could go upto nearly 2030 (Interviewee #4). It is not only a problem of pollution and life hazard, but in the bigger picture of use of imported coal and oil, India is losing billions of dollars in foreign reserves which could otherwise be used for its domestic affairs.

Many Indian cities have had a citizen involved participation in programs like 'Swachh Bharat Mission' (and 'Swachh Hyderabad' - Clean Hyderabad) aimed at keeping the cities clean, cleaning plastic waste on beaches, clean up of city lakes, events supporting public health and others. However there has not been an organized campaign and participation in support of clean energy technologies or reduced emissions, in other words, air pollution. The rhetoric has only been limited to scientific community, researchers and certain ministries. Nevertheless, India ranks 5th globally in terms of solar capacity installed and 4th in terms of wind capacity installed. The GoI wants to leave no stone unturned in reaching the 175GW target. With states now leading the way, the competition among them is hoped to bring the best for the country.

1.4 Problem Introduction: The case of Telangana

TS is a rapidly growing south Indian state with high ambitions for decarbonizing its electricity sector by aggressively pushing for Solar PV. Hyderabad, the capital city of the state of Telangana, is a rapidly growing megacity and the fourth largest city by population(>10.5 million) in India (MoSPI Govt. of India, 2018*b*). The current electricity system of TS is dominated by fossil fuels, primarily run on coal. While it has an installed capacity of more than 3.5 GW of solar power, the state also imports nuclear energy and other RE from its neighbouring states which brings the overall share of non-fossil fuel based energy in the total energy generation to nearly 30% as of 2018 (MoSPI Govt. of India, 2018*a*). As a rapidly growing mega-city, Hyderabad, and TS with increasing power consumption year-on-year, it is imperative to have more RE based power in the mix to feed the growing demand and also have sufficient capacity of storage technologies necessary to store this intermittent RE.

However, at this moment, around 6GW of coal power plants are under construction in addition to existing operational 6.8GW. One of the main reasons is the pace at which the demand is growing that makes it nearly

impossible to slow down coal plant construction and the lack of capital needed for storage technologies. Further, the additional RE needed for storage too will need more time and money. The percapita energy consumption of Hyderabad is almost twice the average of that of Telangana and nearly thrice that of India's. The growth rate of electrical energy consumption in the state is the highest in India at 13.6% in 2018 compared to 2017 August (Koride, 2018). Commissioning newer coal plants implies a considerable increase in the emissions from electricity sector for coming decades as well as transportation sector too as it will slowly electrify. And it is this polluting technology that will power the exponential economic growth of Hyderabad as well. Therefore, at these staggeringly high growth rates and given the landscape of India's Paris commitments in 2015, this is not a sustainable way to grow. While the policies of the state promote RE, there is no holistic vision that targets a continuity of sustainable energy supply and reducing emissions.

Apart from electricity, there are two more sources of emissions: transportation and burning firewood.

Emissions from transportation: for example, vehicular traffic contributes to 49% of the primary sources of air pollution in the city of Hyderabad (EPTRI and MoEFCC, 2016). This is an alarming proportion. Therefore, along with emissions from power plants, transportation sector also has to be considered in developing low carbon pathways. However, it will be seen that transportation sector contributes to a fifth of total CO_2 emissions approximately if the entire state is taken into picture.

The use of firewood for cooking has been substantially reduced in TS with increasing LPG connections. However tribal communities still use them in some parts of the state where the communities live in or close to forests(Singh, 2018). However, there are additional developmental problems associated with shifting those communities from conventional firewood to gas based cooking. Since emissions from domestic firewood burning contributes to a tiny percent of total emissions, they will not be considered for now (but they do have a negative impact on the health of the households).

Especially for developing regions in the world, decarbonizing brings a number of additional developmental challenges along with it. One of the most important one often being mentioned is that environmental protection often goes against economic development and this has been discussed earlier in section 1.1. Construction of hydro power projects, highways, coal power plants, etc., affect the environment we live in and have an inevitable impact. Therefore a conscious choice has to be made. While the issue of accessibility for electricity is addressed, both, by GoI and govt of TS, the issue of reliability and sustainability is yet to be addressed. The 'Power for all' (Government of Telangana, 2015) plan by the govt of TS promises to provide continuous, reliable, electricity supply for everyone in a short span of time. However,this comes from a number of new coal power plants being built, which is not a sustainable way to grow. This thesis endeavours to explain how can TS sustainably achieve greater energy security while decarbonizing.

A number of actors need to be empowered by legislation as well as practical pathways have to be developed for sustainable energy. If a meaningful contribution to emissions reduction has to be made, significant shift in fiscal and socio-economic policies need to be ushered to facilitate the transition towards electrification of transportation. Hence it is necessary to assess ways of making the state sustainable in its energy sector. In this thesis, the word energy will be used primarily to convey the electrical energy consumed in electricity and transport sectors. Non-electrical energy consumed in transport sector in the form of gasoline, diesel, CNG and other fuels too will be included in discussions and a distinction will be made when needed. But the focus in this thesis is on electrical energy and the word energy in the research question refers to electricity.

1.5 Research Questions & Objectives

Following the problem introduced in earlier section 1.4, the the primary Research Question (RQ) developed is thus:

"What are the transition pathways that can be developed for the state of Telangana towards a sustainable energy system by 2040?"

In order to answer the above question, a set of following sub-questions are developed. The methodology to study and understand them is also explained.

1. *How is the current energy system organised and how is energy used in Telangana? Who are the major stakeholders involved in this?*

   Objective: This question aims to understand the status quo of current energy system in the state. Further, since participatory backcasting involves engagements and opinions of multiple stakeholders who are involved, it is necessary to study and map them. Further, the legislation that guides the power system will also be studied. This is done from varied literature survey from the portals of the city administration, state and central government publications and Acts passed by the Parliament.

   To understand the prevailing macro-level situation in the state, a PESTEL analysis is proposed to discuss the political(P), economic(E), social(S), technological (T), legal(L), and environmental(E) challenges that make up the system in the location. To understand and analyze the roles of the numerous stakeholders Actor Analysis method discussed by Hermans et al. (2010) will be used.

2. *What are the various types of Renewable energy sources available in Telangana and what are their potentials?*

   Objective: Since a future with high penetration levels of Renewable energy is desired, the study to understand the available potential of various RE sources (solar PV, Wind, biomass, hydro, geothermal) is individually assessed. In the later chapters, recommendations will be made on utilizing every source that can be economically extracted to generate energy.

3. *How is the energy consumption expected to grow in the future?*

   Objective: In developing countries, there is a strong co-relation between energy and economic growth rates. How the future electricity and transport sector's energy consumption will grow is important to be analysed to understand how the future energy demand will look like and how it can be addressed. Therefore, the future energy demand is forecast by studying various factors that contribute to the growth of economy and thereby energy.

4. *How does the system configuration change with respect to increased RETx penetration?*

   Objective: While it is necessary to understand how the configurations change with respect to the desired futures that are envisioned in different scenarios, the main objective here is to build a simple model that will aid the study, analyze, understand and help us make projections to obtain the one future desired vision on which backcasting study is intended to be done. It is done as follows.

   First, the current electricity demand is studied and projections are made for the future time period built on certain stated assumptions. Similarly for transportation sector, fuel demand of petrol and diesel is studied. The current situation of the energy system of the state is obtained. Then projections are made for future total energy demand and percapita demand as well. These projections will be developed as 2 scenarios which will be generated through forecasting, each of which has its specific set

of assumptions. A future vision will be defined based on the inputs received from stakeholders and will be explained with all its key elements.

5. *What are the key recommendations suggested and the transition pathways that will be developed?*

   Objective: The discussions and interviews that were done with the stakeholders will form a key part in answering this question as their inputs will be analysed and the recommendations necessary will be provided. The vision will be backcasted and multiple pathways to achieve it will be explained following which policy packages will be discussed and recommended. The scenarios developed earlier will partly aid in understanding the possible demand levels for the future for electricity and transportation. Thus, what flows from backcasting are the transition pathways.

1.6 Overview

This section will provide an overview of all the chapters that will follow.

Chapter 2 discusses the literature review done, publications referred to, frameworks and theories explored and those that were chosen to be used in this thesis. The knowledge gaps too will be mentioned followed by the academic, scientific and social significance of this thesis.

Chapter 3 introduces the location of the subject of this thesis on the geographical (regional and global), socio-economic and developmental context. The status quo of energy generation & consumption The current policies in the energy sector and specifically renewable energy promotion are further discussed. This sets the context of the what and how of the location that will aid in a better understanding of later chapters.

Chapter 4 discusses the availability of various types of Renewable Energy and the potentials of each of them is calculated.

Chapter 5 discusses about the stakeholders, how they are chosen, who are they and a brief description about each of the stakeholder interviewed is given. The stakeholders are divided into 6 categories and they will be accordingly explained.

Chapter 6 develops scenarios are to understand future demand projections for electricity and transportation sector and therefore total demand is forecast along with the assumptions made which will be explained.

Chapter 7 initially discusses the summary of the main outcomes of the interviews and then discusses the idea of the vision through its key elements, which are derived from them. It starts with the explanation of the basis of developing the vision and eventually the vision is elaborated, along with the targets to achieve.

Chapter 8 analyses the barriers in reaching the vision and elaborately explains them in detail.

Chapter 9 performs the backcasting analysis of the vision and shows 2 possible transition pathways of achieving the same, A_C and A_M.

Chapter 10 concludes by discussing how the research questions were answered, then the recommendations suggested and finally ends with the reflections on the limitations of this thesis research and feasibility of the pathways developed.

2 Literature Review & Research Methodology

> We will never be able to tackle climate change without bringing climate into our culture.
>
> Narendra Modi, Indian Prime Minister

Summary

In this chapter the literature that has been primarily referred to, frameworks and theories that have been used, and the challenges in finding the right frameworks to apply are discussed. The knowledge gaps that led to this research and the significance of this work is explained. The methodology leading to the backbone of this research is explained in detail.

This thesis makes use of literature as well as emperical evidence from stakeholder discussions and interviews. This chapter explains the generic backcasting framework that is employed and the literature referred to. The significance of this research and the knowledge gaps that led to this thesis will be will be explained. A brief overview of the backcasting methodology that is followed, is given with the context of the Research questions discussed in section 1.5.

2.1 Energy Transition

The long-term societal 'Energy Transitions' which have been continuously changing over the course of history are predominantly shaped by economic development, technological innovation, and policies among other factors. While explaining these transitions, sometimes the focus was on energy transition, sometimes on low carbon transitions, or some other times on sustainability transitions (Cherp et al., 2018). This is shown in the figure 2.1 which also shows where this thesis is placed. However overlapping they are, there are significant differences and therefore they are not explained by the same theories. Primarily, changing from conventional coal based power system to a Renewable energy system entails a monumental transition in policy, infrastructure and user behaviour; most importantly they are spread out over a long time-frame. Their management involves sensitivity to existing dynamics and regular adjustment of goals to overcome the conflict between long-term ambition and short-term concerns (Rotmans, J., Kemp, R., Van Asselt, 2001).

The definition of transition is taken from (Grubler et al., 2016), who define an energy transition '*as a change in the state of an energy system as opposed to a change in individual energy technology or fuel source*'. This is justified from the fact that a such deeper transitions involving many different technologies and encompassing national and global scales would be required for mitigating the risks of the climate change and addressing other sustainability challenges.

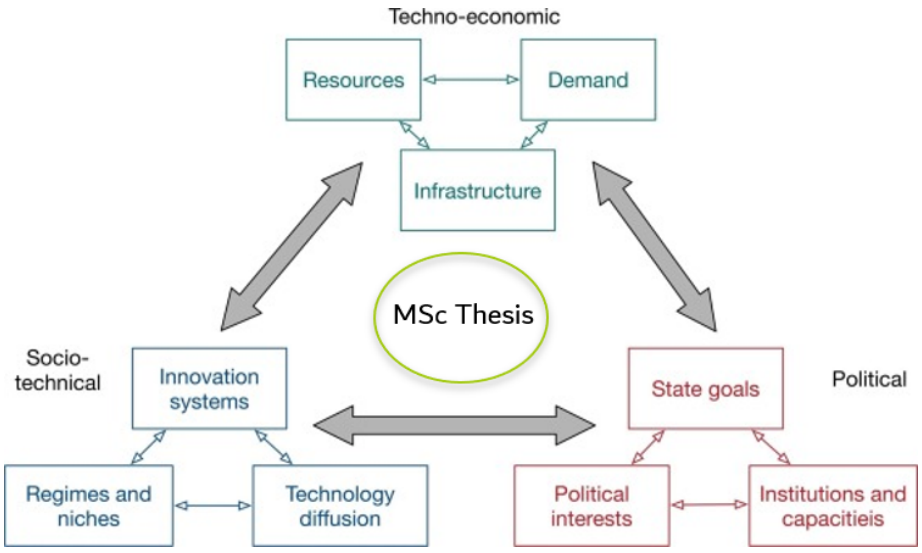


Figure 2.1: This succinctly explains the placement of this thesis and the fields of perspectives it influences and is also influenced by (wrt Energy Transitions). Source: (Cherp et al., 2018).

An increasing number of studies combine different disciplines for transition research (Cherp et al., 2018). Socio-technical analysis is sometimes combined with political analysis like in Kern and Smith (2008), discussed for the Netherlands; Hultman et al. (2011), discussed for Brazil, Sweden and the US specifically comparing nuclear and biomass energy; and in Lauber (2016), where politics and economics of constructing, contesting and reducing the 'socio-political space' for renewables connected to the German Renewable Energy legislation is considered. However, some other times Socio-technical analysis is combined with energy-

economy modelling for future scenario building like in Holtz et al. (2015) where the authors explain how modelling can contribute to understanding transitions & thereby the increasing impact of transition studies. They further explain that models are explicit, clear and systematic, allow to study complex dynamics, and facilitate systematic experiments. Most importantly they emphasize the importance of collaborating with non-modellers and stakeholders and suggest future approaches for stronger participatory co-operation and gaming approaches for decision-making.

Li and Strachan (2017) models energy transitions for UK climate targets under landscape and actor inertia where they discuss the role of quantitative models for assessing the uncertainty in the challenge of achieving climate targets by the adoption of alternatives by the established socioeconomic and technological systems. Dasgupta et al. (2016) quantitatively show in one of their publications for UNU-WIDER[1] that environmental policy, institutions, political orientation, and lobbying on energy innovation significantly affect the incentives to innovate and create cleaner energy efficient technologies.

The use of scenario building to project future energy demands will be strongly employed as one of the methods in this thesis to gain perspectives of a possible future trend in energy demand. While making these projections, certain policies that are anticipated to be in place in future will be considered; along with them, literature and stakeholder inputs too will be made use of in the model to understand the scale of transition that might be needed for the future. The perspective of transition studies is especially broad, covering multiple sectors including inter alia institutions, markets, various types of actors and actor networks, technologies and infrastructures. One of the challenges that Holtz et al. (2015) outlines is that given this broad perspective, models of transitions have to either include many elements and relations making them large and complicated, adopt a comparably high level of abstraction, or purposefully limit their scope of analysis. Given the scope and time involved for this thesis, certain macro-level assumptions will be generalised and therefore a certain level of abstraction will be inherent. Efforts will be taken to make sure that this level of generalisation will not compromise the validity of the results.

While projecting futures through forecasting methods that rely on historical data may give us a picture of the future, by no means it can help us achieve that or even assure that it is a desirable future worth looking forward to. This is where Backcasting methods come into picture.

2.2 Backcasting

Several approaches for strategy and future analysis methods exist such as scenario technique, forecasting, backcasting, Delphi method, to name a few. The objective of this thesis is to explore and develop possible sustainable energy futures for the state of Telangana over a timeline with 2040 as its end point. In this context of exploring sustainable energy futures, forecasting methods are dominant, but the complementary development of backcasting planning methodology is particularly useful when problems at hand are complex and when present time is part of the problem such as sustainability issues (Miola, 2008). The use of backcasting through scenarios is explained here under.

2.2.1 Types of Scenarios

Backcasting can be distinguished from other future study approaches based on the questions they ask and the futures they study. One of the most basic, although contested, concepts in this field is *scenario*. It can denote both, descriptions of possible future states and descriptions of developments. We can distinguish

[1] The United Nations University World Institute for Development Economics Research provides economic analysis and policy advice with the aim of promoting sustainable and equitable development (Dasgupta et al., 2016).

between predictive, explorative and normative techniques studying probable, possible and preferable future. Predictive scenarios study *what will happen*, explorative scenarios study *what can happen* and normative scenarios ask *how a certain target can be reached* (Börjeson et al., 2006). Traditional forecasting applies a predictive scenario approach, whereas backcasting, as mentioned, applies a normative approach (Vergragt and Quist, 2011).

Börjeson et al. (2006) classifies scenarios into 3 types the above mentioned principle questions and each type is further divided into 2 types that is seen in figure 2.2. Predictive scenarios attempt to predict *what is going to happen* in the future and can be subjectively explained through probability or likelihood of the outcome. In this type, *Forecasts* answer what will happen and *What-if* answers the same question, subject to conditions. Explorative Scenarios answer the question *What can happen* through either External scenario method, *What can happen to the development of external factors?* or through Strategic scenarios, *What can happen if we act in a certain way?*. The aim with explorative scenarios is to explore situations or developments that are regarded as possible to happen, usually from a variety of perspectives.

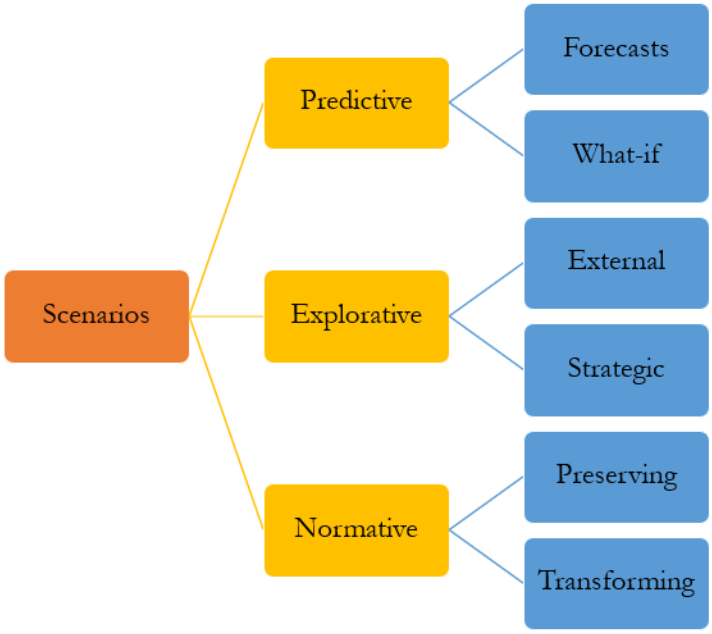


Figure 2.2: Scenario typology with three categories and six types (Börjeson et al., 2006).

Normative scenarios answer the question *How can a specific target be reached?* through either Preserving scenarios *How can the target be reached, by adjustments to current situation?*, or through Transforming scenarios *How can the target be reached, when the prevailing structure blocks necessary changes?*. According to Börjeson et al. (2006), the preserving scenario approach would be appropriate when it seems possible to reach the target within a prevailing structure of the system while the transforming scenarios are more appropriate if a transformation into a structurally different system is supposed to be necessary in order for the goal to be attained. This is the kind of scenario that will be backcast in this thesis.

2.2.2 Why Backcasting?

Saghafi et al. (2013) summarizes Mattson (2000) who suggests that Backcasting and forecasting trends are complementary and that the former is used particularly when the common trends move toward an undesirable state, which in turn was developed through forecasting techniques. That is, if, according to forecasting,

the outlook seems unlikely, the estimations can suggest a Backcasting model which envisions the future or the scenarios of the realization of images (Hojer and Mattsson in Saghafi et al. (2013)).

Conventionally used forecasting method can only be as good as its accuracy and a number of assumptions that can be justified by the limited means with which the forecast is made. This is what Robinson (Robinson, 1990) meant when he mentioned that '...in long-term forecasting, models serve more to display the results of assumptions embedded in the inputs or model structure than to reveal the likely future'. Even with an accurate prediction of a long term future, the question still remains if the prediction *is* the desirable future. Therefore, unlike in forecasting, no estimate of a likelihood is possible since this would depend on whether the policy proposals resulting from the backcast were implemented. Thus we can say that energy backcasting is more closely oriented to the policy process than is forecasting (Robinson, 1982).

Vergragt and Quist (2011) explain that it is a method with a focus on problem-solving, and developed with the purpose of integrating a systemic perspective and long time spans making it very well suited for dealing with the high complexity and uncertainty associated with energy planning. The major distinguishing characteristic of backcasting analyses is the concern, not with likely futures, but with how desirable futures can be attained (Robinson, 1982). Quist and Vergragt (2006) defines backcasting as the creation of a desirable future vision, and then looking back at how this desirable future can be achieved. A sustainable future for TS can be considered as a normative concept and therefore backcasting is equipped to be applied to explore the possible futures.

While TS has a vision that addresses accessibility and affordability of electricity as mentioned in their 'Power for All[2]' document (Government of Telangana, 2015), there is no holistic vision for decarbonization. What can be understood from the document and the current policies in place is that their vision of decarbonization is only driven by adding more Solar PV through utility scale and roof-top. However, these positive effects are undone with addition of greater volume of coal power, which will be eventually discussed in later chapter. Therefore in order to create a vision for a sustainable future, applying backcasting approach with a sustainable electricity sector by 2040, may mitigate the limitations in the current planning and forecasting approach.

While exploring backcasting for electricity sector for China through Renewables, Ng (2009) cites K.L. Anderson (2001) who explains that investigating the use of backcasting for the electricity industry with sustainable development enabled the development of alternative strategy and the facilitation of a more flexible and responsible policy agenda, beyond mechanistic optimization. But Ng (2009) also points out that while China's energy requirements are constantly growing over years and the same is expected (rather forecasted) for the future, there is a question about the continuing pathway not leading to a future that would achieve a sustainable growth. This is a perfectly valid question and this is precisely what was pointed out in Robinson (1982, 1990) when Robinson explained that there is a need to analyse the degree to which undesirable futures can be avoided or responded to and desirable futures created.

2.2.3 Participatory Backcasting

Participatory Backcasting started in the early 1990's in the Netherlands (Quist and Vergragt, 2006). Addressing complex sustainability problems by system innovations towards sustainability requires participatory approaches. Quist (2007) and Quist (2013) explain that such approaches should have a long-term system orientation and take a broad notion of sustainability into account, as well as the social dynamics of complex social change processes. Stakeholder involvement is crucial since not only are their stakes affected, but they also

[2]'Power for All'programme is conceptualized as a joint initiative between Government of India and the State governments. This is a core programme which enables greater co-ordination amongst all the stakeholders concerned. Its objective is to provide 24x7 quality, reliable and affordable power supply to all the consumers within a fixed time frame (Government of Telangana, 2015)

have essential knowledge and necessary resources. Quist and Vergragt (2006) developed a methodological framework for participatory backcasting. It includes 5 steps, not necessarily in that order however there are a lot of iterations in it and there mutual influence between two steps following one to another.

1. Strategic problem orientation;
2. Construction of sustainable future visions or scenarios;
3. Backcasting;
4. Elaboration, analysis and defining follow-up and (action) agenda;
5. Embedding of results and generating follow-up and implementation.

This thesis mainly relies on this framework of Participatory backcasting. Usually while normative assumptions and goals are a part of the first stage sometimes even before problem orientation, however, in this thesis I decided to go in the above order of initially discussing the strategic problem orientation by explaining the economy of the chosen location, its energy status quo, potential of various RE sources, a PESTLE analysis and finally stakeholder analysis. Only after this, a vision is defined and its key elements are explained. Later, scenarios are constructed to explain how possible forecasted futures can look like and then a backcasting analysis is then presented to show how the desirable future (the vision) can be achieved. What needs to be done, Who does what, how it can be achieved are the questions that will be answered. Barriers and drivers to achieve the vision are also discussed in detail.

Eventually the backcasting analysis develops 3 possible transition are all elaborated. The inputs for designing these scenarios comes from a host of literature sources and interviews with stakeholders. In the report, the interviews will be integrated and presented in problem analysis, solutions and scenarios discussion. Step 5 of this framework is not entirely followed and a modification is made. Quist and Vergragt (2006) and Quist (2007) discuss this framework in a sense where they include a broad stakeholder participation (and the use of creativity for moving beyond present mind sets and paradigms as well). And they consider achieving agreement on the normative assumptions among stakeholders involved an important part of the process. Furthermore, this process has a dynamic nature, which means that some stakeholders might leave the process and new ones might join it (Quist and Vergragt, 2006).

While this places a great emphasis on stakeholder involvement in every step, and also emphasizes on Step 5, it has to mentioned that due to limited scope of the work and practical difficulties in travelling to the place, the involvement is kept to a medium level of interaction between them and me in a one-on-one fashion, and in some discussions involving a 3 person discussions. Therefore, after step 3 and 4, continued communication with stakeholders is made and the results are discussed. Four major societal groups can be distinguished: companies, research bodies, government and public interest groups and the public according to Quist and Vergragt (2006). However, in chapter 5, a slightly detailed classification will be shown for the stakeholders involved. Four kinds of tools and methods are distinguished that are employed usually in every stage as and when required.

1. *Participatory Tools and Methods*: Useful for involving stakeholders and generating and guiding interactivity among stakeholders. It includes specific workshop tools, tools for generating stakeholder creativity and tools helping them in specific backcasting activities and tools for participatory vision and scenario construction.
2. *Design Tools*: These are not only meant for scenario construction, but also for elaboration and detailing systems and process design tools.
3. *Analytical Tools and Methods*: These relate not only to the assessment of scenarios and designs, like environmental assessments, economic analyses, but also include methods for process analysis and evaluation, stakeholder identification and stakeholder analysis.

4. *Management, Co-ordination & Communication tools and Methods*: This includes methods for communication, for shaping and maintaining stakeholder networks that originate from the backcasting study and for process management.

2.3 Literature Sources and Data Availability

It has been observed that while there is a large body of work and literature available for India as a whole, there is a deficit of works available for Telangana or its capital city Hyderabad, on the topics that are be discussed in this thesis. A preliminary study was conducted and various sources were looked into for gathering data and research on the themes used in this thesis like Scopus and Google Scholar. It was found that a long vision treatment at a more granular level like that of cities or states was not adequately available. While there is information available at macrolevel (country), there is insufficient solid research or discussion that has been initiated from a multi-stake holder based perspective at cities level. Delhi received a large treatment in this regarding compared to other Indian cities.

A search on scopus for the keywords "backcasting india" gave 2 unsatisfactory results. The same search on Google scholar returned significantly large number of results. However, a major observation that was made was that backcasting was a popular choice made for transportation policy to a large extent and groundwater planning, to a lesser extent, in India. Backcasting was applied to a low carbon future vision too, but it did not include Hyderabad. The search was repeated using multiple keywords and combinations like 'backcast India', 'backcasting energy india', 'backcasting energy hyderabad', 'backcast hyderabad energy', 'backcast electricity hyderabad', 'telangana backcasting' and 'electricity backcasting india'. Backcasting was found to be a popular method for policy making, however, its application was not specifically found for TS in electricity sectors in published literature. However, it was a frequent choice, for example, for transportation sector and emissions reduction development pathways for Delhi (Halcrow Group Ltd, 2008; Saxena, 2012; Woodcock et al., 2009).

A search on Scopus with keywords 'Hyderabad' and 'Energy' yielded 460 results. With the addition of the keyword 'electricity' the search came down to 39 results. The addition of the keyword 'future' brought the number of results further down to 12. Upon analysis, the useful papers corresponded to topics of Roof top PV potential, GHG footprint calculation, electricity quality issues, and water-food-energy nexus. A similar search on Google scholar returned a number of results, with very few directly connected and useful results. However some results are useful which analyze energy efficient air conditioning in buildings and on-site decentralised energy generation for buildings in future scenarios.

Center for Policy Research (CPR), The Energy Research Institute (TERI), Council on Energy, Environment and Water (CEEW), Shakti Foundation for Sustainable Energy, are some of the most prominent research organizations and think tanks that are actively working on energy systems and transitions among other aspects of energy, sustainability and policy in India. There is a vast literature available from them that discusses, analyses and proposes solutions from technical and policy point of view like: (Lamb et al., 2018), (Schwarze et al., 2018), (Archer et al., 2014), (Khosla and Bhardwaj, 2019), (Bhardwaj et al., 2019), to name a few.

The policy documents from the Govt of India and Govt of TS were frequently referred to. Statistical year books and reports from both the state and central govt. like MoSPI Govt. of India (2018*a*), GOI (2017), MoSPI Govt. of India (2018*b*), Directorate of Economics & Statistics (2017), and EPTRI and MoEFCC (2016) were extensively referred to particularly in data analysis and for building the models.

2.4 Understanding Research Methodology

The steps in Participatory Backcasting mentioned in section 2.2.3 will now be explained in detail as to how each step is followed in this thesis.

1. Strategic Problem orientation This step involves the understanding of the status quo of the state through various parameters like legislation, stakeholders, incumbents, use of resources(available and currently in use) and need for a change in status quo (landscape factors). The following questions should be satisfactorily answered in order to to clearly understand the nature of the problem.

   (a) How is the current electricity system in Telangana? What is the legislation in place?

   (b) How is electricity used in the state (sector wise or any other classification as deemed appropriate)?

   (c) Who are the various key stakeholders in the system? What are their roles?

   (d) Who are the incumbents?

   (e) What is the potential of various RE sources in Telangana?

   (f) What are the problems in the current system from the perspectives of (a) Indian Power sector; and (b) climate change?

   From the set of questions mentioned above that are proposed to be explored, it is clear that to obtain the macro-level understanding of the region, it is therefore necessary to make use of 'PESTEL' Analysis framework. A PESTEL review is a multifaceted approach to assess big-picture forces in order to better understand the strategic orientation of an organization and to assist in making considered and informed decisions about its activities. PESTEL primariliy concerns 6 factors: Political, Economic, Social, Technological, Legal and Environmental. Therefore using PESTEL framework helps us best to capture the macro-level situation. It is shown in figure 2.3.

2. Develop future visions

   Following from Research Question 3 discussed in section 1.5 the vision that is desired to be discussed and studied is a future powered by high shares of Renewable Energy in electricity and in transportation as well. A vision is constructed from the stakeholders discussions, literature review and meta synthesis. Since this backcasting is of participatory in nature, understanding the vision, capabilities & limitations of the key stakeholders is necessary if practical pathways are to be developed. The concerns from the government as well as non governmental agencies need to be clearly communicated to avoid misconceptions at a later stage. Stakeholder involvement is a necessity, as sustainable development requires knowledge, support and actions from many actors in all societal groups like business, government, research, public interest groups and the general public, while the impact may affect them too (Quist, 2007).

   Then a forecast of future total electricity demand based on past and present trends is made for every year till 2040. This includes the electricity consumption of all sectors and fossil fuel based transportation. An example is shown below that demonstrates the method explained. One of the fundamental requirements is to calculate the energy demand year by year till 2040 which has to take into account increase in population, increase in economy growth rate, and the subsequent increase in per capita energy consumption, and others. An increase is reflected across all the sectors in the state (Agricultural, commercial, industrial, and residential). For simplification, let us consider an average growth rate of $\beta\%$ for all the sectors. It can be safely assumed there will be a considerable increase in efficiency of the electrical appliances and the industry as a whole, which can be taken as $\alpha\%$. We can obtain the present

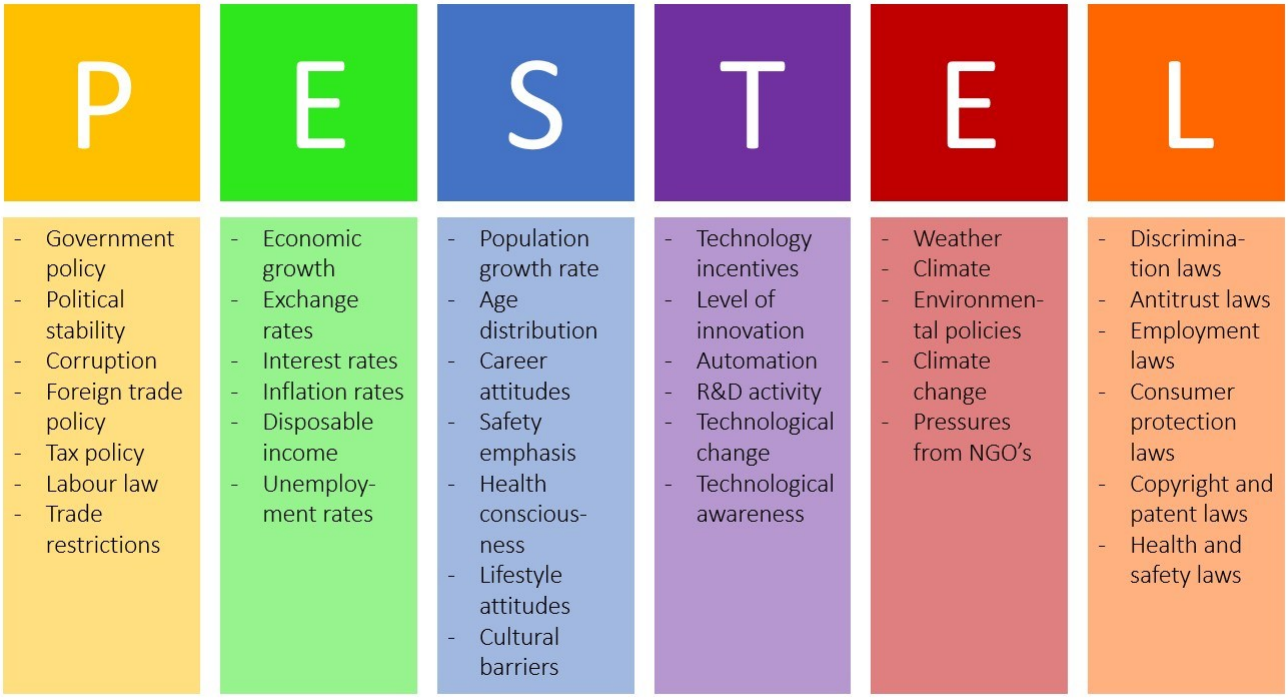


Figure 2.3: An example of the PESTEL Framework Analysis that will be used.

energy consumption value (E_{now}) from literature while the future energy consumption (E_{future}) can be calculated by the following equation:

$$E_{future} = E_{now} \cdot (1-\alpha)^{future-now} \cdot (1+\beta)^{future-now} \quad (1)$$

At $now = 2018$, electrical energy consumed in Telangana, E_{now} was approximately $60.3TWh$. If an α of 3% and a β of 7% is considered, then the E_{future} for $future = 2040$ can be calculated as nearly $137TWh$ according to equation 1. While this basic equation simplifies the complex reality, it gives us an idea of the magnitude of the problem, that has to be addressed more sustainably by 2040.

3. Backcasting analysis

   Now that a vision is established, the next step is to understand how it can be achieved and by whom in what methods. Further, key barriers will be pointed out. To look back from the end point and plan what is required to be done over time. An action plan will be presented that is broken down into multiple time-based steps or time periods (TP) as seen in figure 2.4, which can be understood as targets to be met and goals to be achieved according to the various outcomes as mentioned earlier. This is given as policy package.

   The realization of these short term visions (and subsequently long-term vision) is dependant on a number of factors like political willingness, market push and pull factors, structural and institutional changes, societal acceptance to change to status quo (willingness to cultural and behavioural changes), extent of challenge to the incumbent regime are some of them.

4. Elaborate future alternative and define follow up agenda

   In this step, the actions to be taking to achieve the milestones are detailed. To understand in a birds eye view, 2 major scenarios planned: one with a 75% RE mix and another with a 100% RE mix. From

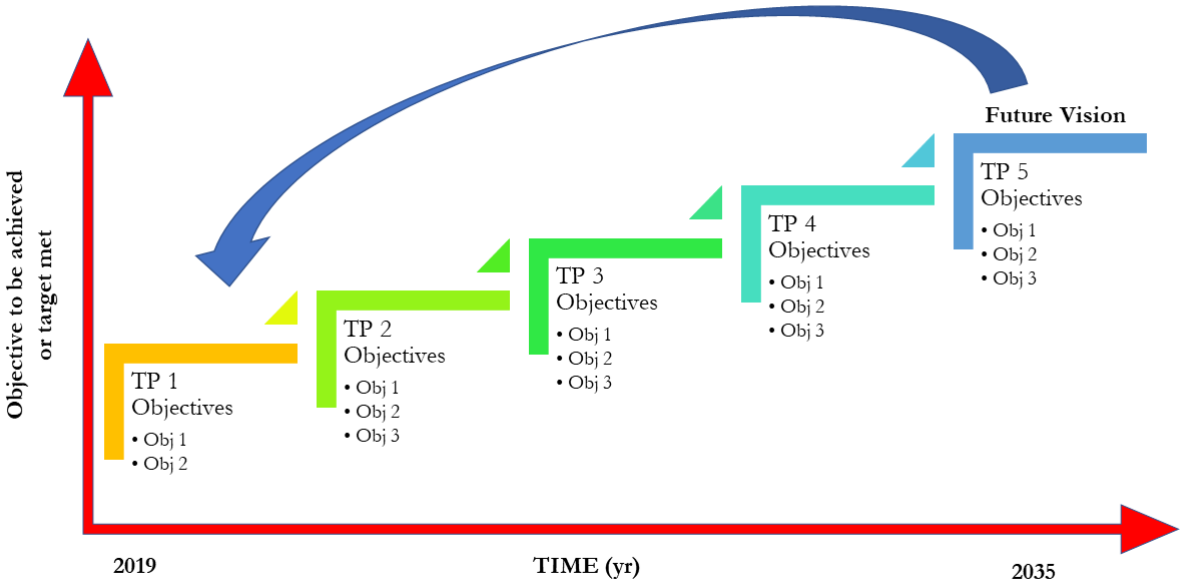


Figure 2.4: Division of a long-term vision into multiple short-term visions in Time periods (TP)

section 7.1 the final vision to be achieved is known and from section 3 what has to be achieved every year or every time period is obtained. But the question that remains is how are the various interventions necessary implemented? What are the pathways to be provided?

In section 3 short term targets planned in every time period were shown. How can they be achieved? For example, for the vision of a 100% Renewable energy scenario, system cannot be deterministically designed for a peak load situation. If this is done, it results in a gigantically sized systems with highly unfeasible economic solutions. It means, the storage and installed power solutions need to be optimized to complement each other and demand side management strategies like load scheduling (deferring certain loads to a specific time periods) or user side changes like vehicle to grid (V2G) during peak load time techniques, etc have to be implemented. Further, home storage systems charge by roof top PV during the say, can help in grid management by lowering the peak consumption from individual load units by consumption from their own storage units instead of depending on grid.

The solutions suggested above are at a large scale and cannot be achieved overnight or over few years. It requires significant changes in policies specifically aimed toward transition to facilitate them over really long time frames. Further, since it is of participatory nature, the results can be communicated to the concerned stakeholders addressed in the thesis to take action. The interviews were performed with prior consent.

Knowledge Gaps & Significance: It can be seen that there is a dearth of literature on backcasting studies for the electricity and energy sector for Hyderabad and Telangana. Such a study has not been undertaken, atleast in published journals so far. While, the government has definitely worked on a energy secure future with a strategy and has outlined it in its Power for All document, as explained before, it is based more on addressing a predicted future demand through more coal powered supply and lesser RE based supply. Therefore, it makes this thesis, the first of its kind study on Telangana considering electricity and transportation sectors over a long timeline through backcasting. It is this particular research gap that this thesis endeavours to focus on.

2.5 Outline of the methodology practiced

Initially the economy of the chosen location was studied and various factors that affect its growth rate were considered. From that, the possible growth rate for energy consumption was derived by relating the both of them. (Since, for developing regions around the world, there is a strong co-relation between energy growth and their economic growth.) Then, the projections of the energy demand were made for electricity and transport sectors till 2040 using the growth rate obtained above. Here, forecasting was made use of to understand the future demand through 2 scenarios. One, a high growth rate BAU scenario and another, a more moderate and an alternative growth scenario.

Interviews were conducted with 13 stakeholders and their opinions were gathered over nearly 2 months. Notes were made during the interviews and 8 of them were recorded digitally (as audio files). They were analysed till a pattern of the vision emerged and a thorough understanding of the barriers was made that inhibit from achieving this vision. Then the relevant definite targets were set and 2 ways of achieving the vision was realised. One which reflected the stakeholders opinions and another, a significantly more ambitious one. Finally, the backcasting analysis was made. The pathways developed through backcasting address only one demand scenario that was forecast, the alternate growth scenario, since backcasting is used for futures that are alternative to BAU.

Part I

Strategic Problem Orientation

3 Location Survey

"By the time we see that climate change is really bad, your ability to fix it is extremely limited... The carbon gets up there, but the heating effect is delayed. And then the effect of that heat on the species and ecosystem is delayed. That means that even when you turn virtuous, things are actually going to get worse for quite a while."

Bill Gates, Principal Founder of Microsoft

Summary

This chapter introduces the location of the subject of this thesis on the geographical (regional and global), socio-economic and developmental context. The status quo of energy generation & consumption and the scope & availability of various types of Renewable Energy types are discussed. The current policies in the energy sector and specifically renewable energy promotion are further discussed. This sets the context of the what and how of the location that will aid in a better understanding of later chapters.

3.1 Geography

The state of Telangana (TS) was carved out of erstwhile state of Andhra Pradesh in 2014 after many years of political agitation. Telangana is in the southern part of India, in the peninsular region on the Deccan plateau with an average elevation of 400 meters. It has a geographical area of 112,077 km^2. Hyderabad, the capital city, has a tropical wet and dry climate with characteristics of a hot semi-arid climate too. It is located at 17.4 N latitude and 78.5 E longitude. At the time of the formation of the state, some sectors in the state economy had negative growth rates and there was power shortage of more than 1000 MW of peak demand.



Figure 3.1: Location of the state of Telangana in India (shown in green)

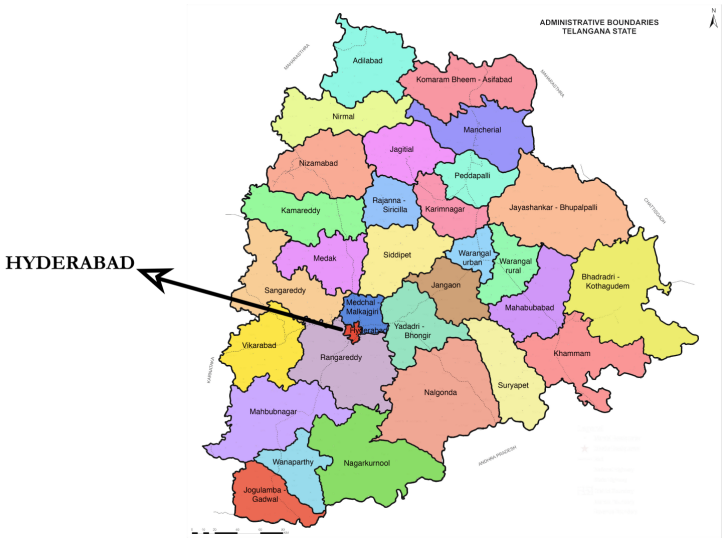


Figure 3.2: Map of Telangana (with 31 separated districts) showing the location of the city of Hyderabad

Over time it has grown progressively and fared generally better than many other states and India average in terms of GDP growth rate, power availability, as well as socio-economic indicators (Govt. of Telangana, 2018) some of which are shown in table 3.1.

Table 3.1: A comparison of Socio-Economic Indicators of Telangana and India (2016). Source: Directorate of Economics & Statistics (2017) and NITI State Statistics Portal.

Indicator	Telangana	India
Infant Mortality Rate (per 1000 live births)	31	34
Immunization (<2 yr)	68%	62%
Life Expectancy (2014)	69 yr	67 yr
Sex Ratio	.985	.943
Fertility Rates	1.7	2.3
Literacy Rate (2011)	67%	72%

Figure 3.3 compares India's and TS's decadal population growth rates. The 1970's and 80's show an indiscriminately large population growth rates that led to the current high population levels in the state. While the annual rate has come down to nearly (or less than) 1%, the current social trends of delayed marriages and

consequent child bearing, fewer number of children per couple and higher migration rates, the population rate is expected to slow down into the next decades.

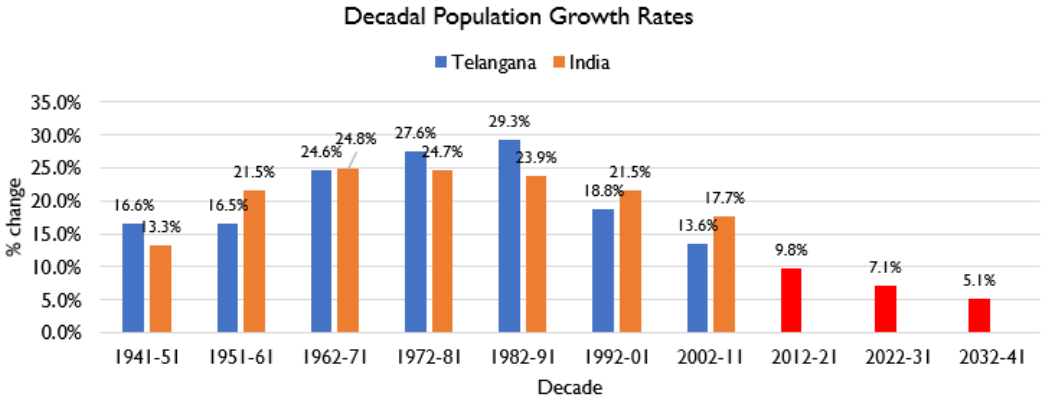


Figure 3.3: The decadal population growth rates for Telangana are compared to that of India from 1941. While the growth rates nearly increased closely, TS has seen a sharp fall since 1992 and this trend is expected to continue. The bars in red project TS's future rates. Source: Directorate of Economics & Statistics (2017) and Office of the Registrar General & Census Commissioner (2011).

Figures 3.4 to 3.7 summarise and capture the climate of the region and explain the radiation, sunshine hours, temperatures and rainfall received by the city. May and April are the hottest months with December and January, the coldest, as seen in 3.6. Summer starts in March, and reaches peak in May with average high temperatures of around 42 deg C. A dry, mild winter starts in late November and lasts until early February with little humidity and average temperatures in the range of 22 - 23 deg C. The onset of south-west summer Monsoon in June can be seen in figure3.7 with increase in rainfall in the mid of June till late September. The average or normal rainfall of the state is about 905.3 mm and about 80% of annual rainfall is received from the south-west monsoons alone during June to September. The rainfall in the state is erratic and uncertain, and the distribution of the rainfall is uneven throughout the districts (Directorate of Economics & Statistics, 2017). A corresponding drop in the average monthly sunshine hours can be noted in figure 3.5 during those rainy months.

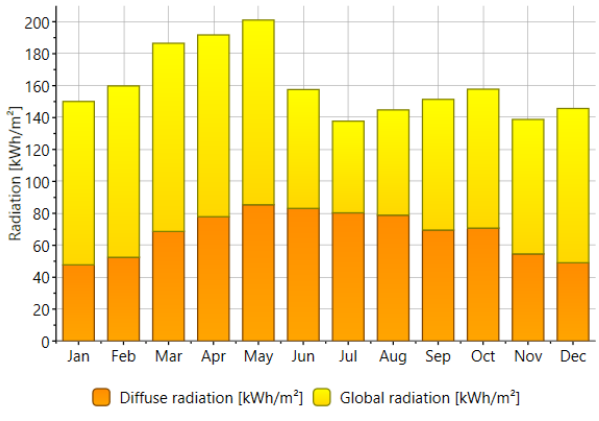


Figure 3.4: Average monthly Radiation. Annual Irradiation received: 1972 $\frac{kWh}{(m^2).yr}$

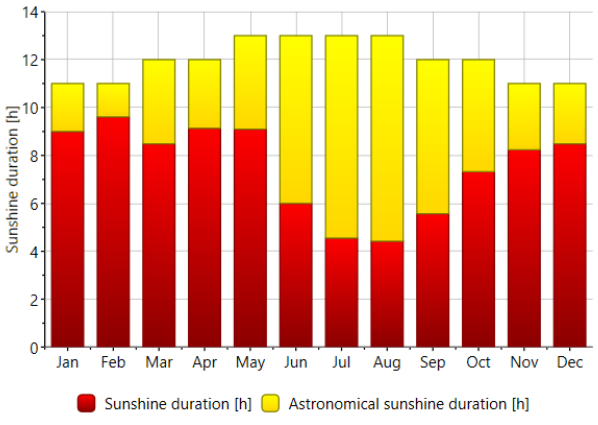


Figure 3.5: Average monthly sunshine hours. Equivalent Sun Hours (ESH) Annually = 5.4

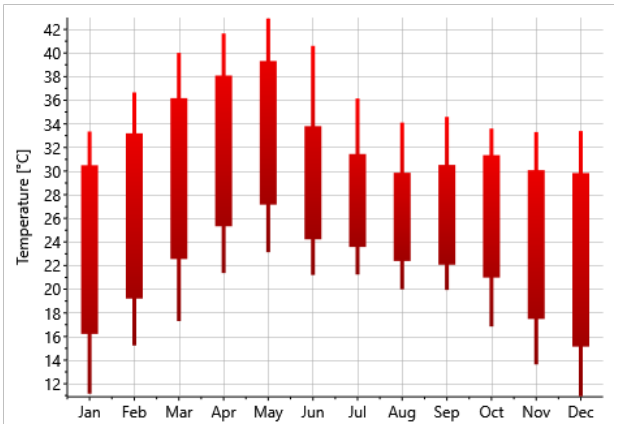


Figure 3.6: Month-wise Ambient Temperatures range.

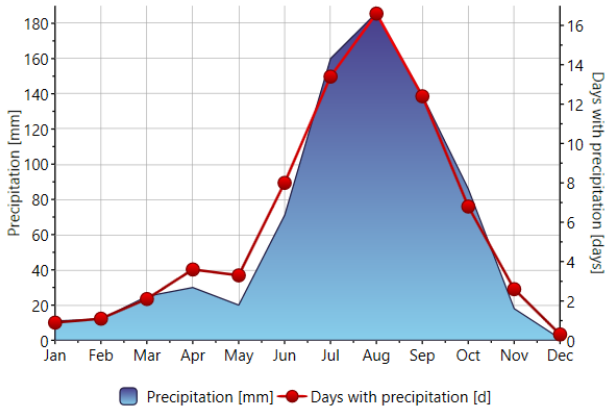


Figure 3.7: Average Monthly Precipitation.

The city of Hyderabad including the Metropolitan region has an area of nearly $7,257 km^2$ and a population of more than 10 million and a population density of $18,480/km^2$ (that is nearly 60 times higher than that of the state's at $312 persons/km^2$). It is at an average elevation of 542 meters above sea level on the deccan plateau with a hilly terrain and a number of artificial lakes constructed since the 16th century.

3.2 Economy

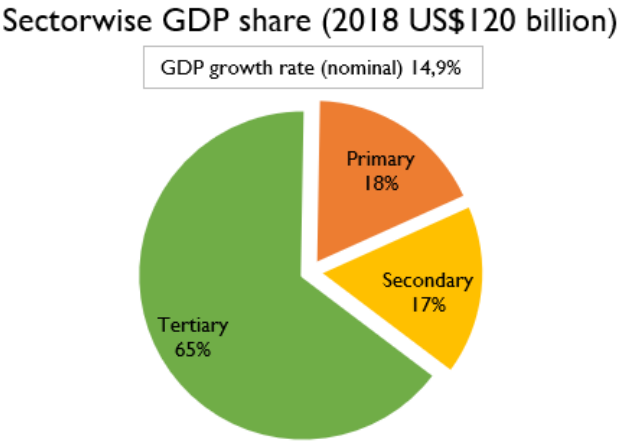


Figure 3.8: Sectorwise GDP share (2018)

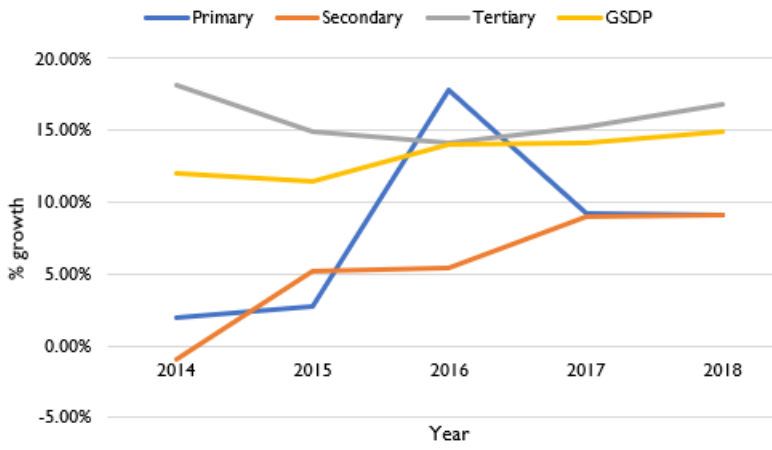


Figure 3.9: Sector-wise growth rates (at current prices)

Telangana's economy has Agriculture, Information Technology, Bio-technology, Textiles and minerals as the major sectors. The state's GDP is around $120 billion and the GDP growth rate is at a massive 14.9% (at current prices[1] during 2018 financial year (PRS Legislative Research, 2018). The nominal percapita income is around US$3,000 and ranks seventh in the country, but Hyderabad's GDP per capita is higher than $5,500 and ranks fourth (MoSPI GSDP Report, 2018). Hyderabad is a fast growing globally relevant city that serves as the pharma & bio-sciences capital of India and a major IT hub in the world. In the JLL City Momentum

[1]The value of anything expressed simply in the money of the day is called as a nominal value. Since inflation means that money can lose its value over time, nominal figures do not explain inflationary distortions. They include inflation changes too, but are not adjusted for inflation. Thus, current price is the value indicated at a given moment in time, and said to be in nominal value. Its opposite, constant prices, are in real value, i.e. corrected for changes in prices in relation to a base line or reference datum.

Index[2] of 2019, Hyderabad was ranked 2 among other cities globally in the world's top 20 most dynamic cities (JLL Global Research, 2019). Figure 3.8 shows the sector wise GDP contribution to economy and growth rates of individual sectors of the state and figure 3.9 compares sectoral growth rates that give an idea of the relative position of different sectors in the economy over a period of time.

3.2.1 Sectors in the Economy

Primary Sector consists sub-sectors like agriculture, livestock, forestry & logging, fisheries, and mining & quarrying. This sector is predominantly labour oriented and majority of rural population eke out their livelihood from it. The performance of this sectors has direct impact on standard of living of rural residents. Agriculture and allied sectors also influences the performance of secondary and tertiary sectors. Nearly 55% of the total workforce in the state is depends on agriculture for their livelihood. Crops grown in the State broadly consist of cereals, pulses, millets, oil seeds, cotton, plantation crops, fruits and vegetables. Non-food crops represent a third of all the crops grown and mainly are edible & non-edible oils, cotton, and tobacco. Overall, paddy and cotton are the most grown (in terms of area) crops.

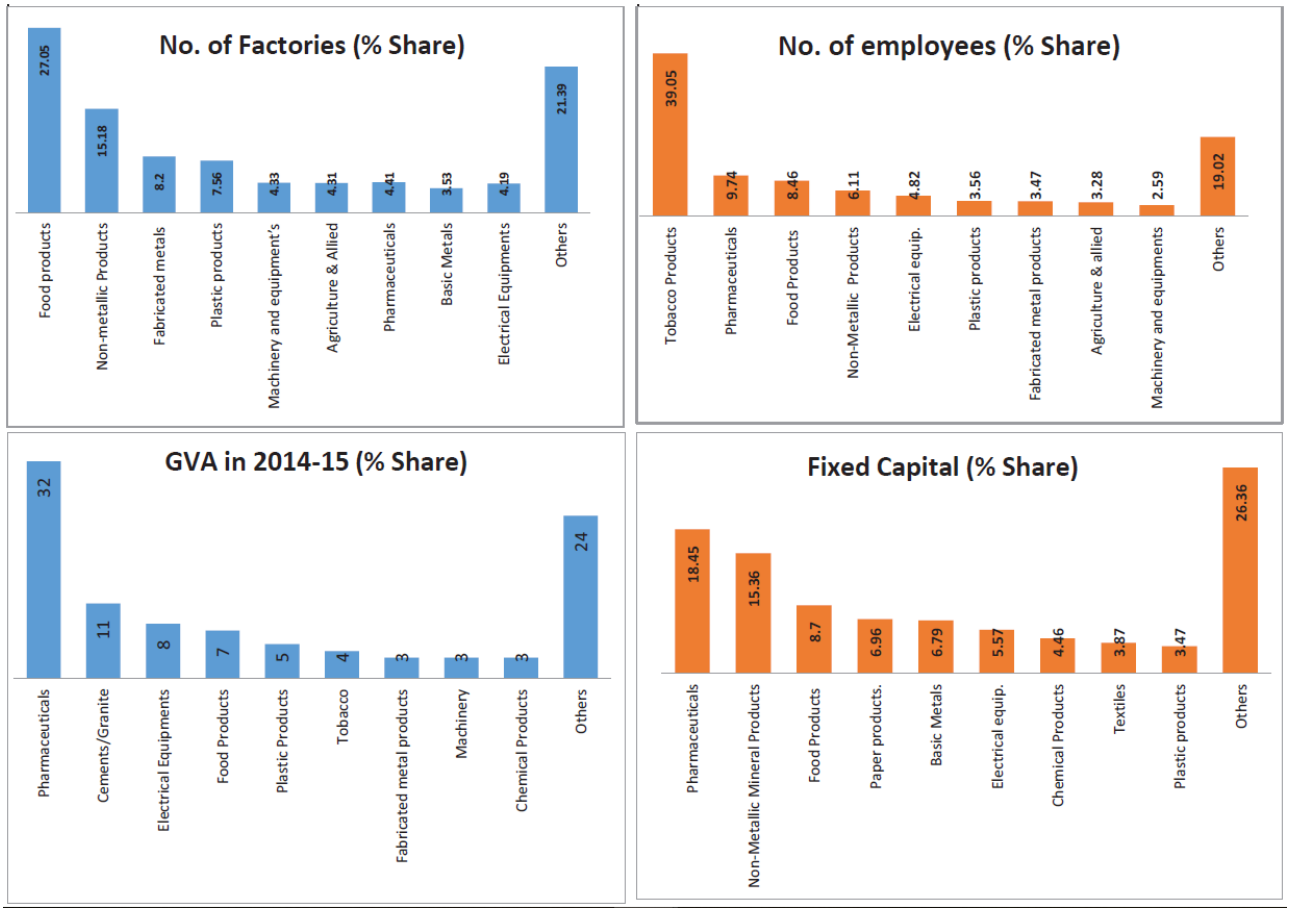


Figure 3.10: An overview of major industries and category wise breakdown. Source: Annual Survey of Industries, 2015

Secondary sector consists of manufacturing, electricity, gas, water supply & other utility services, and construction sub-sectors. The manufacturing of pharmaceuticals, cotton & textiles, non-metallic mineral products, machinery, electrical equipment, TS GENCO (power generation company) and TS TRANSCO (power

[2] It covers 131 major established and emerging markets and identifies cities that have the strongest short-term economic and real estate market momentum.

transmission company) are key contributors for the industrial sector in the State. The growth rates of industrial sector have significantly improved in recent times due to enactment of TS-iPASS[3] industrial policy and increased reliability and availability of quality power supply (Govt. of Telangana, 2018). After the implementation of TS-iPASS, TS ranked first in the state level *Ease of Doing Business Rankings* awarded by the World Bank and Department of Industrial Policy Promotion, Ministry of Commerce.

The major manufacturing units/industries in the state are shown in figure 3.10. The key industries are:

- pharmaceuticals (32%, in terms of GVA[4] and 19%, in terms of fixed capital),
- food products and processing (27%, in terms of number of units),
- tobacco products (39%, in terms of number of people employed), and
- and non-metallic mineral products (cement, granite, glass, ceramic), plastics, and fabricated metals put together (26%, in terms of fixed capital)

Pharmaceutical products contribute to the largest share of 44% followed by organic chemicals at 24% of the total merchandise exports (2017).

Tertiary sector consists sub-sectors viz., trade & repair services, hotels & restaurants, transport - including Railways, Road, Water, Air & services incidental to transport, communications & services relating to broadcasting, financial services, real estate, ownership of dwellings & professional services, public administration, and other services. Major contributors in this sector in terms of value include trade, real estate, IT and ITeS[5], and communication services. There are over 1500 IT & ITeS companies, both large and small, which together employ over 430,000 professionals, besides providing indirect employment to over 700,000 people. The employment rate in this sector is about 16%. The IT exports from TS (which are more than half its total exports) contribute to more than 10% of India's IT exports and Hyderabad ranks second in the country in terms of revenues from IT. The state ranks first in the country in terms of electronic transactions that is in line with the vision of Digital India to move towards a low cash and eventually a cash less economy.

The share of the state's GDP to the country's is 4.37% (2017). Figure 6.2 compares the changes in the GDP growth rates (at constant prices) of Telangana and its neighboring states vis-a-vis India over a 12 year period starting from 2005. It can be seen that the states predominantly performed better than nation-wide average (in terms of GDP). For Telangana, the big drop in 2009 is attributed to the crashing down of the American economy due to the sub-prime lending crisis. It was during this time when a major part of the state's economy (services sector mostly dependent on Hyderabad) was dependent on IT and ITeS and majority of the software companies working with American clientale that resulted in lay-offs in large numbers leading to wide-spread unemployment, and also various other small employed groups that are dependent on this class of people. Further, in the same year agricultural output too took a very sharp plunge which worsened the crisis.

Inflation is measured using various methods depending on the target group, usually by Wholesale Prices Index (WPI) and Consumer Prices Index (CPI). Figure 3.12 compares the CPI of the state and the country over the years. There has been a continuous decline in CPI from 2012 and it can be observed from figure 6.2 that the real growth rate has been increasing after a lowest dip in 2012. It can be implied that the net growth trajectory of the economy has moved decisively to a higher growth trajectory in a short span of time.

[3] TS-iPASS or Telangana State Industrial Project Approval and Self-Certification System is an Act to enable speedy processing of applications for issue of various clearances required for setting up of industries at a single point based on the self-certificate provided by the entrepreneur and also to create investor friendly environment. The process allows a single mechanism for doing business with the state, including obtaining required permissions within stipulated timelines.

[4] Gross Value Added is the measure of the value of goods and services produced in an area, industry or sector of an economy.

[5] Information Technology and Information Technology enabled Services

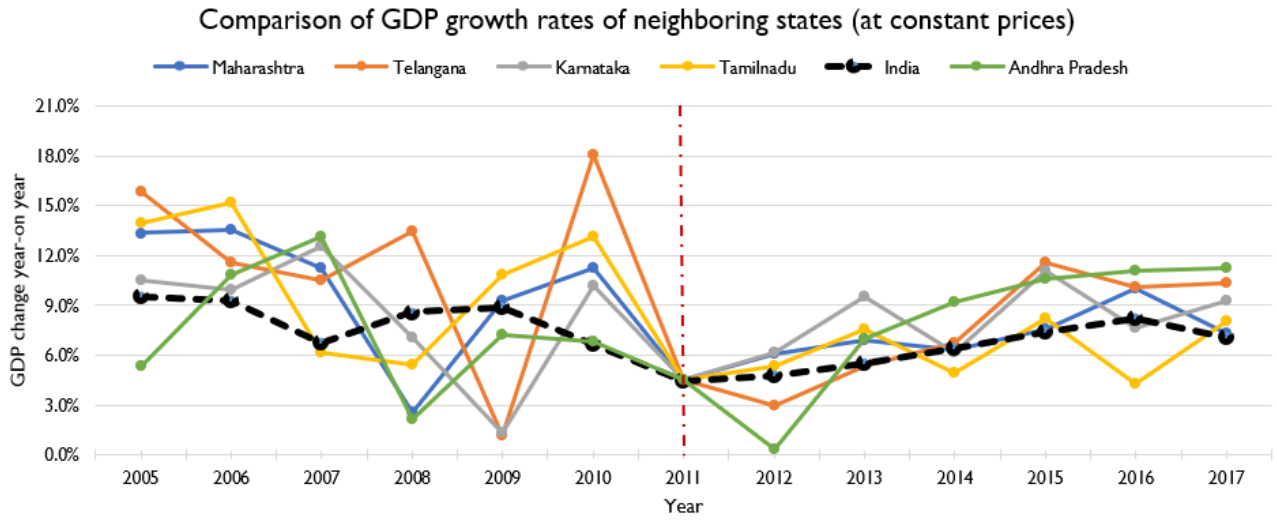


Figure 3.11: GDP growth rates (at constant prices) comparison of Telangana and its neighboring states vis-a-vis India over a 12 year period starting from 2005. The dotted and dashed vertical red line: To the left of it, the base year used for calculation was 2004-05 and to the right of it, the base year used was 2011-12. Source: Reserve Bank of India Statewise GDP Report

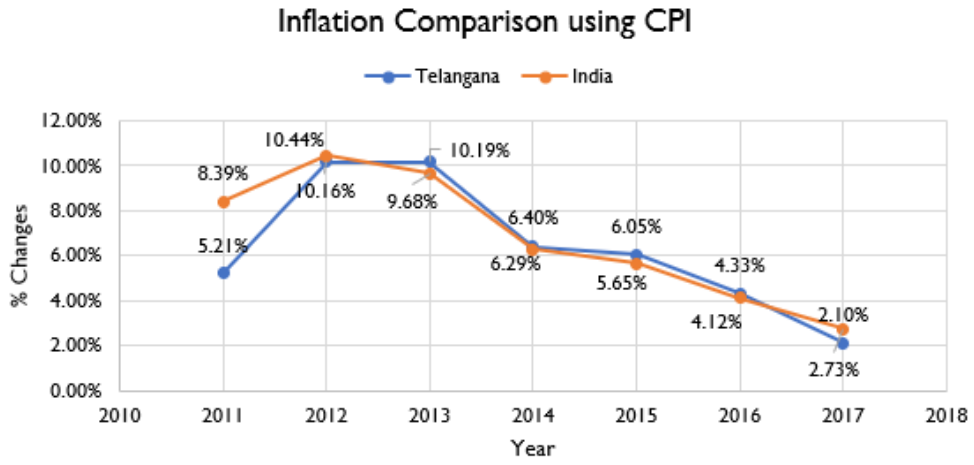


Figure 3.12: Comparison of Inflation measured using Consumer Price Index (CPI) for Telangana and India. Source: Directorate of Economics & Statistics (2017).

Hyderabad is completely urbanized city that extends beyond its district limits into nearby ones. Service sector predominantly drives the city's economy. The city's knowledge economy comprising Information Technology (IT) and manufacturing economy comprising bio-&-pharmaceuticals contribute to its major industries. IT includes ITeS[6], business process outsourcing, entertainment industries, and banking & financial services. After Bengaluru, Hyderabad ranks second in terms of total IT exports in terms of revenues generated (more than $15 billion in 2017) in India (New Indian Express, 2018). The rise of pharmaceutical and bio-tech sectors gave the title 'Genome Valley of India' to Hyderabad. A number of Indian central research and manufacturing organizations in Life and Bio sciences, chemicals, nutrition, agriculture, electronics and defence make it a cosmopolitan industrial service sector. Hyderabad houses the largest number of Special Economic Zones in India (IBEF, 2019). Public transportation is served by a fleet of more than 4,000 buses under the state road transport (TSRTC - TS Road Transport Corporation), Metro train (Hyderabad Metro Rail), and on the ground train services MMTS (Multi-Modal Transport System), together transporting nearly 2.5 million

[6] IT enabled Services

and more passengers every within the city.

It is home to many successful start-ups with a specific focus on deep-tech[7]. India's largest start-up incubator, *T-Hub*, is located in the city and is a public-private initiative between the city government, three educational institutions and the private sector. As one of India's top cities, it has been successful in recent years in drawing high levels of foreign direct investment (FDI), while structural reforms are also encouraging greater interest from foreign real estate investors who are seeking to tap into the country's favourable growth dynamics (JLL Global Research, 2019).

It is the largest city in the state. While there are other smaller cities in the state, none of them are as developed or technologically advanced. Therefore the energy usage is quite different. Out of the remaining 30 districts, only 3 other districts have more than half of urban population. A quarter of the districts have a third of urban population and the rest are prodominantly rural. More than 35% of the urban population in the state is in Hyderabad. The peak power demand in the city was nearly 4 GW (as of May 2019). Transportation and industrial sectors have the largest share in electricity demand followed by commercial sector and in the end, residential sector in the city. There is no agricultural power demand in the city. However, the overall state's energy and electricity shares have agricultural demand as a major share. They are shown in figures 3.14 and 3.13 respectively. The main demand for agriculture comes from irrigation. It can be seen that transportation takes nearly half the total share in energy consumption.

The main sectors of energy in the state are

1. Transportation
2. Industry
3. Agriculture
4. Residential

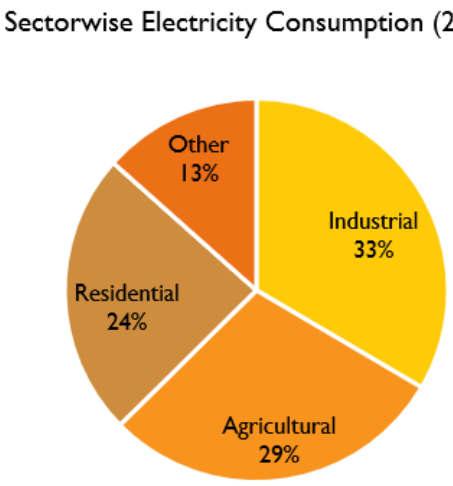


Figure 3.13: Sector wise electricity consumption.

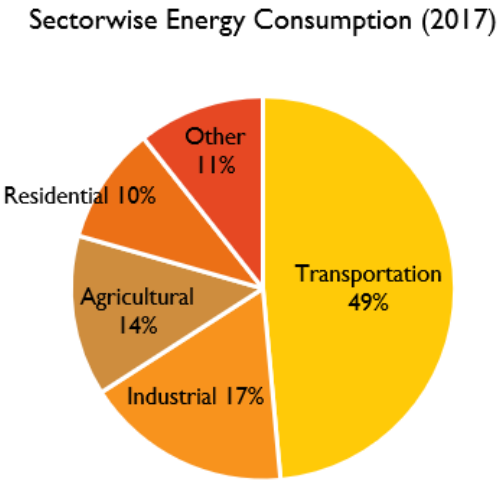


Figure 3.14: Sector wise energy Consumption.

[7]Deep tech, or deep technology start-up companies are based on substantial scientific advances and high tech engineering innovation. They often require longer term, large investments, substantial research, and can take longer for possible commercial success. Because of this, they tend to be much harder for competitors to replicate. Some examples include applications of artificial intelligence and machine learning in agriculture and life sciences, aerospace industry, clean energy technologies, autonomous systems, robotics, etc.

However, in terms of electricity consumption, majority of the consumption in others category is the commercial sector which comprises office complexes, shopping centres and other allied services. The figure 3.15 shows the load profiles of the sectors on a given work day. Load profiles or load curves illustrate the variation in demand/electrical load over a specific time. Generation companies use this information to plan how much power they will need to generate at any given time. The load on y-axis is represented as a percentage of total load of the day to compare the four types and contrast them. The nature of all four sectors varies, with agricultural load peaking at the first half of the day, industrial load being constant during the day time, commercial load being higher during second half of the day and residential peaking at night time.

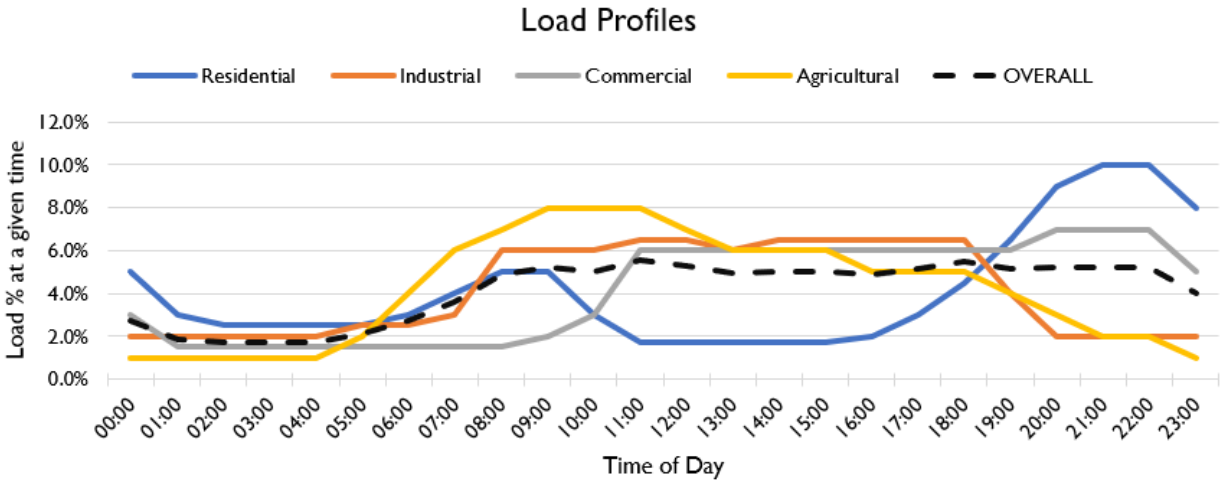


Figure 3.15: Sector-wise load profile on a given work day. The load is represented as a percentage of the total energy consumption of the day. Compiled with inputs from Interview #1.

The electricity sector, as of 2017 is dominated by coal based power. The share of Renewables (primarily driven by solar) stands around 19% in terms of installed capacity. A 150 MW of nuclear power is sourced from the neighboring state of Tamilnadu through a Power purchase agreement (PPA). The total share of non-fossil energy sources as installed capacity is 39% in 2017. However, in terms of generation, coal source contributed to more than 90%. It is seen in the figures 3.16 and 3.17 below. There is an installed capacity of .9GW of a gas power plant. However, due to unavailability of gas, it has been dysfunctional for the last few years. The share of RES generated from sources within the state stands at a mere 7%. The same for 2018 stands at 12.3% (CEEW).

3.2.2 Energy Balance Sheet

An Energy Balance Sheet is prepared for TS for the year 2017. It is an approximate balance sheet that includes electricity and transportation sectors only with coal, hydro, oil, RES, and nuclear energy carriers. It is shown in table 3.2.

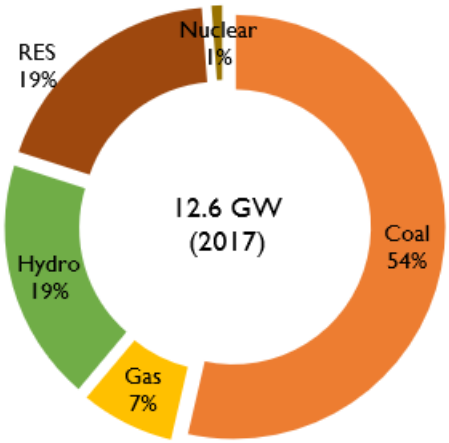


Figure 3.16: Source-wise share of total installed capacities (2017).

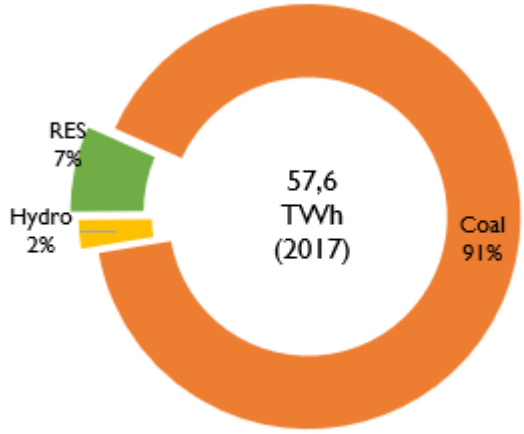


Figure 3.17: Source-wise Share of Electricity generation (2017).

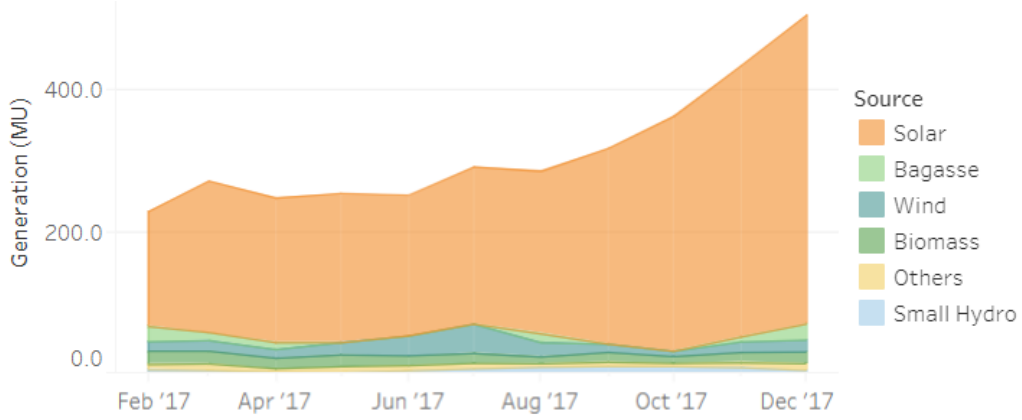


Figure 3.18: The share of PV among other RE in the electricity mix for Telangana in 2017. Source: Prayas Energy Group

.

Table 3.2: Energy Balance Sheet of Telangana (2017). All values are approximated and are in GWh.

	Coal	Gas	Petrol	Diesel	Hydro	RES	Nuclear	Electricity	Total
Production	226,633	-	-	-	1,404	3,859	-	-	231,896
Imports	-	-	17,318	55,337	-	-	-	25,624	98,278
Exports	-135,980	-	-	-	-	-	-	-	-135,980
Stock Changes	-	-	-	-	-	-	-	-	-
TPES	90,653	-	17,318	55,337	1,404	3,859	-	25,624	194,194
Electricity Plants	-25,914	-	-	-	-1,264	-3,473	-		-30,651
TFC	64,739	-	17,318	55,337	140	386	-	25,624	163,544
Transportation	-	-	13,854	31,431	-	-	-	-	45,286
Industry	2,266	-	-	3,695	-	-	-	19,094	25,055
Agriculture	-	-	-	4,776	-	-	-	16,780	21,556
Residential	-	-	-	464	-	-	-	13,887	14,351
Other	453	-	-	2,201	-	-	-	8,101	10,755

3.3 PESTEL Analysis of factors affecting Telangana's Energy sector

?? A PESTEL Analysis will be made in order to explain the internal and external factors in and around the renewable energy ecosystem for Telangana through 6 variables of Political, Economic, Social, Technological, Environmental, and Legal factors. The fundamental constraints and status quo is explained in brief to get a clear picture of the state.

3.3.1 Political

TS has one one of the most progressive solar power policies in India. This flows down from a strong political commitment for clean energy technologies. However wind energy policy is still in the making; while a draft is available since 2016, no action has been taken to take it forward. While the subject of EVs comes under Ministry of Heavy Industries nationally, there is no state specific policy Ministry of Power (2019) yet. There are limited incentives, however, from the central government. Feed in Tariffs (FiT) were removed after implementing for 3 years due to the complexities that arose in their implementation among central and state govt. agencies(Prateek, 2018). However, there is a limited subsidy per annum with varying MW quota for residential and non-residential roof-top PV. There is a carbon tax paid by all industry consumers of coal.

There is a good private sector participation and private ownership of the solar farms instead of the conventional government based ownership. While Power Ministry and MNRE is the top level of the decision making structure at the central government and state designated agencies at state level make decisions, there is less autonomy for municipalities to make decisions (Srivastava, 2018). There are not many politically active lobby and advocacy groups for RE (Interview #13). Majority of the current energy infrastructure is owned by the government and hence there is no strong incumbent to lobby against transition to RE. The government is very stable and strong in the state and therefore enjoys high investor confidence as it has been seen in the past few years. Paradoxical policies supporting both RE and coal power continue to dominate the scene at both state and central level governments to address the needs of growing population.

3.3.2 Economic

As a developing country, there are additional developmental challenges along with pushing clean energy agenda. Governments have to prioritise, optimize and allot funding for agriculture, healthcare, education, industries, infrstructure, etc., in addition. In the recent past, the advantages of decentralized energy generation are better understood and are being pushed forward for better socio-economic development. However, there are some large economic (financial) implications for the government on transitioning to clean energy.

TS has become India's highest percapita electricity consumer. The year-on-year growth rate is around 13.6% for total energy consumed for 3 consecutive years (Koride, 2018). GDP growth rate is above 10% for 2016 and 2017. TS has recently implemented a Renewable Power Purchase Obligation (RPO) for power consumers. Faster Adoption & Manufacturing of Electric Vehicles policy (FAME) provides subsidy per kWh to buyers of EVs. Further, India has become the lowest cost producer of Solar PV at 793 $/kW (Singh, 2019). While this is in the north-western part of the country, auctions[8] in TS too saw similar lower prices.

[8] Auctions here refer to the competitive bidding process in which utility scale solar power projects are auctioned as per the lowest possible cost of energy at which the bidder can sell once the project is commissioned.

3.3.3 Social

Activism on climate related issues in general regarding the sustainability of energy, growing vehicular pollution in the city and electric mobility is very low in TS and is only seen in and around Hyderabad. It is mostly confined to the academic community and NGOs. However, there is activism and civil societies against corruption and pro good governance. Population growth rate slowing down. TS performs one of the better states in terms of socio-economic indicators of education and health in India. The necessary behavioural change for energy efficiency, conservation, DSM, etc is at a very early stage to judge. Domestic rooftop pv sector has the slowest growth rate since a highly cost conscious consumer would stay away from it due to high investment lock in wrt long time normalised benefits. This is also stems from the fact that despite subsidies, roof-top for residential segment is not attractive since the price a residential consumer pays is significantly low and therefore the financial benefits would be marginal.

3.3.4 Technological

Solar and Wind technologies are highly mature and are in a thriving business ecosystem. However storage is yet to catch up with them wrt technological maturity and commercially lucrative ecosystems. The technology involved with bio-gas too is mature and is deployed across the state in multiple small capacities for decentralized uses. The technologies available for Waste-to-Energy are varied and are at different maturity levels. They are constantly growing and improving over time. However, the ones in use are based mainly on incineration technologies which is not the most efficient and clean way of producing energy. While it is solving one problem of waste management, it is adding up to emissions. Further, WtE is highly competitive when it comes to bidding yet a number of them close down every 2-4 years and new ones come up. One of the biggest concerns is waste segregation at source which becomes a complex social and behavioural problem despite the availability of expensive technological solutions.

Due to the availability of other bio-based raw material locally, traditional and low-key technological methods are still in use in some parts of the state. The infrstructure of Transmission and Distribution (T&D) is slowly being upgraded to lower the high AT&C losses. However the TSTRANSCO is in the process of releasing a draft for developing EV charging infrastructure soon. Modernization is being carried out at a number of R&D centres throughout India to be implemented nationwide. TS is not yet a fully mature knowledge/innovation based economy (wrt all the above mentioned technologies) but is slowly becoming one with increasing number of global R&D centers and indigenous research taking place in Hyderabad.

Electric cars are still considered highly expensive and not favoured for use due to the perception of expensive (relative to an IC car), range anxiety, and a real obvious factor being lack of charging infrastructure. However, alternate forms of electric vehicles especially in 3W are on the rise.

3.3.5 Environmental

As discussed in section 1.1, the spurt in economic growth in Telangana (and Hyderabad in particular) is accompanied by a worsening Air Wality Index over the years. An example AQI data for the month of April 2019 is shown in the figure 3.19. Summers getting hotter every year and heat related deaths have been on the rise since the past 3 years. Winds during monsoon season becoming less predictable and more fierce (Naidu et al., 2017).

TS falls in the rain shadow region of south-west monsoon and has perennially been a highly water stressed state. Water use is always mired in controversy and the priority levels for water usage from rivers, canals and lakes is always: drinking water, followed by irrigation and then for energy and industry. Further, due to the

erratic monsoon behaviour, water availability various every year and also within an year. This further implies that hydro-power is less reliable. From figure 3.17, it can been that overall contribution of Hydroelectric power is marginal. It also explains issues wrt usage of mini and micro hydel power projects which are no more getting permits with ease since negative environmental externalities (damage to the marine life, flora and fauna and water usage policies) outweigh the benefits. Also, as a result, Pumped Storage Power projects for Hydro power plants cannot be reliable throughout the year.

Another impact of water shortage is the reducing participation in bidding for capacities in TS in the last one year from March 2018. This has also seen a rise in price per kWh offered in the bids Gleick (2004). India has a policy of pushing for large utility scale Solar farms only on land classified as wastelands (unfit for any other purpose - agriculture or building construction) or non-forest land.

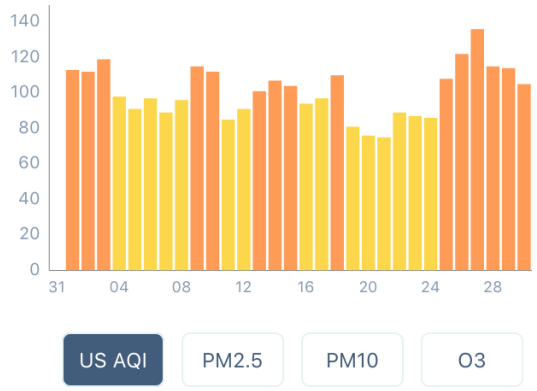


Figure 3.19: The US Air Quality Index for the month of April 2019 for Hyderabad. Source: IQ Air Visual app.

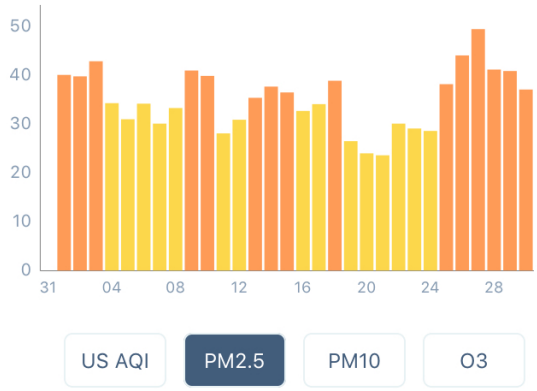


Figure 3.20: PM 2.5 levels in $\frac{\mu g}{m^3}$ for the month of April 2019 for Hyderabad. Source: IQ Air Visual app.

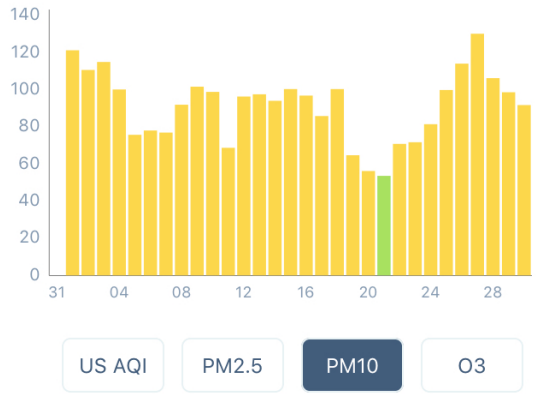


Figure 3.21: PM 2.5 levels in $\frac{\mu g}{m^3}$ for the month of April 2019 for Hyderabad. Source: IQ Air Visual app.

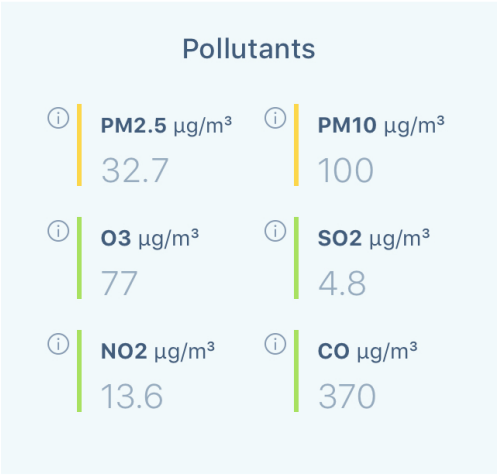


Figure 3.22: General pollutants levels. Source: IQ Air Visual app.

3.3.6 Legal

The value chain of electricity system, that comprises of generation, transmission, distribution, and trading, is unbundled (except for trading) by law. Despite a free market entry in electricity distribution, there has not been any private participation in it due to restrictive legal constraints that limits them from taking a strong decision making (Srivastava, 2018). The rates of private participation seen in Mumbai and Delhi is not seen anywhere else in the country.

The Supreme Court of India has interpreted the fundamental right of Right to Life further as Right to Clean air amongst various other rights and further as a right not to get polluted (Sahu, 2008). Therefore this places onus on the central and respective state Pollution Control Boards to entertain law suits from petitioners or take serious action against offenders.

While the central government plans to make India a hub of Solar manufacturing, the policies in place seem counter-productive. For instance, the introduction of 'domestic clause' which dictates 80% of the components have to be sourced locally (Shadikhodjaev, 2017), for procurement of solar modules to avail any govt benefits has not gone well with most of the companies in India working in the RE ecosystem. Recently the central govt. has created a small list of manufacturers from whom PV modules can be purchased and only then will the buyers be eligible for incentives announced as a part of the scheme. Further there are heavy restrictions on import from China and an additional anti dumping tax of 225% on imported solar panels making it extremely difficult for EPC contractors to procure the necessary PV modules and complete projects on time (Bilal, 2019). Thus, while the intention is to encourage domestic manufacturing, it is crippling the current growth rates.

4 Renewable Energy Potentials

It is not economy versus ecology. Economy and ecology need to go hand-in-hand. Ecologically sensitive Economics have to be crafted.

Sadhguru Jaggi Vasudev, Indian Spiritual Guru and Environmentalist

Summary:

This chapter calculates the renewable energy potentials for different sources available. It will be seen that the potential of Solar PV far outstrips the potential of any other source.

The main sources of Renewable Energy available in Telangana (in the order of abundance) are:

1. Solar
2. Wind
3. Hydro-electric
4. Biomass
5. Geothermal

However, their rates of exploitation is vastly different. The following sections briefly discuss and assess the potentials available for each source. Figure 4.1 below compares the electricity mix for key states in India that have relatively high shares of RE in their total energy mix (till 2019 March). One significant observation that can be made from this is that among the others, TS emerges as an outelier with only Solar PV as the major RE source in comparison with the others that also have significantly high shares of wind energy, small hydro and biomass. It is highlighted in yellow on the left. The total share of RE is 12% in the mix. The figure 4.2 on the right shows the cumulative generation of various RE sources from 2016 till 2019 March (Source: Prayas Energy Group.).

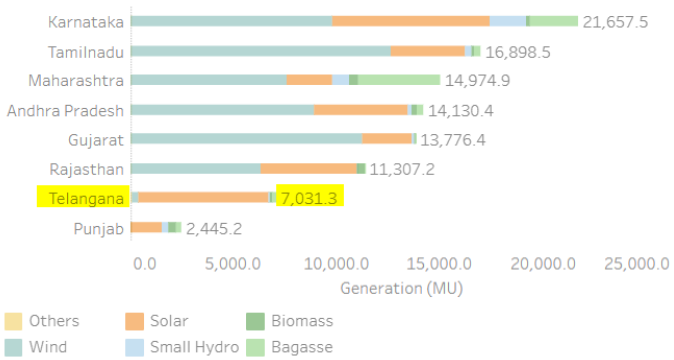


Figure 4.1: Telangana (highlighted in yellow) compared with other states int erms of RE share in total energy mix.

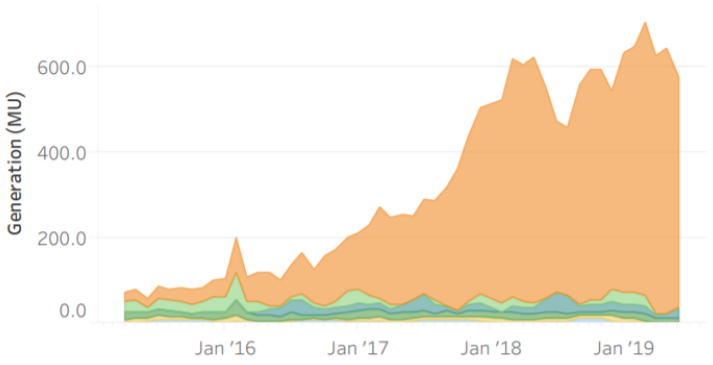


Figure 4.2: The increasing share of PV (in orange) in the energy mix of Telangana from 2016 to 2019 March. The rest of the sources contributed to 1-2% each or lower.

The potential that can be further extracted will now be discussed.

4.1 Solar PV

India receives a very high solar irradiation annually due to its location along the tropic of cancer. There is 28.18 GW of installed solar capacity as on 31 March 2019 in India (Central Electricity Agency, 2019). Of this, over 3.6 GW (or 12.42%) is installed in Telangana including utility (ground mount) and rooftop solar PV. National Institute of Solar Energy(NISE), an autonomous institution under the Ministry of New and Renewable (MNRE), is the apex National R&D institution in the field Solar Energy. It assists the Ministry in implementing the National Solar Mission and to coordinate research, technology and other related works. In 2014, NISE published the solar energy potentials for every state in the country and estimated the solar energy potential (PV) of India at 750 GW (Solar R&D Division (Government of India), 2014). The same

report estimates the SPV potential in Telangana at 20.4 GW. However, this thesis calculates a different and a much higher potential than reported by NISE.

To calculate the assess the SPV potential, first, the annual irradiation received by the module needs to be calculated. Solar irradiance is the power per unit area, received from the Sun in the form of electromagnetic radiation, expressed in $\frac{kW}{m^2}$. The annual irradiation received is the total amount of irradiance over a period of time (in this case one year or 8760 hours), expressed in $\frac{kWh}{m^2}$. 2 independent studies will be discussed, one by Harinarayana and Kashyap (2014) obtained through modelling and another by Solargis which is real values obtained through historical data. Then the values from the both are shown and a particular value for irradiation will be taken from the discussion. Harinarayana and Kashyap (2014) showed through modelling in PVsyst, Google Earth and Surfer software programs the irradiation received for India and Telangana specifically. Their result for Telangana can be seen in figure 4.3. Their model resulted a minimum of $2,000 \frac{kWh}{m^2.year}$ irradiation annually.

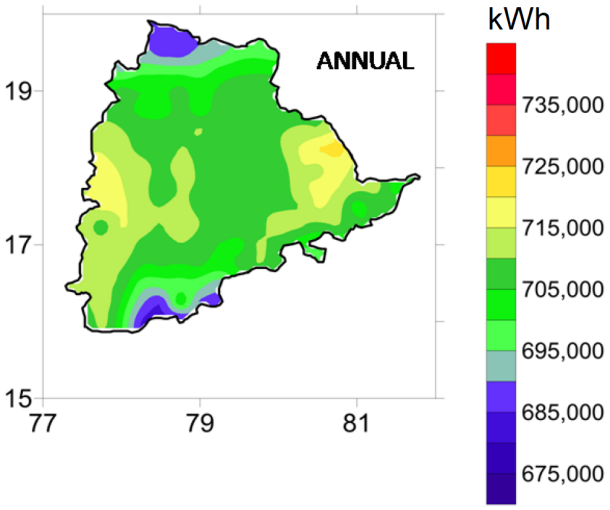


Figure 4.3: Annual Irradiation received for Telangana (the scale in the figure corresponds to kWh per acre). Region with highest value at $2,150 \frac{kWh}{m^2.year}$ and that of lowest value at $2,000 \frac{kWh}{m^2.year}$. Source: Harinarayana and Kashyap (2014).

This value is the total solar energy received by a flat surface over an year. However, for the given location, the modules will have to be placed at a tilt (angle) to receive the optimum amount of sunlight. Then, the surroundings must be understood as well to check the effect of buildings, or other natural objects like trees, or powerlines, etc since they may cast the shadow on the modules or a part of the light received may be blocked by them and therefore generate lesser energy. Then to calculate the energy that can be converted into electricity by a module placed at this angle, we will have to make certain assumptions and proceed. The equations explaining these affects and the calculations that follow are given in detail in appendix A.

The total irradiation received by a module (G_M^{tot}) is the sum of the 3 components: direct, diffuse and albedo. Before discussing about them, 3 definitions have to be explained.

- DNI: Direct Normal Irradiance (DNI) is the amount of solar radiation received per unit area by a surface that is always held perpendicular (or normal) to the rays that come in a straight line from the direction of the sun at its current position in the sky.
- DHI: Diffuse Horizontal Irradiance (DHI) is the amount of radiation received per unit area by a surface that does not arrive on a direct path from the sun, but has been scattered by molecules and particles in the atmosphere. Basically, it is the illumination that comes from clouds and the blue sky.
- GHI: Global Horizontal Irradiance (GHI) is the total amount of shortwave radiation received from above by a surface horizontal to the ground. It includes both DNI and DHI components.

Direct component (G_M^{dir}) received is the product of DNI, shading factor (SF: percentage of the area of module free from shading/covering from trees, buildings or any structures in the surroundings, which can possibly bring down the total energy generated by the module), and the angle of incidence (AOI: AOI is the angle between the surface normal of the module and the incident direction of the sunlight). Diffused component (G_M^{dif}) is the product of DHI and Sky view factor (SVF: The fraction of sky visible to the solar module). Finally, the albedo component (G_M^{grnd}) is the irradiance received by module due to reflectance of light from

the ground on which the module is placed. The values from DNI, DHI and GHI, and the required angles of altitude and azhimuth are obtained from the software Meteonorm. The data obtained is for one location in the city of Hyderabad and is assumed throughout for the entire area in the state.

The next step is to assume a model of solar PV module. Given the climatic conditions of Telangana and owing to the latitude and terrain, mono-crystalline Silicon PV modules are the best possible option. The Indian Solar module market is highly fragmented with no visible market leader or a company with dominant share. Vikram Solar is an Indian multi-national company that manufactures PV modules and EPC of solar installation projects. Their Solivo Grand Ultima module is chosen which has a power output between 340-370 W and has a higher efficiency of 19.1% in comparison to modules of other companies considered like TATA Solar and Adani Solar. The datasheet is given in appendix A. The module is tilted at 15 degrees to the ground and placed. Other assumptions that are made are Balance of Systems efficiency is chosen at 92% that takes into account the losses due to cables, charge controller, inverter and other system losses. A Land Utilization Factor (LUF) of 70% is considered. LUF indicates the percentage of land considered which is covered by the solar modules.

Table 4.1: Assumptions made in the calculations. (Value of albedo is taken from PVSYST Directory (2014) and SVF is calculated from the tilt angle.)

Shading Factor (SF)	Albedo (α)	Sky view Factor (SVF)	Module efficiency (η_{mod})	Balance of Systems Efficiency (η_{bos})	Land Utilization Factor (LUF)	Grid Efficiency (η_{grid})
1.00	0.18	0.98	19.10%	92%	70%	90%

Finally, we come to the area calculation for the PV modules. This is done separately for 3 categories: utility scale/ground mount large solar parks, rooftop and others.

4.1.1 Utility scale/ground mount

In the calculation for utility scale, by law, only wasteland areas are made available for use of solar parks. These are vast stretches of barren regions that are uncultivable due to soil salinity, water logging, desertification, soil erosion etc. Most of these wastelands are unfit for construction of buildings as well. Therefore they are available for the purposes of solar parks. In their state-wise potential report, NISE assumed a 3% of wastelands area for their PV potential calculation. If this is considered, Telangana which has 11,264 km^2 of wastelands gives nearly 338 km^2. This area is calculated[1] by taking the wasteland area from National Wastelands Atlas, 2011 (Dept. of Land Resources and National Remote Sensing Centre, 2011). However, in the assumption for a fresh calculation in this thesis, I would like to consider increasing the area from 3% till 8% to understand the exploitable potential. Following these above mentioned assumptions, the SPV Potential is tabulated in table 4.2. The energy potential per unit area (E_{km^2}) is around 138.4 $\frac{GWh}{km^2}$. The calculation is shown in appendix A.

Table 4.2: The potential of Solar PV that can be exploited on wastelands.

% of Wasteland area considered	Area in km^2	Area as % of total state area	Energy Potential AC side [GWh]	PV needed [GW]
3%	338	0.30%	46,775	30
8%	901	0.80%	124,734	79

[1] This is calculated from the 2011 Wastelands Report of India. The wastelands areas of Telangana districts has been calculated from the Andhra Pradesh state wastelands section of the report, page 36.

Can wastelands area be considered beyond 8% for calculation of the total SPV potential?
There is no information or data available, or immediate or future plans on wasteland management in TS, so far. Therefore, an alternate explanation is provided with inputs from Balasubramanian (2016) as to the reasons why a higher area cannot be considered.

Wastelands are categorized into five types: degraded, salinized, waterlogged, desertified and soil eroded. With increasing population and also an increasing need for more buildings, roads, and agricultural purposes, land requirements will rise and alternate ways to make use of wastelands will be explored in greater depth. Sigificant areas in each of the stated categories has the potential to turn into non-wasteland area if proper efforts are in place. However, some of the following reasons can be considered why 100% of the wastelands cannot be considered as an assumption in the calculation done earlier in table 4.2.

- At least half the total waste lands are non-forest lands which have temporarily become barren and have immense potential to turn fertile again. Therefore, this could either be made into agricultural land or forest cover (to increase the minimum forest cover needed to meet the legal requirements of state to have at least 33% forest area). These lands can also turn into grazing lands for livestock population, if the government decides to do so. This can refer to degraded, desertified and soil eroded categories. Therefore they are not considered.
- Of the remaining land, certain parts have no strength at all to bear any structural load and are too weak to operate. Mainly waterlogged and salinized lands. Strengthening them to use for PV parks would increase the cost of the project and therefore render it less attractive for project developers. Hence they cannot be considered.
- Waterlogged zones are mostly wetlands. These are transitional zones between permanently aquatic and dry terrestrial ecosystems. Wetlands is a collective term for marshes, swamps and bogs. They help to retain water during dry periods, keeping the water table high and stable. Certain waterlogged areas are temporary wetlands which have an environmental value due to its above mentioned ecosystem services that it can render and are often left untouched. Thus they cannot be considered too.

4.1.2 Rooftop

The second potential available is in the form of roof-top SPV for residential and commercial/industrial segments. The roofs of buildings such as residential apartments and houses, commercial and office buildings, educational institutions, hospitals, airports, train stations and others. From Govt. of Telangana (2018) Socio-Economic Report, we have the total area occupied by buildings in the state in nearly 5,600 km^2[2]. Assumptions similar to the ones made earlier are shown for rooftop segment in table 4.3. Of the total area of buildings available, 10% of all the buildings is assumed for the calculation. Can a higher value be assumed? In the future with more research in this area, certainly yes, however there is no sufficient information available on aspects like the shading factors, sky view factors, skyline patterns, structural strength of buildings (to support PV on their roof), orientation issues, etc that can help us understand how well the PV modules can be exposed to irradiation. Therefore, a 10% assumption can be considered valid. With this assumption, the potential comes to nearly 44,124 GWh. This requires atleast 28 GW of PV to be installed to achieve it.

[2] Taken from Page 17, table 3.1: Land put to non-agricultural uses - 7.6% of the state's total geographical area. Of this, buildings are assumed to be accounted for 5% and the rest for roads and others.

Table 4.3: Assumptions made in the calculations for Rooftop PV potential. (Value of albedo is taken from PVSYST Directory (2014) and SVF is calculated from the tilt angle.)

Shading Factor (SF)	Albedo (α)	Sky view Factor (SVF)	Module efficiency (η_{mod})	Balance of Systems Efficiency (η_{bos})	Land Utilization Factor (LUF)	Grid Efficiency (η_{grid})
.85	.25	.75	19.10%	92%	45%	90%

4.1.3 Others

Other possibilities that can be considered are laying PV panels over national highways over a height of 5.7m as suggested by Harinarayana and Kashyap (2014) and floating PV on the lakes, rivers and canals in the state. They make excellent case for solar PV technically since most of the highways and water bodies are free from shadow regions in the surroundings. There are 3,786 km of highways in the state. While some of them are 2 lane, some others are 4 lane or higher. Their widths are 14m and 26m respectively. If 10% of the open area on the highways is taken, the area available is 7.12 km^2. Given the large open area conditions, this can be treated almost as utility scale in terms of area needed per MW. In such a case, multiplying this area with the E_{km^2} the potential comes to nearly 985 GWh (AC side).

The total surface water bodies area is taken approximately at 3% of the state's geographical area (Ferrant et al., 2017) that comes to 3,300 km^2 (Govt. of Telangana, 2018) and if 5% of this area (around 165 km^2) is made suitable for floating PV, then this can add to a further potential of 19,400 GWh. The potential of Others category comes to Here, the E_{km^2} of floating PV is assumed to be approximately 85% of that of utility scale (Singh et al., 2017). The total overall potentials of PV is given in table 4.4.

Table 4.4: Total Solar PV potential of Telangana.

Category	Energy potential (AC side [GWh])	Installed PV needed [GW]
Utility Scale	124,734	79
Rooftop	44,124	28
Others	20,385	12
Total	189,243	118

This potential is significantly much higher than the one estimated by NISE. NISE's includes a module efficiency of 15%, but the module here is above 19%. Further, the NISE report considers that 50 MW_p of SPV utility scale requires nearly 1 km^2 however in the calculation done here, 0.56 km^2 was sufficient to achieve the same. Their calculations however does not explicitly mention the buildings area taken or the total number of buildings.

4.2 Wind Power

India's wind potential was initially estimated around 102GW by National Institute of Wind Energy (NIWE). This was a very low value in comparison to the other studies that were performed which eventually forced NIWE to re-evaluate their methods and publish new estimations. The new estimations show a minimum extractable potential of 2161-2759 GW at a 100m hub height and 2540-2959GW at a 120m hub height (?). Therefore, there's a potential of almost 2000 GW for onshore wind farm with wind turbines at 80-m height and nearly 1000 GW of offshore wind potential (Hossain et al., 2016). Currently 34.3 GW of wind power is

installed across India. A 2 GW off shore project is underway along the western coast of India that is being built with co-operation of EU (FOWPI - First Off shore Wind Energy Project in India).

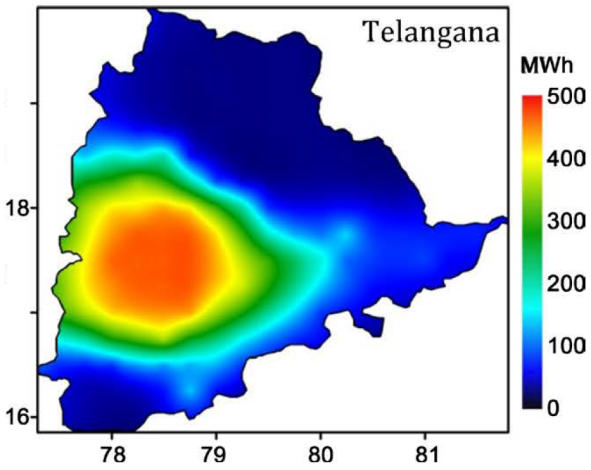


Figure 4.4: Annual Wind energy generation potential (at 75m hub height; per km^2) for Telangana state. Average Capacity factor $C_f = .06$

Wind power potential in Telangana was estimated at 4.2 GW by NIWE. The study by Tank et al. (2016) in figure 4.4 shows that the major wind potential site in Telangana has an annual generation of around 500 MWh over an area of 300 km^2 which translates to an energy density of 1.7 $\frac{MWh}{km^2}$. This shows that the capacity factors are a very low value around less than 0.1 (around .06-.07). Thus, the wind speeds in the region are very low that makes extraction of wind power uneconomical and thus not exploitable. While NIWE's 4.2 GW may be purely a technical value, at a C_f of .06, the energy potential is around 2000 GWh annually. However, so far only 100MW of wind power is installed in the state as on December 2018 (IWTMA, 2018) and (Interview #1). To put the potential in perspective, the state of Tamilnadu that is to the south of TS has a wind energy density of about $1600\frac{MWh}{km^2}$ (Tank et al., 2016). Therefore it is highly economical to exploit it there, unlike TS.

4.3 Hydro-electric Power

India's hydro-electric power installed capacity is at 45.4 GW as on March 2019 (Central Electricity Agency, 2019) and the same for Telangana is 2.4 GW (TSGENCO, 2019). There is a pumped hydro storage facility installed and is operational that can serve peak power of 800 MW. There are smaller hydro-power projects across other smaller rivers with varying capacities from 2MW to 240MW. A 90MW hydro-power plant is under construction. According to MoSPI Govt. of India (2018*a*), the total potential for small hydro is 150MW. The plant load factors (or capacity factors) at which the hydropower facilities are running in the state are dismally low at .07-.09 due to low water availability. In such a case the energy potential comes to 120 GWh. While multiple hydel (very small hydropower) power plants are planned for the future, their execution is unlikely due to the numerous environmental issues they pose and thus the likelihood of their realization is very low. The case for large Hydro is closed in Telangana with 2 large hydropower installations across the 2 major rivers in the state.

4.4 Bio-based sources

In bio-based energy sources, TS has a potential of .5 GW through various sources like agro wastes and residues, Industrial, Urban & Municipal Wastes and co-generation with bagasse. So the potential for electricity from biomass energy (at .85 capacity factor) is 3,723 GWh. Some of the reasons for such low potential is that agro wastes were used as manure on fallow agricultural lands that act as a mulch and provide nutrients back to soil and so they were not made available for either heat or electricity (Raghuwanshi, 2017). Other household and municipal wastes have high moisture content making it less feasible to extract more energy. Methods to make them suitable for energy extraction are uneconomical. While industrial wastes have good potential, municipal solid waste has seen many ups and downs (Vaish et al., 2016). A number of Waste to Energy (WtE) plants have come up but were closed down in 3-4 years due to uneconomic operations. Also, limited supply chain infrastructure at all places and lack of efficient waste segregation at source were cited reasons (Nixon et al., 2017). Biodiesel from Jatropha seeds began successfully many years back but on a large commercial scale, they have failed to provide the necessary calorific values and emission rates and thus biodiesel from Jatropha is not extracted anymore in the state (Interview #8).

Table 4.5: Comparison of various Biofuels (bio-diesel feedstocks) adapted from Mata et al. (2010). Last 2 columns refer to the diesel consumption in Telangana.

	Plant Source	Seed Oil content (% Oil by wt. in biomass)	Oil Yield $\frac{L}{km^2.year}$	Billion litres biodiesel from 100 km^2	Share of 2017 diesel demand	% of State area needed for 2017 diesel demand
1	Corn/Maize	44	17,200	0.002	0.04%	209.42%
2	Jatropha	28	74,100	0.007	0.18%	48.61%
3	Canola/ Rapeseed	41	97,400	0.010	0.24%	36.98%
4	Castor	48	130,700	0.013	0.32%	27.56%
5	Palm Oil	36	536,600	0.054	1.33%	6.71%
6	Microalgae (low oil %)	30	5,870,000	0.587	14.54%	0.61%
7	Microalgae (medium oil %)	50	9,780,000	0.978	24.23%	0.37%
8	Microalgae (high oil %)	70	13,690,000	1.369	33.91%	0.26%

Ministry of New & Renewable Energy (MNRE) has released a National Biofuels Policy to ensure that a minimum level of biofuels become readily available in the market to meet the demand at any given time (Ministry of New & Renewable Energy, 2008) which mandates bio-ethanol and bio-diesel. This is expected to encourage the growth of biofuels. The table 4.5 gives an overview of key bio-diesel feedstocks and calculates the possible fuel amount extractable to serve 2017 diesel needs of Telangana. From the table microalgae comes out strikingly as a highly competitive source, one of the reasons being that they can also contribute to a reduction in land requirements due to their higher energy yields per unit area as well as to their non-requirement of agricultural land. Besides their cultivation is not directly linked to human consumption, they have low space requirements for production. Microalgae reproduce themselves using photosynthesis to convert sun energy into chemical energy,and they can grow almost anywhere, requiring sunlight and some simple nutrients with little or even no attention, using water unsuitable for human consumption (Mata et al., 2010). Therefore, they are a highly attractive option from a practical point of view to cultivate. (Note that this fuel is for transportation sector and the energy is not assumed under electricity.)

4.5 Geothermal Power

Assessment of Geothermal resources was initiated in 1973 in India. Geological Survey of India(GSI) is the prime organisation involved in investigation of geothermal resource (Sarolkar, 2018). India has a geothermal potential of more than 10 GW (Sharan and David, 2017) from all the sites shown in figure 4.5.

Table 4.6: Details of the Geothermal energy location in Telangana shown in figure 4.6. Source: (Sharan and David, 2017)

Location	Surface Temp. $[T^oC]$	Reservoir Temp. $[T^oC]$	Heat Flow $[\frac{kW}{km^2}]$	Thermal Gradient $[\frac{^oC}{km}]$
Khammam dist. (Munuguru)	50-60	175-215	93-104	60

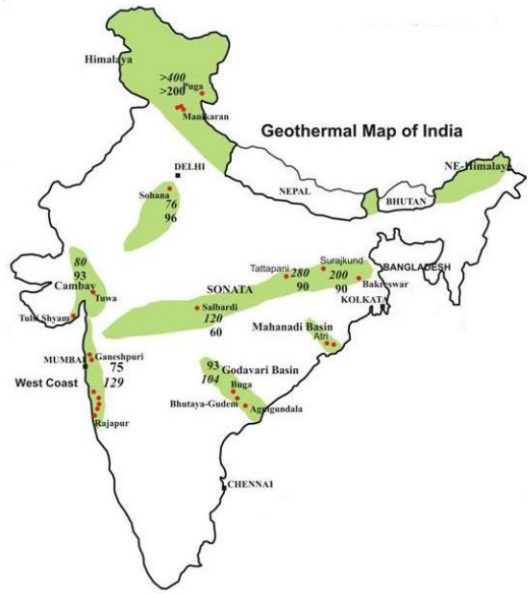


Figure 4.5: Geothermal Energy Locations in India. Total potential: 10,600MW.



Figure 4.6: Location of 150+ MW geothermal potential in Khammam district (in red).

The location shown in the figure 4.6 is the region with a high potential for geothermal power of more than 60MW. In that site, 25MW was planned to be build as India's first commercially extracted Geothermal site. It was guarranteed with a Power Purchase Agreement (PPA), a first of its kind for geothermal power in the country to have executed with India's one and only geothermal company. The Khammam site has a total potential of about 60MW which would be exploited over a period of time. The land required for the 25 MW plant would be just about an acre (Sharan and David, 2017). As per the latest update from Telangana State Renewable Energy Development Corporation (TSREDCO), 135MW more of geothermal power has been sanctioned to be exploited. Therefore, assuming a capacity factor of .6, the total potential is 850 GWh.

The potential for storage technologies is discussed in chapter 8.

Figure 4.7 gives an overview of the overall potentials of the available energy sources.

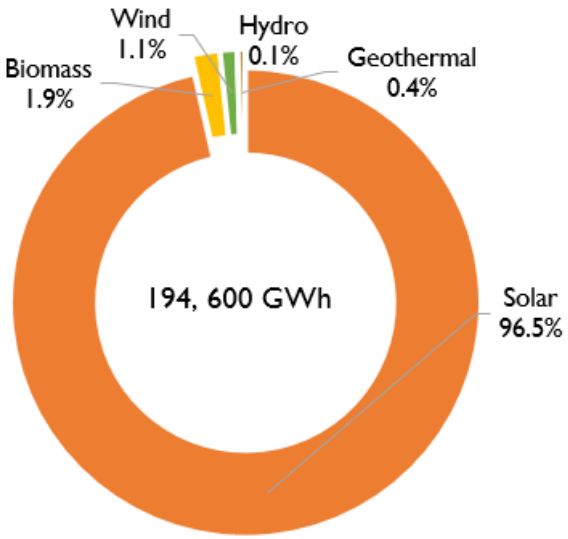


Figure 4.7: RE source-wise potentials available in TS

5 Understanding Stakeholders

"We seriously have to question the motivation of those people referred to as climate change sceptics, who are denying the evidence of human-caused climate change and preventing us from moving forward by spreading disinformation and supporting unchecked carbon pollution."

Kofi Annan, former UN General Secretary

Summary

This introduces and discuss the roles of key stakeholders in the power and transport sector in the state. Further, the supply structure and the related regulatory authorities involved, private and public stakeholders involved are introduced, and their roles are explained. The basis of choosing the actors for interviews is also explained.

5.1 Introduction

Addressing complex sustainability problems requires the participation of numerous entities in a socio-technical system or regime. Socio-technical regimes are relatively stable configurations of institutions, techniques and artefacts, as well as rules, practices and networks that determine the 'normal'development and use of technologies (Smith et al., 2005). These entities are called actors or stakeholders. An actor is a social entity, a person or an organisation, able to act on or exert influence on a decision. However, while it is interchangeably used with 'stakeholder; the latter is used to refer to those groups that have an interest, or stake, in decision making processes, but that have relatively few means to influence decision-making or the system (Hermans et al., 2010). It can therefore be understood that stakeholders are a category of actors. In this thesis, their importance lies in the fact that interviews with them not only give a picture about what is currently happen and what can likely happen in the future, but also show their participation in the future by taking into account their limitations.

5.1.1 Choosing the Stakeholders for interviews

Choosing the right set of stakeholders in participatory backcasting is important to understand the scale of the problem correctly, the capacity to take action, the limitations and future course of action. Moreover, their responses in the interviews can shape the future desired vision and the pathways that can be developed. Therefore, the main question in choosing the right stakeholder is 'Who influences, directly or indirectly, relevant system factors?'. There are various approaches discussed in Hermans et al. (2010) that can help in identifying the actors. Four methods that were employed in this research are given below.

1. Imperative Approach: Identifies actors who feel strongly enough about a certain policy problem or an issue to act on their feelings. It could also extend to 'Who can feel the consequences of the issues around the problem or the solution?'Environmental activists, civil society groups, and citizens fall in this category.
2. Positional Approach: Identifies actors with a formal position in policy making by studying formal legislation and policies in place. It also extends to those who formally operate under such actors.
3. The rest of the actors were chosen by a mix of social participation and opinion leadership approaches. Social Participation approach identifies actors to the extent that they participate in activities related to policy issue by attending meetings or conducting workshops. Opinion leadership method identifies actors who tend to shape general opinion of other actors either through research publications or through action.

It can be understood that, actors identified through positional approach are the most powerful with high stakes involved. Incidentally, they are also the public sector organizations. While choosing the actors from the above approach, it may not be practically possible to approach all the important actors for interviewing. As a result, while efforts were made to approach the important stakeholders, only a few were available for interview. All the chosen stakeholders have a role to play, either directly or indirectly, through policy or through action, on the energy system. The list of actors who were interviewed is presented in appendix C and the concise version of transcripts of the discussions in the interview with questions and answers are also provided in the same.

The next section will start with explaining the organisations that form the major part of the power supply structure in India. After this, the actors in the power sector in TS are explained. In this chapter, a non-exhaustive list of major actors in the energy sector that include electricity, oil & gas and transportation sectors is provided. The organisations, from which the people are interviewed, and their roles, will be explained

eventually. Finally the power flows will be briefly discussed among them. The organisations include both state and non-state actors. Other major actors who play an important role but could not be interviewed are described in the appendix C.

5.2 Power Supply Structure

With the Electricity Act 2003, there was a complete restructuring of Indian power sector with the unbundling of State Electricity Boards (SEBs), privatization of generation & distribution companies (GENCOs and DISCOMs), corporatisation, open access, multiple licensees, etc. Power trading was given a separate identity and power exchanges were established. A National Load Despatch Centre[1] (NLDC) for optimum scheduling and despatch of electricity among the Regional Load Despatch Centres (RLDC) was established. Southern RLDC looks after schedules and allocations inter state level and Central generation stations power for 5 states in southern India. It is also the coordinating agency for SLDCs in respective region. Neither the National nor Regional LDCs have transactions of monetary nature. Further, every state government has State Load Despatch Centre (TSLDC) which will be operated by the State Transmission Utility (TSTRANSCO). This is shown in figure 5.1 (NITI Aayog et al., 2018). This is the primary strategic chain of power flows from a national to much granular level. Telangana's power control is under the Southern RLDC.

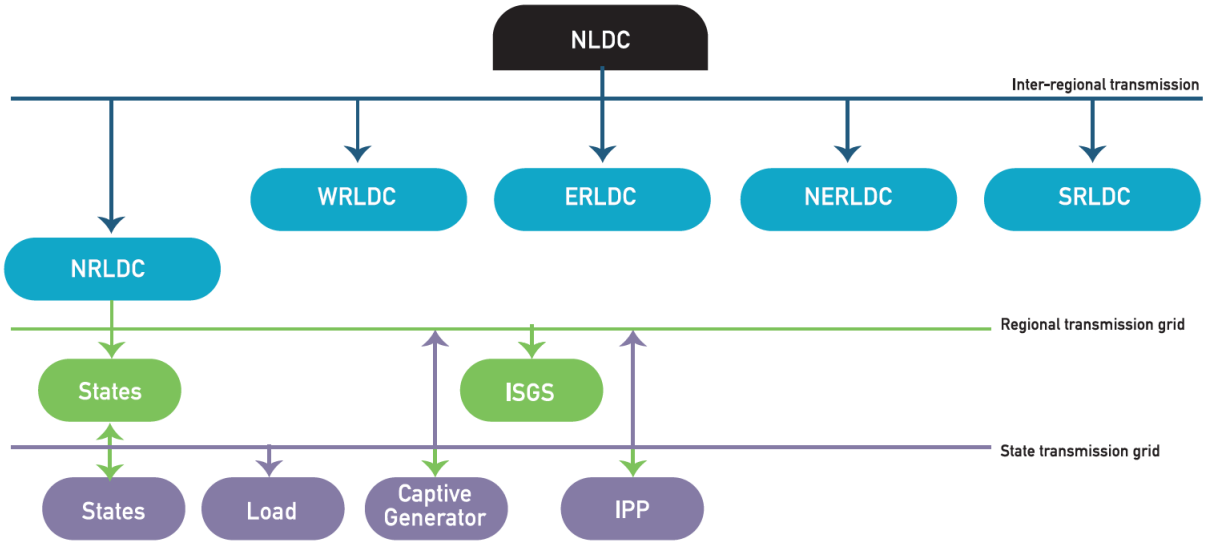


Figure 5.1: Power Supply Structure system operation

ISGS or the Inter State Generation Systems are the power plants that are (usually) established by the central government and a share of power from the installed nameplate capacity is allocated to the states that usually share borders with the state in which the power plant is installed in. IPP or Independent Power Producers are generators of power run and operated by private companies. With increasing decentralised energy sources, there has been a greater interest of private companies in the generation space. But in TS the entire coal power capacity, and 99% of hydro-power plants are owned by public sector enterprises i.e., some of which are central and some others are state government owned.

[1] A Load Dispatch Centre (LDC) is the nerve centre for the operation, planning, monitoring, and control of the power system. Thus, it co-ordinates generation, transmission and distribution of electricity from moment to moment to achieve maximum security and efficiency. It is the equivalent of the Grid Operator

5.3 Power Sector of Telangana

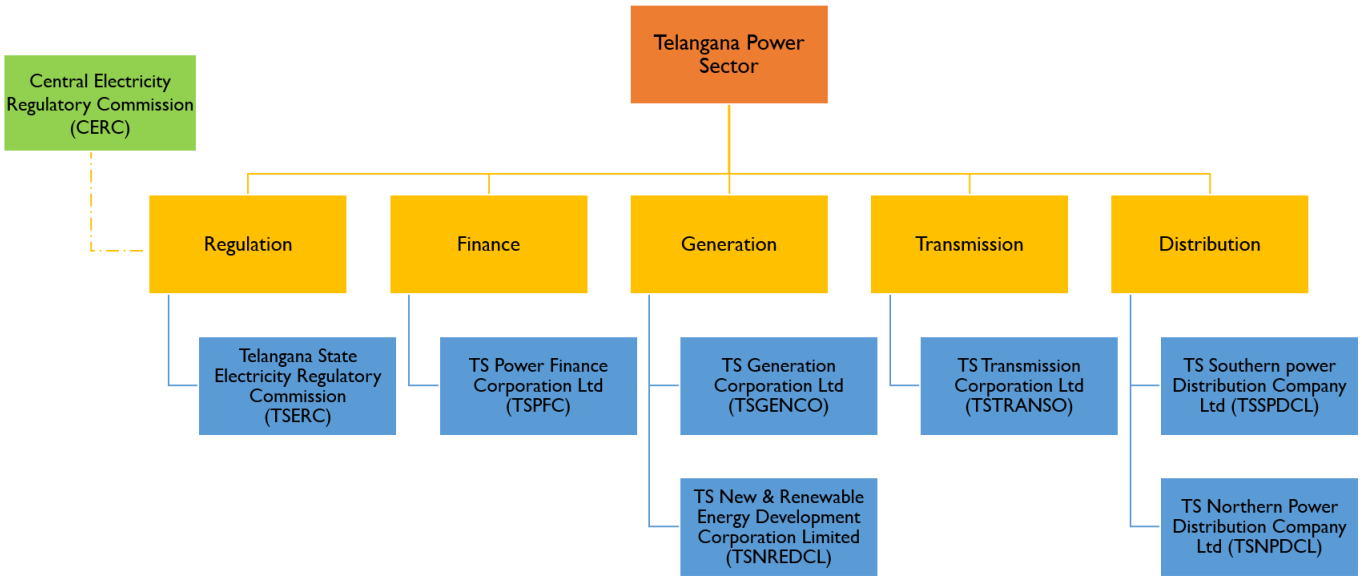


Figure 5.2: Brief overview of stakeholders and institutions at the state level.

The power sector of Telangana is shown in the figure 5.2 where only state government constitute the system in all aspects of the electricity value chain.

TSERC: Telangana State Electricity Regulatory Commission
In all matters of formulating policies, TSERC is the priamry regulatory body in the state. Some of its main duties are to (MINISTRY OF LAW AND JUSTICE (Legislative Department), 2003)

- determine the tariff for generation, supply, and transmission
- regulate electricity purchase and procurement process
- facilitate intra-state transmission and wheeling of electricity
- specify or enforce standards

TSPFC: Telangana State Power Finance Operation
It enables the financing required for projects under state government.

TSGENCO: Telangana State Power Generation Corporation
is the primary company in TS that owns majority of the coal and hydro-electric power plants. It receives the quantum of energy to produce from the SLDC and it generates accordingly.

TSTRANSCO: Telangana State Power Transmission Corporation
is the sole electricity transmission company of the govt. that has the powers of controlling system operations of Power Transmission in the state. It will look after transmission System in state, evacuation of power generating station and supply of power from Extra High Voltage (132 kV and above) till 33/11 KV substations of DISCOMs. There are no private companies involved so far. State load dispatch center at state level which will monitor and control schedule and loads at state level based on availability works under the control of TRANSCO. SLDC also make the schedules/allocation to DISCOMs based load forecast data submitted by DISCOMs on 15 minute intervals.

DISCOMs: Distribution Companies
Distribution of electricity is divided into 2 companies, North and South Distribution companies. Primar-

ily they look into Distribution and Retail supply of electricity. They submit the Day and year wise demand/requirement to load dispatch center for finalization schedules & allocation. Often, state DISCOMS do not work on market principles, i.e., they do not price electricity to cover costs and reasonable profit. In the absence of cost reflective tariff structure, state power utilities are continuously making losses. Political intervention does not allow state commission to timely revise tariff structure (Agrawal et al., 2017).

TSREDCO: TS Renewable Energy Development Corporation
It plans and prepares policies for promoting RE, energy efficiency and conservation programs and is also the R&D promoter of projects.

All above mentioned organisations work as per the directions of TSERC. Given that the state power sector has a strong government role, financing is looked after by companies that are set up by the government itself specifically for activities related to it. DISCOMs and TSREDCO were interviewed from the state power sector.

5.4 Other Stakeholders

The However, to understand the influencing actors country-wide in the overall sector (restricted to the limits of this thesis), the stakeholders mentioned in 5.3 shows the list in classification. The categories shown are briefly explained below.

1. Finance & Banking: Financial capital is needed in significant amounts at the early stage of the beginning of energy transition and this makes financers a very important group of stakeholders. Reserve Bank of India (the central bank) can implement measures or provide directives to other banking and non-banking financial institutions in India that can impact funding for RE and related projects. Public as well as private sector banks have a mandate every year to finance 5% of all the loans that they disburse for Renewable Energy related projects (Interview #10).

2. R&D and Thinktanks: They play a very important role in terms of aiding the government in creation, implementation, and monitoring of policies. There are several such organizations in India, some of the main ones being The Energy Research Institute, The Council for Energy, Environment and Water (CEEW), Centre for Policy Research (CPR), etc. They focus exclusively on issues related to climate change, sustainability, energy, and environment. There are certain public research institutes as well like National Institute of Solar Energy, Petroleum Planning and Analysis Council, etc., which are either placed under a ministry, or operate autonomously, carrying research independently or in collaboration with other national and international organizations.

3. Policy makers: This set of stakeholders are the most important ones with respect to the power they wield (which comes from legislation). While NITI Aayog is India's most powerful government organization that helps in the formulation of policies in all the areas of governance, other institutions like Central Electricity Authority and Central Electricity Regulatory Commission operate autonomously with their attached ministries. They create policies for the power sector in the country at both central and state government levels.

4. Public Sector Companies: They are responsible for designing, building and installing energy technologies, energy efficiency measures and power infrastructure. There are many regional and national companies involved in this process. The public companies of Telangana were explained in earlier section.

5. Industry: This comprises of the private companies operating in clean energy space like MEML; industry associations like NSEFI for solar industry, IWTMA for wind turbine industry, SIAM for au-

tomotive industry, etc. They run businesses, employ more advanced infrstructure (than public sector companies), also do technological R&D for their products and services and generate revenues. They have significant stakes in the policy formulation and implementation.

6. Others: Others mainly comprise academia, citizens and civil society groups. While there are several large universities in the state, and in the country, the interaction with industry and knowledge creation is limited to a very few universities. Civil society groups and citizenry are slowly increasing in number but their influence is significantly small in clean energy space.

Those who were interviewed are described in this chapter and the rest of the important ones who could not be interviewed are described in the Appendix C.

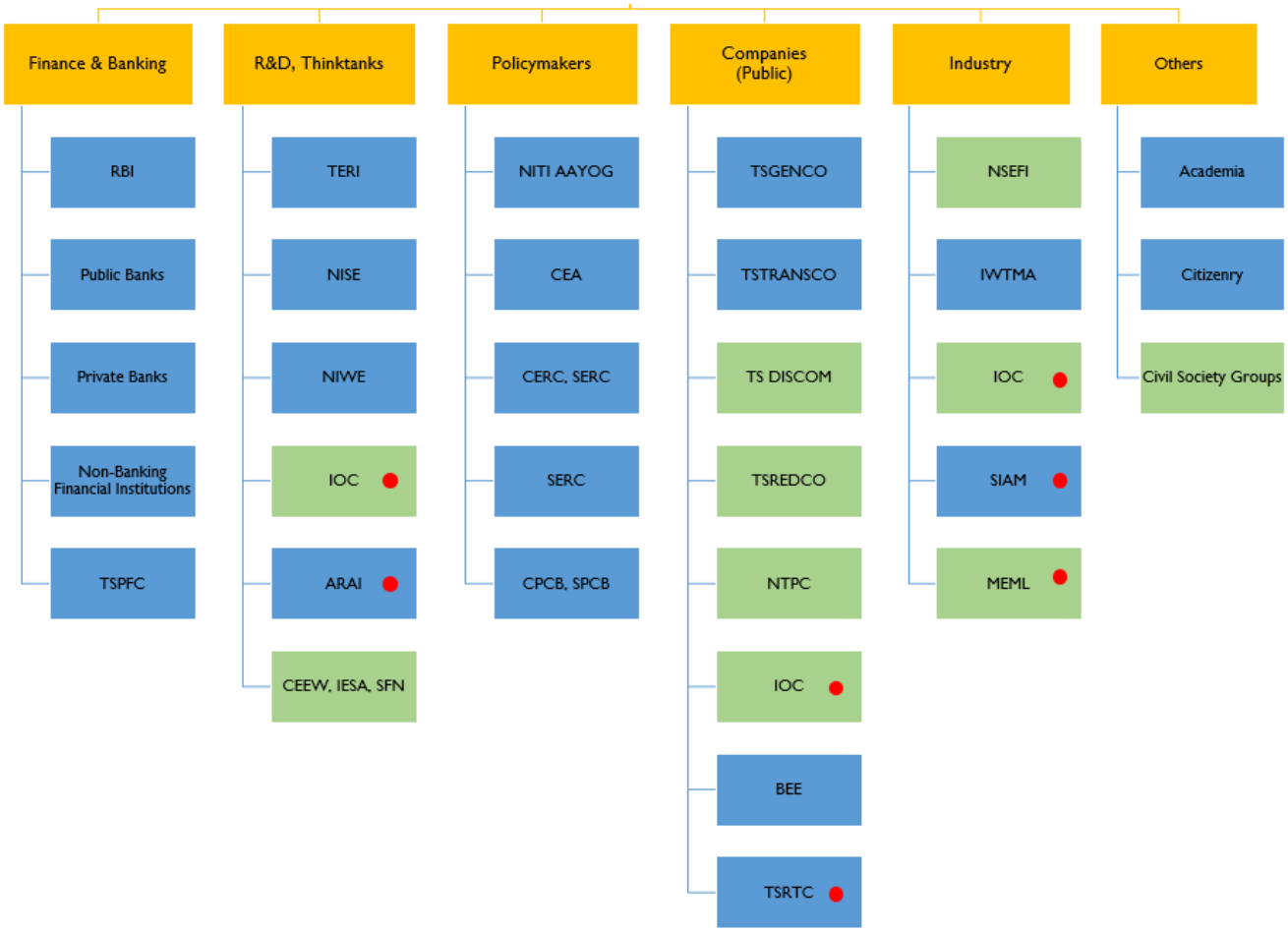


Figure 5.3: An overview of the major stakeholders (non-exhaustive list) who will be discussed throughout this thesis. The actors interviewed are shown in green those with red dots are exclusively in transport sector.

A brief description of the major stakeholders interviewed is provided. They are either directly or indirectly involved in policy making, or are composed actors[2], or operate in the energy space in either public or private sectors.

1. CEEW: The Council on Energy, Environment and Water is an independent, non-partisan, not-for-profit policy research institution, devoted to research on all matters affecting the use, reuse, and misuse of resources. Its reports and research is frequently referred to in terms of policy making.

[2]Organizations that can be involved in the problem situation with more than one of its parts are Composed Actors. For example, Indian Oil Corporation operates in the policy making, research and industry categories.

2. IESA: Customized Energy Solutions (CES) is the founding member and manager for India Energy Storage Alliance (IESA) which is one of the fastest growing energy consulting & services company for the past 20 years. IESA was incorporated in 2012 to assess the market potential of Energy Storage Technologies in India, through active dialogue and subsequent analysis among the various stakeholders to make the Indian industry and power sector aware of the tremendous need for Energy Storage in the very near future.
3. IOC: Indian Oil Corporation Limited is the state owned oil and gas company that owns the entire value chain of petro-chemicals, gas and their products from crude oil refining to sale at retail outlets along with gas. They are also involved in research projects on solar energy, EV charging infrastructure, Hydrogen based transportation, and bio-fuels.
4. MEML: Mahindra Electric Mobility Limited is an Indian company based in Bangalore, involved in designing and manufacturing of compact electric vehicles. It is a part of the Mahindra & Mahindra Group. It is one of the 2 large Indian companies involved in the R&D, production and sales of Electric Vehicles (Cars) in India[3].
5. NSEFI: National Solar Energy Federation of India (NSEFI) is an umbrella organization of all solar energy stakeholders of India. It works in the area of policy advocacy and is a National Platform for addressing all issues connected with solar energy growth in India. It consists of leading international, National and regional companies and includes Solar Developers, Manufacturers, EPC Contractors, Rooftop Installers, System integrators, and Balance of Plant suppliers and manufacturers, Small and Medium Enterprises and works in a complementary manner with the Central and State Governments.
6. NTPC: National Thermal Power Corporation Limited, is an Indian Public Sector Undertaking, engaged in the business of generation of electricity and allied activities. Under the central government, it owns coal power plants in many states across India.
7. PXIL: Power Exchange India Limited (PXIL) is IndiaâĂŹs first institutionally promoted Power Exchange that is a marketplace for buyers and sellers of electricity.
8. NewMo: NewMo is a Strategy, Partnerships, and Investment Advisory firm focused on the world of New Mobility. The person interviewed was chosen mainly as a Subject Matter Expert in this field.

[3]The only 2 Indian companies that have EV models launched in the market are MEML and TATA.

Part II

Developing Future Visions

6 How does future demand look like?

> The saddest fact of climate change - and the chief reason we should be concerned about finding a proper response - is that the countries it will hit hardest are already among the poorest and most long-suffering.
>
> Bjorn Lomborg, Danish Author and Environmentalist

Summary

The possible future demand scenarios for energy is projected for electricity and transportation sectors and various factors that contribute to it are discussed and analysed.

Before we design a desirable future that we want to live in, it is important to know where does the current growth trajectory lead us to. How is electricity consumption increasing? How much energy in transportation is coming from electricity in the next decade? How is fuel oil demand changing and is impacting amidst many global landscape factors? How does total energy demand look like in 20 years from now? What is the quantum of saving that energy efficiency can bring in? Importantly, are we reducing our carbon footprint? The following sections answer these questions.

6.1 Understanding Causality Factors

The energy demand is affected by a large number of aspects in the economy, some within its control and some out of it. Most of the factors considered here are found to only increase the demand for the considered time period. For transportation sector however, there is a change in demand from petrol and diesel to electrified forms of mobility. The net result is a decline due to increased efficiency of the technology and others that are discussed below.

1. *Gross Domestic Product (GDP)*
   It is an important tool to understand a country's or a region's economic status. While not entirely sufficient, the GDP growth rate has become popular over the last few decades and can also be considered as a major factor in looking at future electricity demand for developing economies in the world since there is a direct proportionality between them. Figure 6.1 shows the relationship between the GDP, services sector, and electricity demand. Since services sector has more than half the share in the total GDP of the state, it has significant impact on the electricity consumption. The curve of services sector very closely follows the GDP growth rate curve. It is also seen that in the years with higher growth rate of services sector, there was higher electricity consumption rate. Barring a few exceptions (years), the relationship appears direct and proportional.

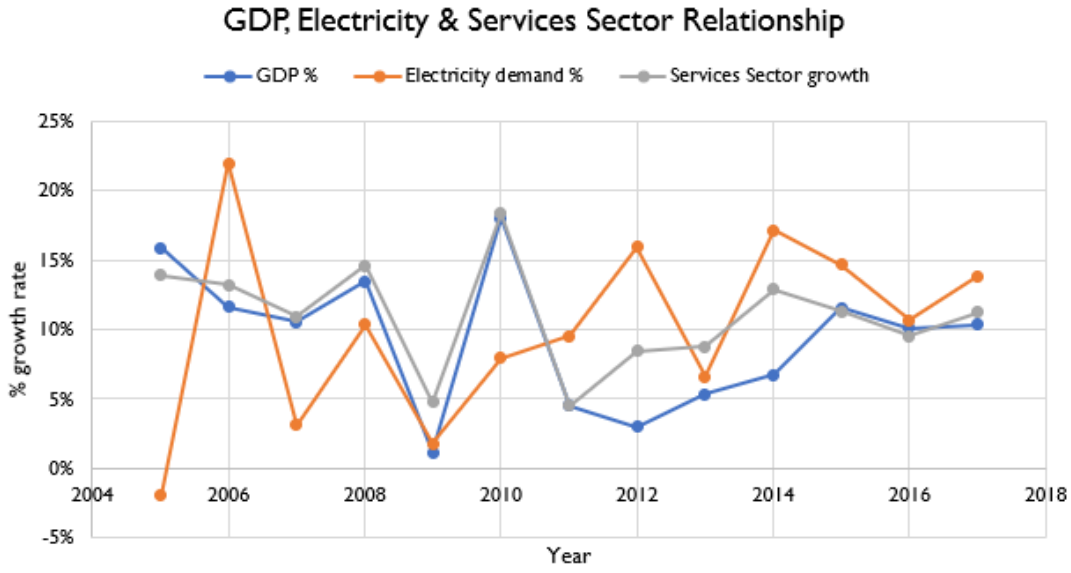


Figure 6.1: The relationship between (i) GDP and Electricity demand rates, (ii) services sector growth rate and electricity demand can be seen. Compiled from Directorate of Economics & Statistics (2017) and Reserve Bank of India State Wise GSDP Report, 2018.

   The ratio of energy consumption to gross domestic product, or the 'energy-to-GDP ratio' (EGR), is a widely used energy indicator in energy policy formulation and analysis. This relationship has been

studied extensively (Ang and Goh, 2018) and (Ang, 2006; Ang and Goh, 2018). In other words, it explains how energy efficient an economy is by detailing the quantum of energy consumed to create one unit of GDP. India's 2015 EGR is nearly 4.73 $\frac{MJ}{\$}$ and that of the Netherlands is 3.93 $\frac{MJ}{\$}$ (at 2011 $ PPP GDP) (World Bank et al., 2018). Another way to explain it is to use the monetary energy intensity which is the total energy use divided by the (gross) value added (Blok and Nieuwlaar, 2016). It can be used either for a company or a sector, like manufacturing sector where it is most popularly used. It is used for a nation's economy where it is usually referred to as energy intensity of GDP. In nearly all countries, energy intensities have decreased over time.

The EGR has often been used to represent the energy efficiency or productivity of a country. While it is relatively easy to compute and understand, it also suffers from the drawbacks[1] of being too aggregate and overly broad in context. Nevertheless, it is a highly useful tool in the current context. A decrease in the ratio over time indicates that a country (or a region) uses less energy to generate a unit of GDP (Ang and Goh, 2018). The EGR tool is modified to suit here by adopting Electrical Energy to GDP Ratio as an elasticity factor. This value is multiplied with the GDP rate to eventually obtain a growth rate for energy. Here, it can be defined as the relative change in electricity consumption divided by the relative change in GDP growth rates as shown in equation 1.

$$e_{E\text{-}gdp} = \frac{(\Delta E/E)\%}{(\Delta GDP/GDP)\%} \tag{1}$$

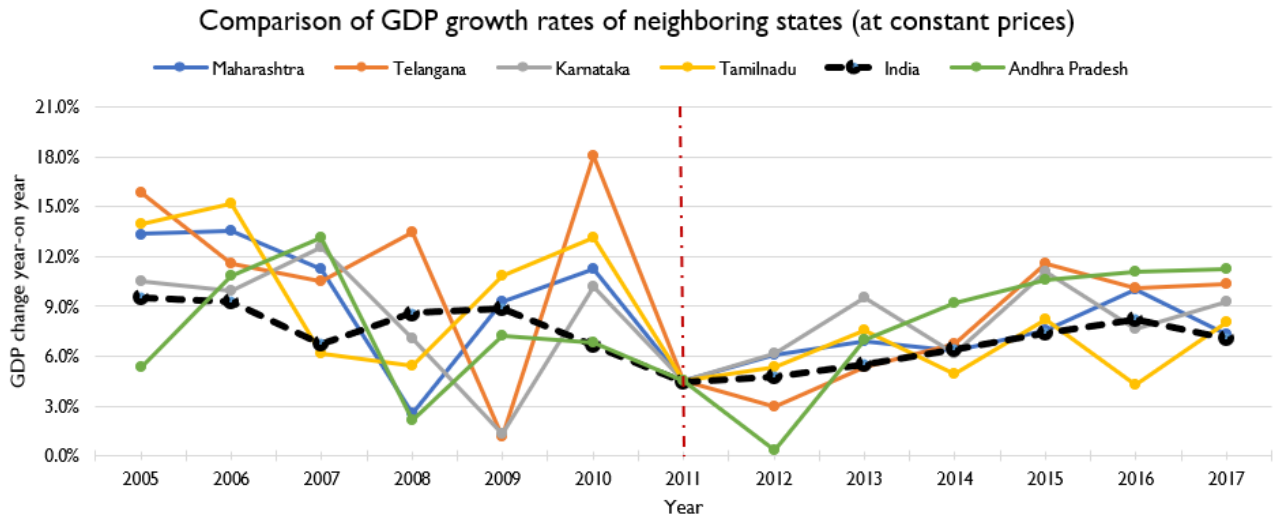


Figure 6.2: The figure compares the year-on-year changes in the GDP of Telangana and its neighboring states vis-a-vis India over a 12 year period starting from 2005 (at constant prices). The dotted and dashed vertical red line: To the left of it, the base year used for calculation was 2004-05 and to the right of it, the base year used was 2011-12. Source: Reserve Bank of India Statewise GSDP Report, 2018.

GDP growth rates are considered at constant prices. The figure 6.2 compares the GDP of a few well-performing states similar to that of Telangana along with that of India's. It can be seen that these states predominantly performed better than nation-wide average (in terms of GDP). For Telangana, the big drop in 2009 is attributed to the crashing down of the American economy due to the sub-prime lending crisis. It was during this time when a major part of the state's economy (services sector mostly dependent on Hyderabad) was dependent on IT and ITeS and majority of the software companies

[1]For example, structural change in economic output is embedded and a reduction in the ratio may not necessarily represent an improvement in energy efficiency.

working with American clientale that resulted in lay-offs in large numbers leading to wide-spread unemployment, and also various other small employed groups that are dependent on this class of people. Further, in the same year agricultural output too took a very sharp plunge which worsened the crisis.

To simplify the task of GDP percentage calculation for future projections,

- future possible drought and its impacts are not taken into consideration since it is very difficult to predict and model in the given context. Further, in the coming years, the share of agriculture in the GDP is expected to go down and therefore may have a slightly lesser impact than earlier occurrences. (However, effects on market food prices and thereby Wholesale Price Index and Consumer Price Index may be significantly experienced but may be eased with supplies from neighbouring states.)
- the impact of a possible global recession. In the year 2009 the state GDP took a plunge owing to the fall in US economy and its trickle down effects.
- while the developed economies have gradually decoupled energy and economic growth rates over a period of time from the last few years, India and many other emerging economies are assumed to have a strong co-relation between the two for time to come, till a transition to a more mature services based (less energy intense) economy and a more efficient energy system is reached.

Thus, the GDP is therefore expected to continue its current growth for a short period of time and gradually slow down and then stabilize.

2. *Population growth rate*

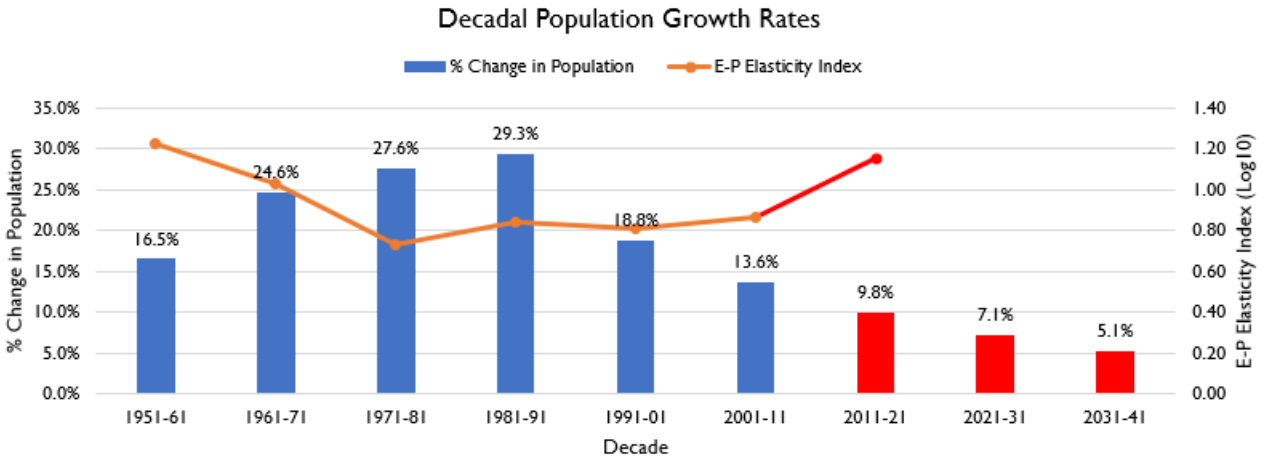


Figure 6.3: Decadal Population Growth Rates and Electricity-Population Elasticity Index. Compiled from: Directorate of Economics & Statistics (2017), Andhra Pradesh State Electricity Board (1998), Government of India (GoI) (2002). (Blue: Historic, Red: Projected)

The decadal population growth data can be seen and rates in the coming decades is accordingly estimated from previous data in 6.3. An Electricity-Population index or elasticity i.e., change in electricity consumption wrt change in population is taken on the right hand axis. The graph shows that initially the consumption of electricity grew proportionally with increasing population, however slowed down as we see that the index is less than 1. Therefore this implies that the total demand was significantly constrained by supply side and there was power deficit. It is expected that the index will rise for this decade and then slowly decline and become less relevant due to increased per capita consumption and slowing down growth rates and most importantly energy efficiency. This also reflects the future trend

of developing and developed regions where economic development linked rise in energy consumption will be delinked.

The population growth rate has seen a declining trend after 1980's and is expected to fall with increased literacy levels, improved socio-economic conditions for women, and an overall better standard of life. Thomas Piketty (Piketty and Goldhammer, 2014) explains that economic growth always includes a purely demographic component and a purely economic component, and only the latter allows for an improvement in the standard of living (p.72). Economic growth is measured by changes in a country's GDP which can be decomposed into its population and economic elements by writing it as population times per capita GDP.

From a vast array of literature that was analysed by E. Wesley F. Peterson (2017), a 1.46% increase in population growth in India corresponded to a 6.93% GDP growth rate during 2000-2015. This is adALTed in this thesis to explain the continuous high GDP growth rates and a subsequent electricity demand rates that follow. While it may look trivialised, it is assumed that the slowing down population growth rates can be counter-balanced by increased economic efficiency (or greater percapita GDP) to keep the above mentioned relation relevant.

3. *Urbanization and Rural development*
According to 2011 census nearly 60% of the total population in the state is predominantly rural. This is a decline from 68% in 2001 and 70% in 1991. In 20 years, there has been nearly 90 million greater increase in urban population from rural to urban migration as well as urban addition (Directorate of Economics & Statistics (2017)). This massive urbanization trend is only projected to increase before it stabilises and eventually declines. Currently there is a massive investment in infrastructure in rural parts through various housing schemes, healthcare, education, irrigation facilities and uninterrupted power supply. The economic standards of the rural households is expected to rise within a few years that will enable them to consume more electrical and electronic appliances like television, computers, kitchen appliances, air conditioners, and greater number of devices that they aspire for in urban settings.

Table 6.1: An example to show the additional Energy demand from rural households by the end of 2030 through increased standard of living.

#	Devices	Power Rating [W]	Hours [h]	Energy per HH per day [Wh]	% of new HH	MWh/day
1	TV	65	3	195	25%	4.87
2	Computer	75	1.5	112.50	25%	2.81
3	Kitchen Appliances	500	1	500	75%	25.00
4	Air Conditioning	1,500	2.5	3,750	50%	187.50
	Total demand per day			4,557.50	100%	220.00
	Percapita demand		125.3 kWh/HH/month			
	Addl. Electricity demand for 5 million HH by 2030				3,600 GWh/yr	

This only calculates the expected increase in demand and excludes lighting, fans (since they are already assumed to have) and energy efficiency measures.

According to Smart Power India (2019), average electricity demand of a surveyed household is 39kWh per month. This demand is serviced by multiple sources like solar home systems, rechargeable batteries, mini-grids, and diesel generators which form an important part of the electricity mix. The demand of electric grid users is 51kWh per month. While these are averaged numbers, many houses have much lower or higher demands. Consider a sample of 100,000 rural households. Table 6.1 calculates the projected increase in demand in the rural households. From Directorate of Economics & Statistics

(2017) document according to 2011 census, there are more than 8 million households and 60% of these (4.8million) are rural households. Around half the HH have TV but a miniscule number have the rest. Therefore the table effectively calculates the additional increase in the demand from 100,000 HH as a sample and thereby for the rest of the 5 million. The implication being that there is an increase of more than 100% percent consumption per capita HH by end of the next decade where more than 11GWh additional energy needed per day, meaning an increase of 3.6TWh annually. Therefore, residential sector could increase the highest in terms of electricity consumption by 2040.

While this rural development may slow the pace of rural-to-urban migration, the changes will take nearly a decade and in the interim, the explosive urbanization rates can be expected to continue.

4. *Transportation*
This has been a rapidly growing sector in terms of total number of vehicles and the growth rate has only recently been dropping gradually. The figure 6.4 shows an overall picture of the state. The vehicles are run on either petrol or diesel and there are statistically insignificant number of non-ICE vehicles. From figure 6.5 it can be clearly seen that three fourths of the vehicles is dominated by 2 wheelers that comprise scooters and motorcycles, which are all driven on petrol. Out of the 13% share of cars, nearly 5% can be assumed to be run on petrol and the rest, on diesel. Finally, half of the 3W are petrol variant. Therefore the share of petrol vehicles is more than 80% of all the vehicles in the state.

However figure 6.6 explains a different story altogether where the consumption of diesel is nearly 3 times that of petrol. What this tells us is that the diesel vehicles that are less than one-fifth of the total vehicle numbers have a significantly dominant share in terms of fuel consumed and the effective number of kilometers driven (also accounting for the fact that diesel based ICE vehicles are more fuel efficient than that of petrol). Thus they contribute to a greater quantum of emissions. Thus, the implication is that shifting this one-fifth of transportation mode to cleaner sources can therefore bring the most benefits than the rest of the 80%.

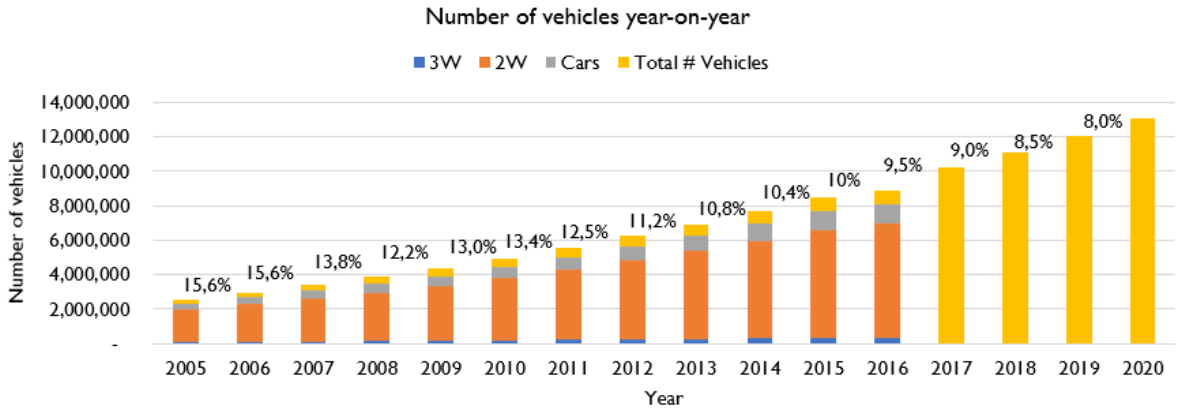


Figure 6.4: Cumulative increase in the total number of vehicles in the state over the period of 2005-2020. Due to lack of availability of data, 2017 & 2018 are approximately estimated and the numbers for 2019 & 2020 are projections. It can be seen that the year-on year growth has gradually fallen from 15.6% in 2005 to less than 10% in 2016. Compiled from EPTRI and MoEFCC (2016) data.

India is yet to bring out an integrated EV policy to support the entire value chain. While a few policy packages have delivered some benefits in instalments earlier, through FAME I and now the upcoming FAME II policies (FAME - Faster Adoption and Manufacturing of Electric Vehicles), a steady user demand is yet to be seen (Interviewee 9). So far apart from manufacturers, the subsidies have gone to ride hailing services and fleet aggregators who cloak maximum kilometers and to whom, therefore, EVs are the most economical in comparison to ICE vehicles. FAME II envisages significant investment in

charging infrastructure as well across major cities in the country. Currently EVs come under Ministry of Heavy Industries, Govt of India, that creates and overlooks the policy framework needed. The state govt. too released a draft policy document in 2017 to elicit a response from stakeholders to understand and promote EVs but the draft hasn't yet been updated or released as a working actionable policy.

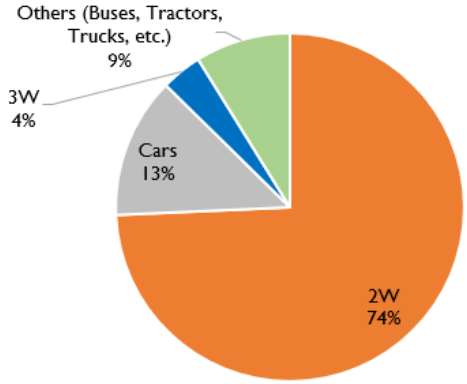


Figure 6.5: Share of the major vehicle segments (as of 2016): 2 Wheelers (2W) are the largest segment followed by cars and then 3 Wheelers (3W). Compiled from EPTRI and MoEFCC (2016) data.

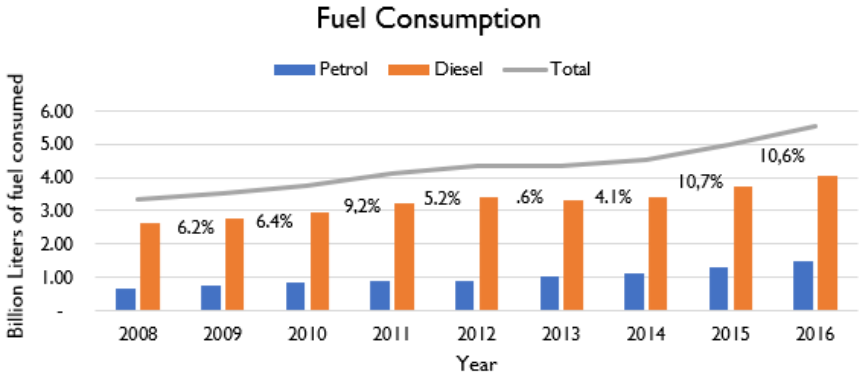


Figure 6.6: Year-on-year cumulative growth (in billion liters) of fuel consumption along with y-o-y growth rates. Compiled from EPTRI and MoEFCC (2016) data.

A draft legislation (from GoI) that plans to introduce mandatory EV sales of 2 and 3 wheelers from 2024 is currently under consultation with stakeholders albeit with reluctance on the part of latter. A similar draft for cars (replacing petrol ones) from 2026 is under contemplation. However, certain automakers have already begun upgrading their infrastructure and are introducing EVs. Mahindra, TATA and Hyundai are 3 major automakers that have running EV models for sale currently. Therefore the demand transportation will see declining levels in fuel oil over the next decades and this will be switched to electric mobility. TSRTC is already running nearly 50 electric buses. An increase in the adoption can be seen from the second half of the next decade in the fruition of the above mentioned legislation and policies.

An alarming inference from figure 6.4 is that at the current increase in number of vehicles every year, a delay of one year in the adoption of EVs adds nearly one million more ICE vehicles on the roads.

5. *Buildings Sector*
There is a projected increase in buildings to the tune of nearly 60% more than the existing ones. This comes from transformation of private independant housing based models to apartment based with higher density in a given area in the burgeoning rural and sub-urban settings too. There will also be a considerable shift from agriculture based population to manufacturing and services based economy thereby increasing the demand for power industrially as well as domestically in buildings. As the disposable incomes rise, there will also be an increase in leisure, paving way for greater commercial buildings for entertainment purposes too (Govt. of Telangana, 2018).

Energy requirements for cooling buildings will grow faster than any other energy demand in the Indian building sector, according to CEEW (Council for Energy, Environment & Water) and other experts (Interviewee #5). With increasing ambient temperatures due to loss in green cover, increasing

buildings and global warming, room air conditioning sector will see the steepest rise in demand for energy. Currently, the penetration of Air-conditioning is limited in India and so is the case in Telangana. While there are no official figures available, from a comparative study in Natural Resources Defence Council et al. (2015), urban household's AC penetration is around 5% in India. Commercial establishments have higher penetration. A comparison with Chinese urban AC penetration went from 0 to nearly 100% in 15 years, which was in the late 90's and early 2000 decade.

The report estimates penetration levels to go upto nearly 50% by 2030 for India and with the current economic prosperity in the state vis-a-vis India, higher levels of penetration can be expected. A sale of more 100,000 ACs for example can mean an increase in peak demand by 1500 MW (without efficiency improvements).

6. *Infrastructure*

   - Roads: Approximately around 3100 km of major roads are under construction in the state and in the next decade, this is projected to grow with improved rural infrastructure that necessitates more roads.
   - Smart Cities[2] Project that will improve and further expand the existing smaller cities in the state which will make them economic powerhouses similar to Hyderabad driving greater power demand.

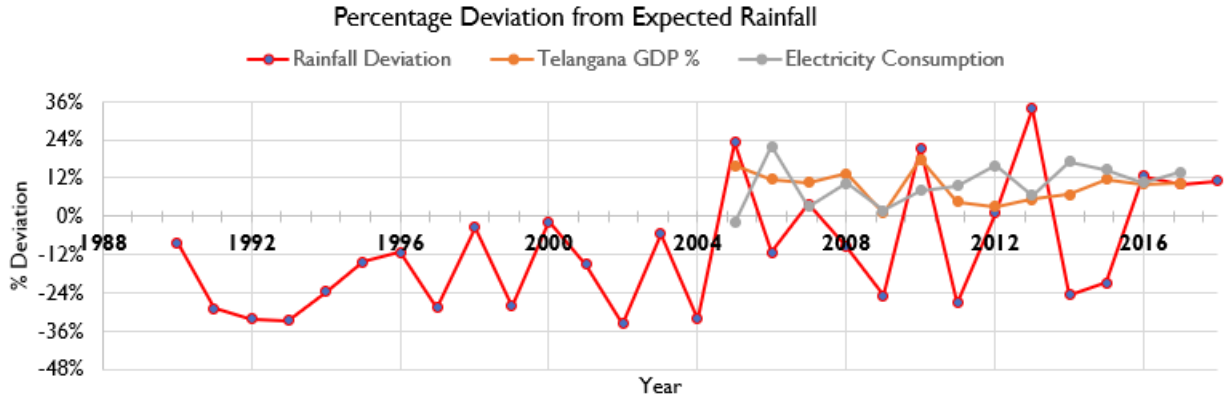


Figure 6.7: Percentage deviation from expected rainfall (905 mm per year) over the last two decades. The (red) curve above 0% corresponds to excess rainfall and below 0% correspond to deficit. A comparison with electricity consumption shows an inverse relationship in most of the years, i.e., an year of deficit rainfall warrants additional electrical power for pumping water. But a more mature and stabilised relationship from the 2016 is seen due to improved irrigation and agricultural infrastructure.

   - Agricultural Infrastructure: In the past few years while there was a growth in water pumps use, reduced water availability brought down their use. Irrigation too was low key and consumed lesser power. Figure 6.7 shows the erratic nature of the rainfall over the last two decades. During years of low rainfall, electricity demand was relatively higher and vice versa. In the last four years however, irrigation has become a large electricity consumer and due to the presence of the massive improved infrastructure for water supply, agriculture dependence on rainfall has marginally reduced unlike earlier years and there is continuous supply of water. Therefore, it is expected to play a major role in rural demand in the coming years. And it will continue to grow along with increased cold storage centres.

[2]Smart Cities Mission, is an urban renewal and retrofitting program by the Government of India with the mission to develop 100 cities across the country making them citizen friendly and sustainable, at a budget of nearly $ 60 billion (at 2017 PPP).

7. *Others*
    - manufacturing industry growth: pharmaceuticals, electrical and electronics
    - increasing entertainment and leisure demands from economically growing middle class,
    - expansion of ICT infrastructure (especially signal towers) that predominantly runs on diesel generators,
    - greater digitization of monetary and financial transactions
    - increasing socio-economic standards enabling people to afford more electrical appliances at home especially those that reduce drudgery like washing machine, kitchen appliances and as discussed earlier, space cooling.

6.2 Future Projections

It has to be remembered that for economies in the transition stage from developing to mature stages, there is a reliance of the GDP growth rate with energy growth. Over time, it gets decoupled (Sharma et al., 2019). This has been a subject of extensive study (Hannesson, 2009; Fotis et al., 2017; Newman, 2018). Here, it is assumed that the energy and GDP growth are closely related and this assumption is perfectly valid since GDP and energy consumption have been growing at nearly the same rate for the past few years for TS. However, it is possible that future growth in energy can be slowly decoupled with that of GDP. Therefore, 2 scenarios are built to explain the trend in future energy growth for both electricity and in transportation sectors. One scenario is akin to a 'Business-As-Usual' (BAU: Sc_{BAU}) and another scenario can be regarded as a more desirable way of growth or an alternate growth (ALT: Sc_{ALT}). The energy demand in Sc_{BAU} grows as fast as the economic growth rate and thus the multiplier or the elasticity ratio is 1 between GDP and energy growth rate. But Sc_{ALT} is assumed to grow slower than the GDP growth rate. Therefore, a value of .9 is chosen as the elasticity ratio.

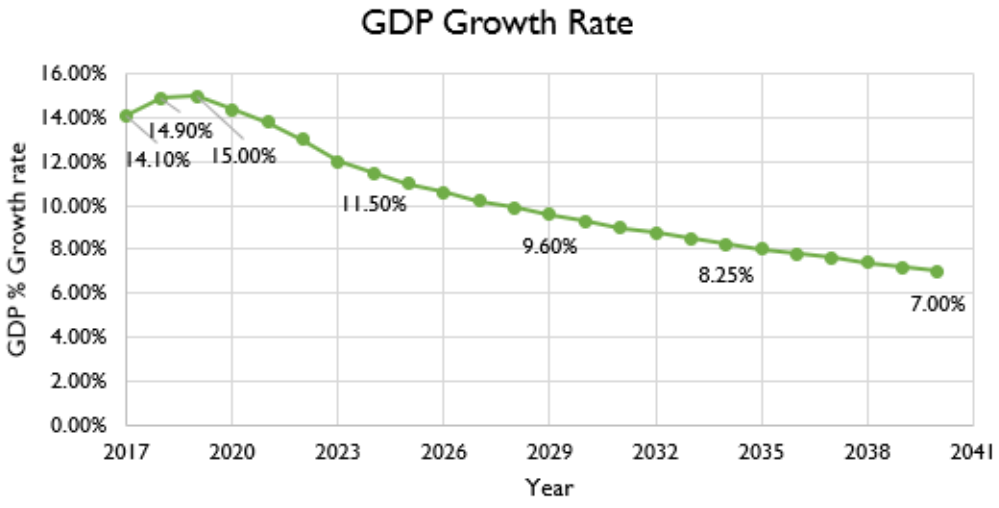


Figure 6.8: Projections of GDP growth rate year-on-year till 2040 calculated through above mentioned factors and semi quantitative methods (subject matter expert discussion).

From the NITI Aayog (2017) document that talks about India's ambitions in terms of an energy secure future, a timeline till 2047 is considered in which India aims a growth rate of 7.5% to bring it self out of poverty, set on an ambitious and sustainable economic growth for all its citizens and be a global leader. While a 7.5%

growth rate seems highly ambitious and phenomenally difficult to sustain till such a long time period, nevertheless it is taken as an assumption. Following the assumption, on a similar line of thought, the growth rate for TS is assumed at 7% in 2040 and the growth rates are back-tracked in small steps.Thus the following GDP growth rates were obtained as shown in figure 6.8. As explained in earlier section, the major sectors were looked into and they showed a promising positive growth. However, as economies grow rapidly, expand in size and eventually mature, the growth rates naturally slow down. The same is seen here. The rate for this financial year is expected to increase after which it gradually slows down till 2040. Initially in steps of .8%, then 1%, followed by .5%, .4%, .3%, and finally .2% steps.

From here the demand rates are successively calculated for the years till 2040. Along with growth rate, an increasing energy efficiency of the entire system is considered. Slower improvements in BAU and baster improvements in ALT scenarios are considered. In The total energy consumption is calculated till 2040 using equation 1 is shown below in 6.9. Both the scenarios are explained further below.

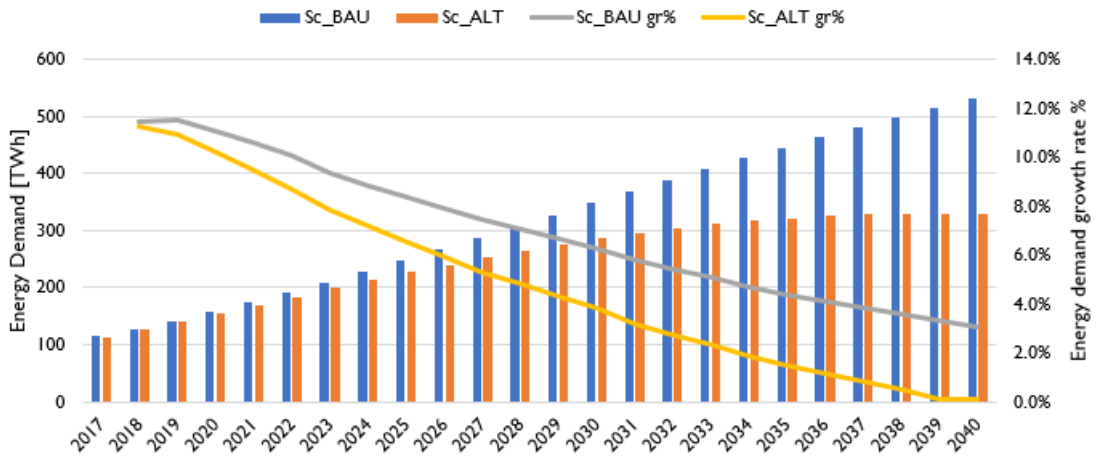


Figure 6.9: Total Energy Demand (electricty and transportation, in terms of final consumption) in both the scenarios shown in bars (left-hand axis) and the gradually falling growth rate curves (right-hand axis). The total demand in Sc_{ALT} stays above zero in 2040. The per-capita energy would increase from 3,000 kWh to 7,320 kWh.

At this point, it is wise to recollect the discussion from Chapter 2 that backcasting and forecasting are complementary to each other. An undesirable forecast of the future system motivates us to create a better desirable future that will be planned to be achieved. These energy forecasts are here to complement the backcasting process by quantifying the energy challenge needed to be addressed and in general provide an alternate path to not just see but create that future. Therefore, this forecast is not to be confused with backcasting that will be explained in the later chapters.

6.2.1 Scenarios: Electricity

E_{BAU} represents the electricity consumption in BAU scenario and E_{ALT} represents an alternative scenario. The primary differences between the two are that BAU grows at the current rate of rapid growth for longer time than in ALT scenario and that the slow down is expected to occur at a much later time period. A brief discussion[3] with an employee at the Planning Department at the government of Telangana revealed that the expected growth rates will be much higher than the ones projected above and the same is the case for electricity consumption. (However, the growth rates are assumed to slow down to provide a more moderate

[3] A formal interview was not possible and only an indirect online correspondence was done.

results.) *The fact that the state govt. is moving ahead with coal power plant projects at nearly 8GW and more in the coming 3-4 years, perfectly demonstrates a BAU situation that not only reflects the urgent growing need and ambition for the state to grow and provide energy to its citizens but also falling short of the vision to do so, sustainably.*

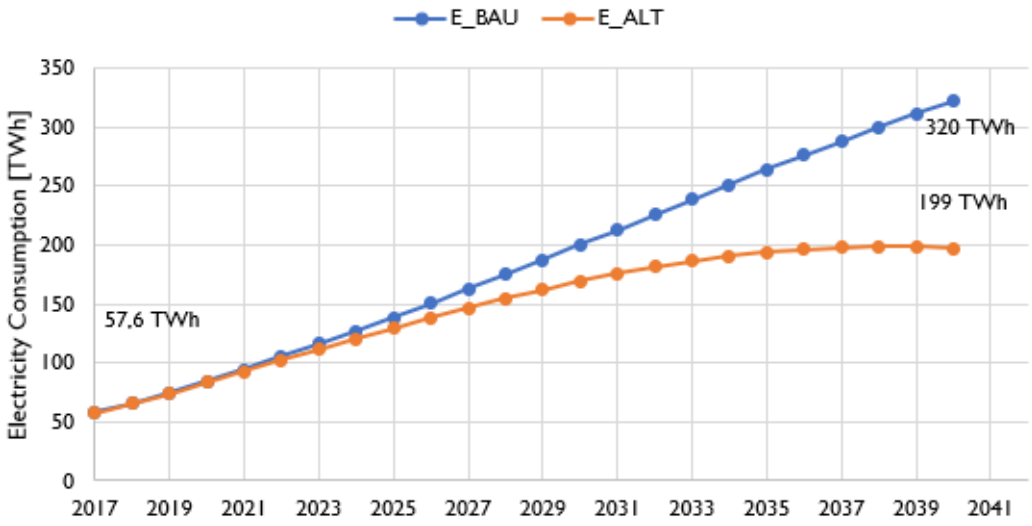


Figure 6.10: The 2 scenarios of electricity consumption. E_{BAU} represents a business as usual scenario growth and E_{ALT} represents an moderate growth scenario. E_{BAU} follows a growth rate equal to that of the GDP growth rate and E_{ALT} follows a rate that is determined from $e_{E\text{-}gdp}$.

In comparison, the electricity consumption of the Netherlands for 2017 was at 121 TWh and that of the European Union (2016) was at 735 TWh (Source: IEA).

Both the curves are plotted and shown in figure 6.10. There is a significant difference of 120 TWh between the 2 scenarios. While energy efficiency measures are in place, the ALT scenario demands a much stronger and committed efforts. Therefore, this scenario employs a higher rate of efficiency but a moderate energy growth rates obtained from equation 1 calculations. The growth rates are shown in detail year-wise in appendix B.

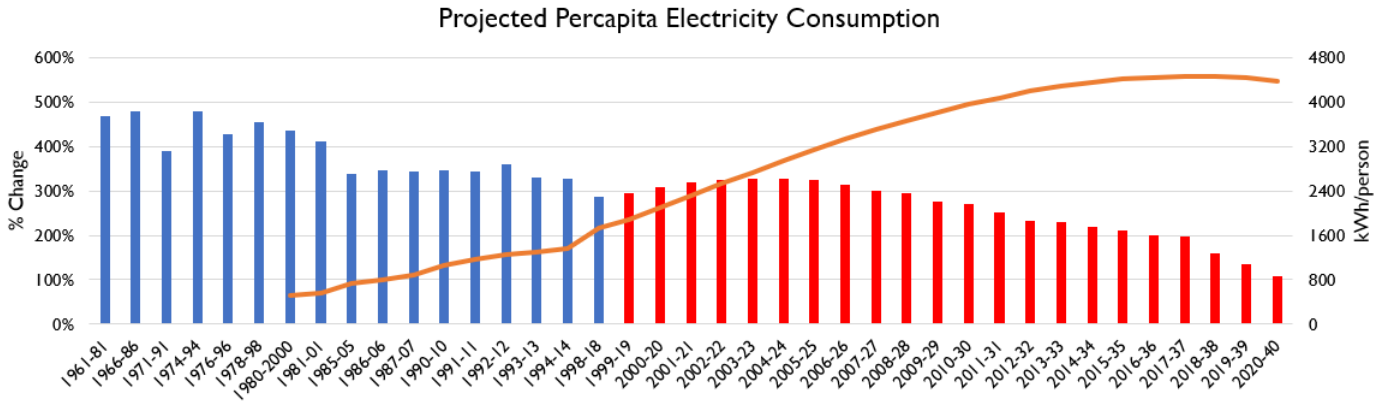


Figure 6.11: The bars in red compare and project the future 20-year per capita electricity consumption changes to that of the historic (blue) data. The orange curve shows the increasing percapita consumption over time. 2018: 1,727 kWh; 2040: 4,400 kWh

We therefore observe in figure 6.11 that the per-capita electricity consumption would increase from the current (2018) 1,727 kWh to more than 4,400 kWh in 2040. The change in population growth is taken from

figure 6.3. The histogram in figure 6.11 compares the rate of change in per-capita electricity consumption (left-hand axis) over 20 year time periods starting from 1961 and shows till 2040. The 20-year increase in per-capita consumption initially showed more than 400% increase that eventually dropped to 300% increase as of 1998-2018. The trend is expected to gradually fall in the future to a point where the 2040 value would be just above a 100% increase over its respective 2020 value. The orange curve shows the linear rise, followed by exponential rise and than a stabilising per-capita electricity consumption (right-hand axis). At 4,400 $\frac{kWh}{person}$, it is expected to be higher than India's national average, which is currently less than the state average.

It should be noted however that the higher value of per-capita electricity can eventually become less meaningful as a tool to assess a region's economic status over time if increased energy efficiency measures can promise the same prosperity with lesser use of energy in comparison to regions that have achieved the same in the past without the efficiency levels available today and those possible in the future.

6.2.2 Scenarios: Transportation

Initially the growth in the number of vehicles is projected. The historical growth rates are considered, then the present and future trends are studied as well, which are primarily: shared, connected, autonomous and electric (Interview #12). These emerging trends are mainly observed from current changes in the mobility sector where increasing ride sharing services, decreasing vehicle ownership (for four wheelers), increasing investments-R&D-testing of the use of deep-tech in automotive industry and the rise of disrupting companies that are able to serve the segment which bigger companies are, at the moment, unwilling to venture and risk into.

From figure 6.12, while the growth rates will go down eventually, the total number of vehicles will nearly double in the ALT scenario (nearly 25million from current 12million - this implies an increase to 556 vehicles per thousand population from the current 290 vehicles per thousand population.) and more than triple in a BAU scenario. The latter scenario, somehow appears less relevant since the current trends already seem more encouraging and seem to be showing the way forward. However, a lot more is to be achieved especially in terms of use of alternate fuels, improving public transportation infrastructure and supporting the innovative forms of mobility that are currently disrupting the rural and urban landscapes.

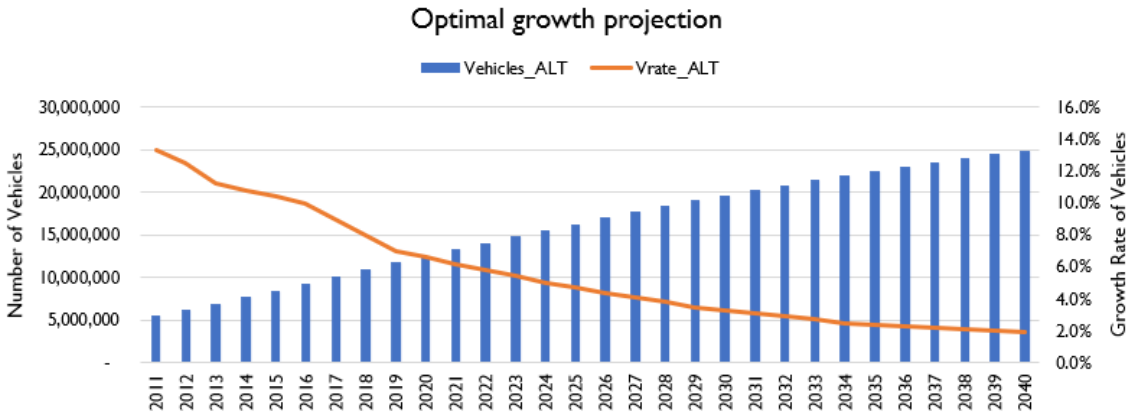


Figure 6.12: The falling growth rate in the overall vehicles and cumulative rise in total number of vehicles.

One possible trends that can be observed differently from figure 6.5 is that the share of 2W may go down (however marginally) and the share of 3W and cars could go up. The reasons could be as explained before that increasing ride sharing can result in lower vehicle ownership that can include 2W and cars, however, the taxi segment in the state is increasing at nearly 50% year on year and has registered the largest decadal

growth rate from 2006 to 2016 at more than 500% (EPTRI and MoEFCC, 2016). During the same period, 2W segment grew at less than half the growth rate of taxis and ride sharing vehicles. And due to the investments in this space by Ola Cabs and Uber, the largest transportation companies offering ride hailing and ride sharing services, many newer companies are growing in this space in rural and semi-urban areas offering similar services in electric 3W that has already boomed after the 2015 FAME[4] subsidies and the current FAME 2 subsidies (Interview #11). Electrification in transportation has been opening doors to newer enterprises from entrepreneurs who are able to serve what the established automotive companies are not able to. Therefore, the future vehicles mix may look different than from 6.5

6.2.3 Scenarios: Fuel

Then, the growth rates for petrol (gasoline) and diesel vehicles is separately taken into account and projected based on the growth of vehicles. And a final total fuel consumption is accordingly projected for the future. A share of the energy needed will be eventually shifted towards electrified forms of mobility that is already started to catch up momentum, and other alternative fuel sources like Compressed Natural Gas (CNCG), Liquefied Petroleum Gas (LPG) and Compressed Bio-gas (CBG). CNG will be predominantly the major alternative fuel source. Figure 6.13 shows the 2 growth in scenarios displaying signifcant differences due to differences in the rates of adoption of EVs particularly in the buses and diesel cars segment that travel greater person kilometers[5], push towards a greater public transportation, and greater ride sharing.

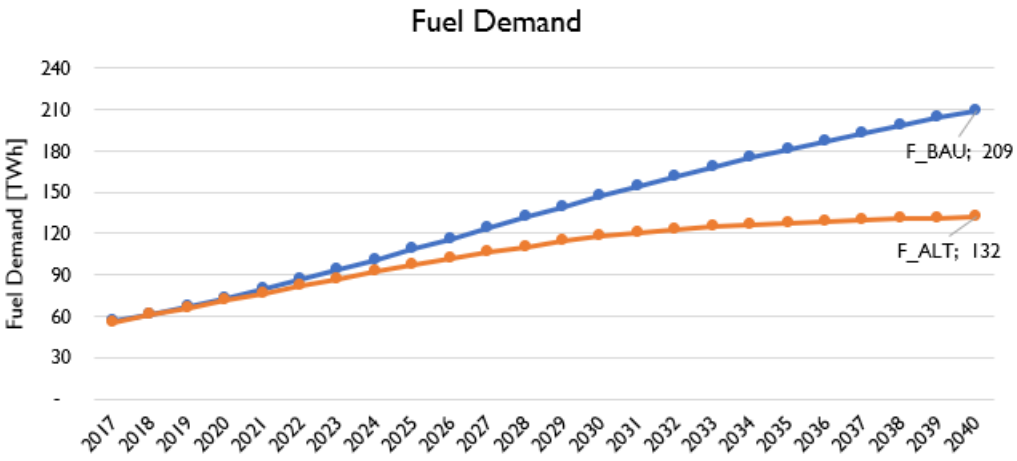


Figure 6.13: Projected fuel demand by 2040 for BAU and ALT scenarios (Fuel includes Gasoline/Petrol, Diesel, and other alternative fuels like CNG predominantly, LPG and Compressed Bio-gas (CBG).

The figure 6.14 breaks down the ALT scenario for fuel demand and shows the growth rates for petrol, diesel and alternate fuels. It is observed that while the former 2 see decreasing growth rates, alternate fuels that promise significantly lowered emissions see a sharper slope. This is also attributed to the government's decision to promote low carbon fuels. However this is a misdirected road laid by the govt in terms of lack of clarity of policy because while on one hand the govt wants to promote alternate fuels it also expressed interest to sell only electric vehicles (ET Bureau, 2019; Mukherjee, 2018). It is important to consider a moment to understand the confusion from a manufacturer point of view.

[4]FAME or Faster Adoption and Manufacturing of Electric Vehicles is a scheme under the National Electric Mobility Mission Plan by the Government of India that provides vision and roadmap for faster adoption of EVs through subsidies and infrastructural support.

[5]person kilometer = number of persons travelling in a vehicle multiplied by the number of kilometers the vehicle travels.

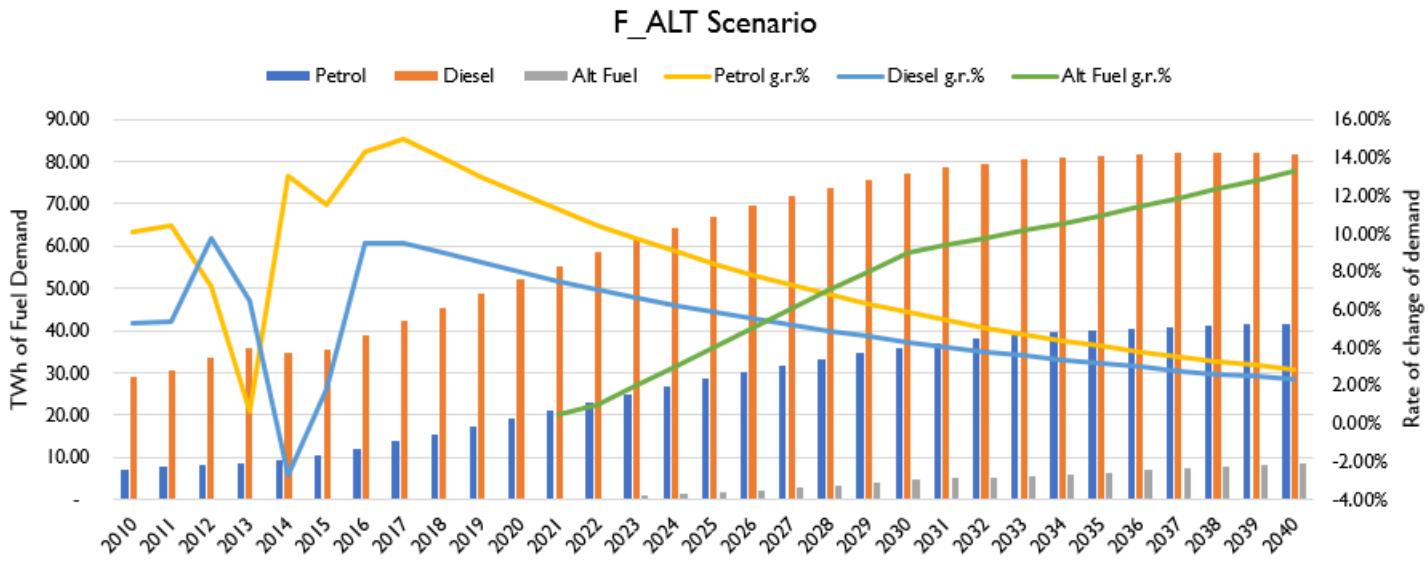


Figure 6.14: The F_{ALT} Scenario is broken down to explain its constituents.

The table 6.2 shows the possible savings in fuel if the penetration of EVs is as given. More than $5 billion can be saved by entirely avoiding the oil imports, by 2040. If one fifth of the total vehicles shift to electrified forms of mobility as seen in the last row, the total share of electricity needed in the transportation sector is 18.47 TWh which is almost 10% of the projected total electricity demand in 2040. (The calculation done for the electric vehicles assumes the proportional number of kilometers travelled on ICE vehicles and equivalent fuel consumed. EV is assumed to take only 70% of the energy taken by ICE vehicles on average for the same distance and similar driving conditions. Ideal test conditions show a much higher efficiency of EVs over ICEs, however Gupta et al. (2016) studied over 23 different powertrain/fuel systems and ALTimised it for Indian Drive Cycle[6]. Therefore, a 70% value is taken from it. Overtime, EVs will become more efficient)

(The tables and additional graphs that show the growth rates, values of energy consumption in TWh and liters of fuel, annual population, percapita energy values, et. al., are shown in detail in appendix B.)

[6]The Indian Drive Cycle (IDC) is used by ARAI (Automotive Research Association of India) for fuel economy and emissions evaluation for passenger cars in India. In this engine losses contribute highest due to lower average engine operating efficiency over the IDC and about 17% of fuel energy is used to overcome resistances to drive the vehicle over the IDC. The vehicle fuel economy mainly depends on drag force, rolling resistance, grade, drive cycle, powertrain configuration and vehicle mass

Table 6.2: Approximate Savings in fuel and oil imports possible by switching to electric vehicles. ($ calculation include crude oil prices that India paid to import as of 2018. Source: Ministry of Petroleum & Natural Gas).

Year	Cumulative % of EVs in Total Vehicles	Cumulative # of EVs (includes all segments)	Energy from Electricity needed [TWh]	Fuel Saved [billion liters]	Crude oil imports avoided [bn $]
2025	0.1%	16,299	0.07	0.01	0.004
2026	0.5%	85,079	0.36	0.05	0.021
2027	1.0%	177,135	0.74	0.11	0.043
2028	1.5%	275,799	1.16	0.16	0.067
2029	2.0%	380,603	1.60	0.23	0.093
2030	3.0%	589,744	2.47	0.35	0.144
2031	4.0%	810,702	3.37	0.48	0.196
2032	5.0%	1,042,765	4.30	0.61	0.250
2033	6.0%	1,285,104	5.25	0.74	0.305
2034	7.0%	1,536,770	6.20	0.88	0.361
2035	8.0%	1,798,460	7.17	1.02	0.417
2036	9.0%	2,069,803	8.14	1.15	0.474
2037	10.0%	2,350,376	9.12	1.29	0.530
2038	12.0%	2,879,681	11.00	1.56	0.640
2039	14.0%	3,426,820	12.89	1.83	0.750
2040	16.0%	3,990,777	14.78	2.10	0.860

7 Developing Future Visions

> We are all living together on a single planet, which is threatened by our own actions. And if you don't have some kind of global cooperation, nationalism is just not on the right level to tackle the problems, whether it's climate change or whether it's technological disruption.
>
> Yuval Noah Harari, Israeli Historian and Writer

Summary

The major outcomes from the interviews conducted are presented briefly. From these, an idea of the vision is developed and explained through its key elements. The elements of the vision will be analysed quantitatively through pathways that are constructed to explain the supply side status of the future in which the ideals of this vision are incorporated. The question What needs to be achieved will be discussed.

7.1 Basis of Framing the Vision

In order to create a vision which reflects a common thread of understanding among the key stakeholders, interviews were conducted and additional literature was made use of where needed. Over time, a vision was developed that reflects their opinions, the difficulties involved, the possible solutions and how they wish to see the future of renewables. To some stakeholders, this was significantly radical to envision a scenario in the future with such high amount of RE, with some even calling it impractical for a 2040 timeline. However, the aim of this thesis is to offer a possible alternative to the Business as usual. Therefore while the vision can be called radical and not fully acceptable as a mainstream, it is necessary to explore such possibilities. Before explaining the vision and its 5 key elements, the basis of the vision will be discussed by providing the summary of the outcomes of the interviews from which a significant aspect of it was framed. An element of the vision that was not sufficiently addressed in the interviews was developed by the author through referring additional literature.

7.1.1 Major Interview Outcomes

A concise transcript of the interviews is given in appendix C and the major outcomes from it are presented in this section.

1. A 100% RE in the total energy mix is nowhere possible and is highly impractical and coal will continue to be the main source of power for a very long time in the future in India. May be a 50% RE in the mix is possible by 2050. It is considered expensive and requires immense capital and skilled manpower. This is not only financially challenging, but technologically too, a 100% RE solution hasn't been figured out yet. The technological issues are: (i) the problem of mega scale storage and (ii) reduced inertia in the grid system. The power sector is not mature to evolve into competitive market forces driven system from the current govt. regulated one.
2. The priorities are not geared towards a complete decarbonization or emphasis on clean energy technologies because there are a number of competing financial priorities like improving healthcare, agriculture, and education. However going for more storage to address demand for peaker and night times implies increased costs and use of technology not fully understood. Further, there is no political motivation to move towards sustainable energy. Further, there are no plans to go beyond having 5GW PV target for the state since it addresses the Renewable Purchase Obligation set by Central Power Ministry. There are no battery storage plants or option that is considered since such expensive technologies were not yet mandated by law or policy.
3. For energy transition to happen, new kind of business practices are needed. Decentralization has to be emphasised not only in technology but also in institutions - more autonomy should be given to agencies like municipalities and DISCOMs (Electricity Distribution Companies) in decision making. More off-grid installations (through multiple microgrids and nano-grids) should be considered and catering to increasing rural and agricultural power demand through solar PV must be prioritised instead of serving through coal based grid. The govt. should focus more on storage capacity, especially with the new Storage Policy in place. Youth participation has to be stressed as they can be main drivers to talk about climate change. Stronger community based action is needed to be made into an important public discussion. Incentivising low carbon activity makes a huge difference. It would be good to have all the ministries working with a common vision to prioritise sustainability. Therefore BAU practices and policies are insufficient to envision a transition.
4. Currently most DISCOMs are loss making entities due to cross subsidies (free power offered to agriculture sector), very low tariffs, high debts. Due to the already low tariffs, there is hardly any incentive

to install PV on rooftop for residential segment (this is despite the 30% subsidy). Most of the PV power gen is during morning and afternoon but residential consumption is higher in the evening and night. So they would require storage systems that will drive the economics out of reach. Further, due to only net metering in place now, there is no concept of Prosumers in place. Therefore electricity prices have to be made demand sensitive and cost (of procurement) reflective. Also its important to make sure that the bad debts don't get compounded and worsen DISCOM financial health. Privatization of DISCOMs is certainly possible. Delhi, Mumbai, Calcutta are good examples. But elsewhere it is a problem of the state governments. It is not a problem of private companies not wanting but govt. not making it happen. Challenges are mainly political.

5. The demand for oil is projected to rise till 2035-2040. But domestic production is low so import dependency continues. Due to air pollution related concerns,there is a shift in priority towards alternatives like Compressed Biogas (CBG), Compressed Natural Gas (CNG), Electric Vehicles; municipalities and other organizations are being urged to adopt the alternatives. New vehicular emission norms (BS6[1]) significantly lower the pollution. Electric Vehicles are also being promoted along side. But there is no clear path ahead and its confusing. Despite mandatory fuel blending with low polluting alternatives, lack of sufficient biofuel feedstock is affecting the blending targets. While the use of Hydrogen has fructified in terms of research (supply side), safety is yet to be proven. It is being mixed with CNG too, however limited. But alternate fuels are expected to play a major role in the coming years.

6. Industrial (manufacturers) subsidies are better, but retail customers too have to be incentivised. Subsidies to manufacturers is better and easier (from implementation point of view). But for the costs to come down, the sales have to scale up, similar to PV. Until then the costs cannot come down. Increase in the adoption of EV will bring down the cost of batteries. The central government's FAME[2] policy that gave subsidies for EVs mainly benefitted fleet aggregators[3] and those with higher utilization (in terms of kilometers travelled per day). The phase 2 of FAME will be targetting public charging infrastructure, in addition to continuing the subsidies. There should be continuity in this policy (for subsidies). Govt. plans to increase import duty on batteries to encourage domestic manufacturing. If DISCOMs can get sufficient funds for RE integration through tariff rationalization, then they can invest in EV charging infra too.

7. Most people are aware of the changing environment, water scarcity problems, the unseasonal rains, heat waves, etc. However, all these events are not linked well in the minds of people. 'We are not a mature society to protest for rights violation in case of clean air or water'(Interview #5). While renewables will temporarily cost more (higher upfront capital) and energy transition requires greater capital with shorter pay back periods, the question of who will pay for it still remains.

Note:
While the information obtained from the actors threw light on many issues, further study was needed to understand more dynamic aspects of policy uncertainty in electric mobility and public transportation space that is currently going on. Since it was practically not possible to reach and interview all the stakeholders involved, and given that this is a currently on-going issue, additional references were explored that were mainly from analysed news sources and externally published interviews of the stakeholders involved.

As the author of this report, I wanted to explore the possible role of people in climate positive action. While interviewing an activist at ground level is one method to understand reality in the state, understanding how citizens played a role in other parts of India and around the world on climate change is another way to know

[1] equivalent to Euro 6 emission standards
[2] Faster Adoption and Manufacturing of EVs
[3] Companies that own large fleet of vehicles and provide them to firms or individuals for period of time; also called Mobility as a Service.

what more can be done not just by the governments but also by the people. Therefore, role of people must be definitively explored and must be a key element of the vision for a sustainable future.

7.2 Desired Vision

In the figure 7.1, the key elements of the vision are shown. These are framed from the point of view of what needs to be done for the future that can be different from the BAU growth. These 5 elements were chosen since a promising change in them can have a significant impact on if the vision can be achieved or not. First the elements are discussed in brief, then why they were chosen is explained and later the vision is elaborated in terms of definite targets to be achieved. The vision represents a more systemic view of how the future of clean energy must look like in terms of the key aspects that need to serve as the guiding framework. The required changes in the institutions, organizations and legislation are therefore inherent and embedded in them. They also represent the shortcomings (or limitations) in the current system that were highlighted in the interviews which need to be addressed to not only improve the status quo but also to move away from BAU towards a more desirable future. It is with this background they are chosen.

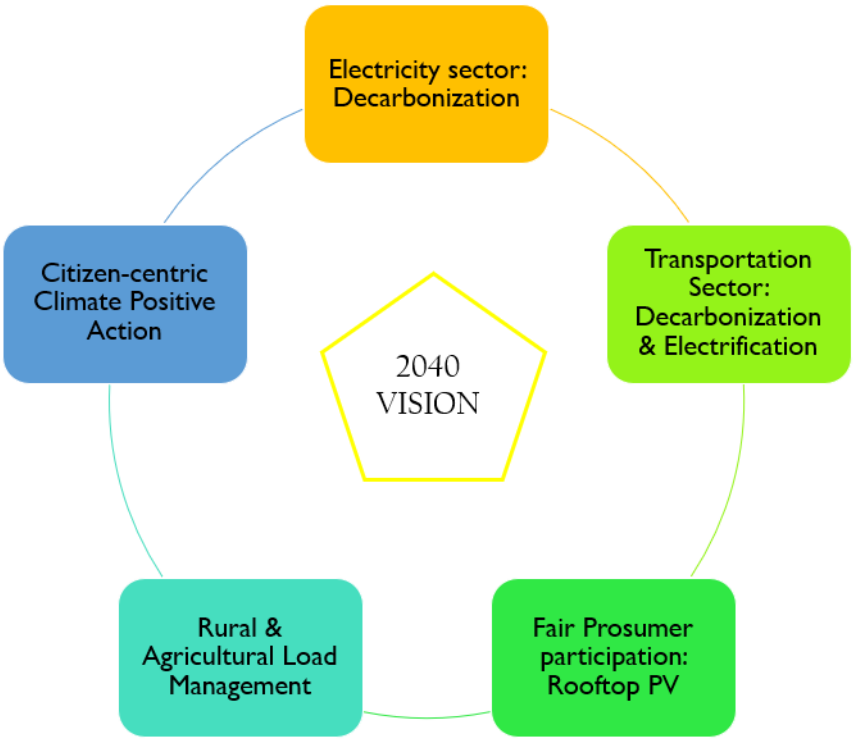


Figure 7.1: Key Elements of the vision for 2040 enabling STRAPSETT

1. Electricity Sector Decarbonization

   This is the foremost change necessary, which is also the main point being discussed throughout this thesis, to shift to a cleaner energy sources based system from the current fossil fuel system. This is therefore a key aspect. The increasing demands from energy will have to be met with sustainable energy sources and expansion of coal power will have to be stopped. Newer technologies have to be adopted, promoted and eventually scaled up. Also importantly, it is necessary to make DISCOMS

work more efficiently and put them through lower liability. Strengthening the DISCOMs is a key aspect to a better decarbonized grid and efficient energy system. Thereofore the challenge of increasing the share of renewables in the energy mix from 12% to 3 quarters or more is phenomenal. This is also where storage technologies will play a crucial role.

2. Transportation sector Decarbonization & Electrification

   This is the next key element which is important because nearly half the total energy consumed in the state is from transport sector and discussing the decarbonization for it is therefore necessary. Here decarbonization in this sector can be understood as the shift towards electrified forms of transportation and low carbon alternate fuels. From figure 6.12 we observed how the overall number of vehicles is likely to increase in the future. However they run mainly on diesel and petrol, and alternate fuels like CNG, LPG, or EVs are statistically insignificant. Bharat Stage 6 emission norms are expected to kick in that will drastically reduce emissions[4]. Stress on electrification and public transportation should be emphasised. But the real challenge is on transitioning the diesel guzzling public transportation and ride sharing diesel cars to electrified mobility which can not only bring down the quantum of carbon emissions but also the PM 2.5 which is the most dangerous health hazard. At the centre of this transition is the economics of this transition and not the behavioural change as assumed before.

3. Fair Prosumer Participation

   The immense potential of rooftop PV was observed in chapter 4. Residential sector is one of the important segments in addition to industrial and commercial segments[5]. But it has the slowest growth rate among the others. Its potential to grow is mainly possible through the right design of tariff structure. Why this is an element in the vision is because of the fact that households can be empowered and can play an active role especially in bringing the peak demand down for utilities through the use of SPV and with a battery system, the excess PV electricity during the day is buffered and later used at night. In this way, households equipped with a PV battery system can reduce the energy drawn from the grid and therefore increase their self-sufficiency. Further an electricity consumer can also become a prosumer and earn by selling the unused energy back to the grid if the Feed-in-Tariffs are attractive. This is also beneficial for the utilities which do not have to invest in additional infrastructure for increasing demand. Because of decentralised generation and consumption, the losses in the overall system are highly minimized. However, current policy of only net metering, lack of Feed-in-Tariffs, ill-designed grid electricity tariffs and debt-ridden DISCOMs limit these other possibilities.

4. Rural & Agricultural Load Management

   One of the reasons the state's demand is growing has to come from the fact that an increasing share comes from agriculture sector where millions of households are getting access to electricity and are also seeing an improved standard of living. However, if this demand is decoupled from the main power grid and is driven by decentralised PV, then significant savings can be obtained. Further, a number of innovative successful businesses[6] that are thriving on solar PV in rural places can be scaled up to address the energy demands. The vision is to see more micro and nano grids in rural parts instead of connecting them to grid.

5. Citizen-centric Climate Positive Action

   Climate positive means that an activity that goes beyond achieving net zero carbon emissions to actu-

[4] Nearly 80% less compared to the earlier pollution standard of BS4 for Sulphur Oxides, Nitrous Oxides and Particulate Matter (PM) 2.5 for diesel; Hydrocarbons and Carbon Monoxide for Petrol. (The Automotive Research Association of India, 2018)

[5] Buildings that come under the category of Commercial segment (regular businesses, office buildings, commercial establishments, etc) or Industrial segment according to the municipality

[6] Simpa Networks and Oorja Solutions.

ally create an environmental benefit (by removing additional carbon dioxide from the atmosphere). It is similar to the term carbon negative. Governments alone cannot drive the change needed for this transition, but people must participate in it as well. People are at the heart of change. Technology is created for the comfort of the civilization and it should ease into a sustainable and a cleaner future. But what drives the use of technology, or for that matter, a natural resource? The way energy is generated and used, food is grown, water is consumed, land is utilised, have all a carbon footprint and an impact of the environment around (Hawken, 2017). What is the social and economic value to an individual to change their behaviour? For a common man, understanding the global implications of climate change could be nearly incomprehinsible, and not fully relevant. But the visible impact on the immediate surroundings and environment can play a role in altering decisions that could create positive impact. Making people at the heart of every change, in this context, to own and drive a clean energy future vision, should therefore be a priority.

Since they serve as the guidance system, there could be multiple ways of reaching it, called pathways. The next section will discuss the 2 possible ways of working towards the vision where the targets of *what needs to be done* will be defined by elaborating the vision elements 1 and 2. The next chapter will discuss *how they can be achieved* and also elements 3, 4 and 5 will be discussed in more detail then with a greater qualitative treatment where the barriers that hinder in achieving the vision will be first analysed and then a backcasting analysis is done.

7.3 Elaborating the Vision: Defining Targets

The next step is to quantify objectives and set targets for the vision. In this section, the vision will be quantified and visualised in 2 ways. The targets are explicitly defined that are demonstrated in the figures 7.2 and 7.3, labelled as A_C and A_M respectively. From the current installed capacity of 16 GW, the system will increase by nearly 4 times upto 70 GW in A_C. A_M in figure 7.3 differs not only with increased installed capacity of 89 GW but also with the consequent increased share of clean energy in the mix.

The total energy of 197,000 GWh corresponds to the value obtained from SC_{ALT} in chapter 6. Since the BAU scenario projects a very high energy demand it will not only become difficult to cater to such levels but also very expensive for the government. Therefore it is desirable to have a more moderate growth and thus the alternate scenario's energy demand will be considered. Further, the same demand scenario will be used for backcasting analysis in the next chapter. Figures 7.2 and 7.3, that deal with the supply side of energy, represent the end states in 2040 and are elaborated as follows.

It was discussed in chapter 2 that this thesis will develop normative scenarios which will answer the question of *how a specific target can be reached?*. While a normative scenario helps us to envision a desired future, it is highly likely that the consequences of today's policy can be reflected in tomorrow's future vision. The point in case here is that certain actions that were taken in the past will have to bear consequences in the future, that will be discussed in and *as a part* the pathways. Therefore, ignoring them in the analysis will render the vision less meaningful. While this thesis is of academic nature, efforts are made to make this practically as useful as possible. Thus, the normative scenarios will include elements of policy decisions and actions implemented that were taken earlier in time. But this does not affect the sanctity of the scenarios entirely. This is because, within the normative approach, 2 types of scenarios can be developed which answer either *How can the target be reached, by adjustments to current situation?*, called a Preserving scenario, or *How can the target be reached, when the prevailing structure blocks necessary changes?*, a Transformative scenario (Börjeson et al., 2006).

The former is deemed to be appropriate when it seems possible to reach the target within a prevailing structure of the system. The prevailing structure, here, is assumed to be the dominant regime of coal based power

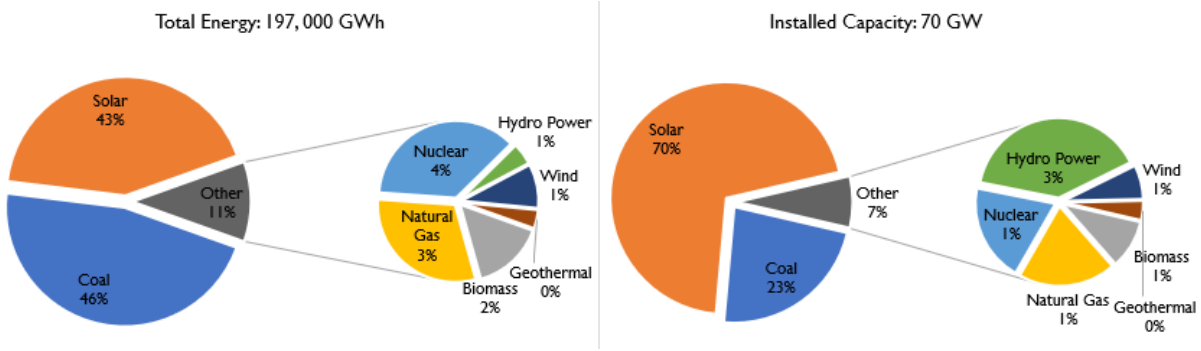


Figure 7.2: Left: Source-wise share of energy mix. Right: Source wise share of Installed Capacity. The share of RES is nearly 50% in this scenario by 2040. (While nuclear is not a RES, it is a clean and non-polluting source of energy.)

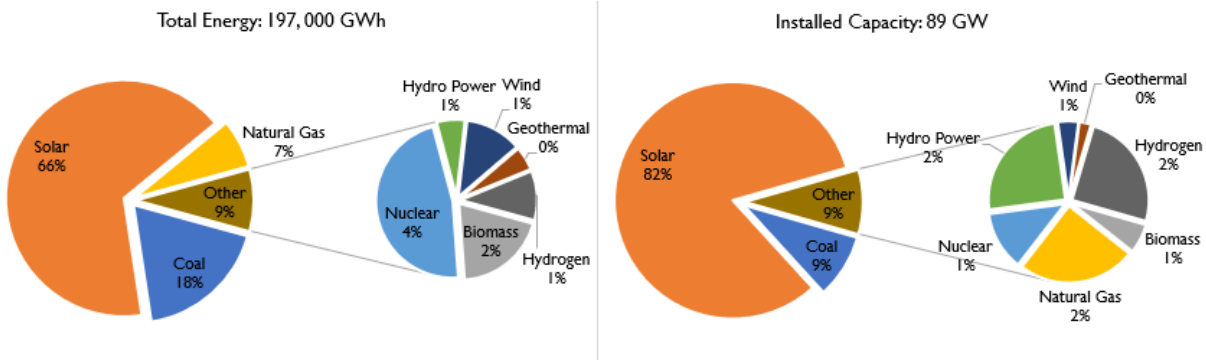


Figure 7.3: Left: Source-wise share of energy mix. Right: Source wise share of Installed Capacity. The share of RES is nearly 75% in this scenario by 2040. (While nuclear is not a RES, it is a clean and non-polluting source of energy.)

and decisions that were taken to continue this into the future. The additional coal power that will be added in the coming years is considered as a part of the future system. Despite this, 3 times more power will be needed that will have to come from renewables which will be necessary to limit the share of fossil fuel based energy to 50%. This implies that this pathway could have greater political approval and ease of implementation since the coal plants need not have to be shut down. Therefore, this is highly likely to be achieved and this this is labelled as an *Achievable Pathway* (A_C). However, other changes needed to be taken do not necessarily conform to this type of a Preserving scenario.

A transformative scenario requires a structurally different system in order to reach the goal. A limitation found across literature regarding this type of scenario is often that modelling the structure of the system often rejected since trends are expected to go in the wrong direction and that the use of trends can make the problematic current structure, a part of the future one. This is reasonable and this thesis too has not built a model *towards the future* for this scenario, however assessing the possible supply side of energy with some numbers can come in handy to understand and feel the size of the problem. Thus, some preliminary normative targets are set in this. Hojer points out that the high level target in transformative scenario can be unreachable if the current regime continues to grow in a business as usual way. While his statement is perfectly valid in this context, it is also necessary to understand the alternate possibilities of softer energy paths and the 'missed opportunity' along with its unexplored costs & benefits. Thus the second pathway is constructed with this point taken into consideration. This pathway will be explained further and the ambitions in this are much higher than that of A_C. This is a challenging situation that can thus be regarded as a highly *Ambitious pathway* (A_M).

The targets in these pathways were developed in a backward approach instead of a trend based forecasting.

The energy demand in 2040 has been projected at 197,000 GWh, from E_{ALT} scenario. Therefore this value was fixed and then the energy from fossil fuel based sources was set at 50% in A_C and 25% A_M for coal and natural gas sources together. This means clean energy sources are expected to contribute at least 50% in A_C and 75% in A_M, which is the normative scenario here. Then, nuclear power value was fixed that was obtained from the NITI Aayog (2017) document; then the limited potentials of the rest of the RES were taken. The energy from all these sources were calculated after considering their probable capacity factors C_f[7] and multiplied with the installed power capacities. Finally, the remaining quantum of energy is allotted to Solar from which the required capacity in GW was calculated. This exercise was done for year 2040. Then the targets for 2035, 2030 and 2025 were set in steps of decreasing order and required power capacities were calculated. Thus, targets for four time periods were set.

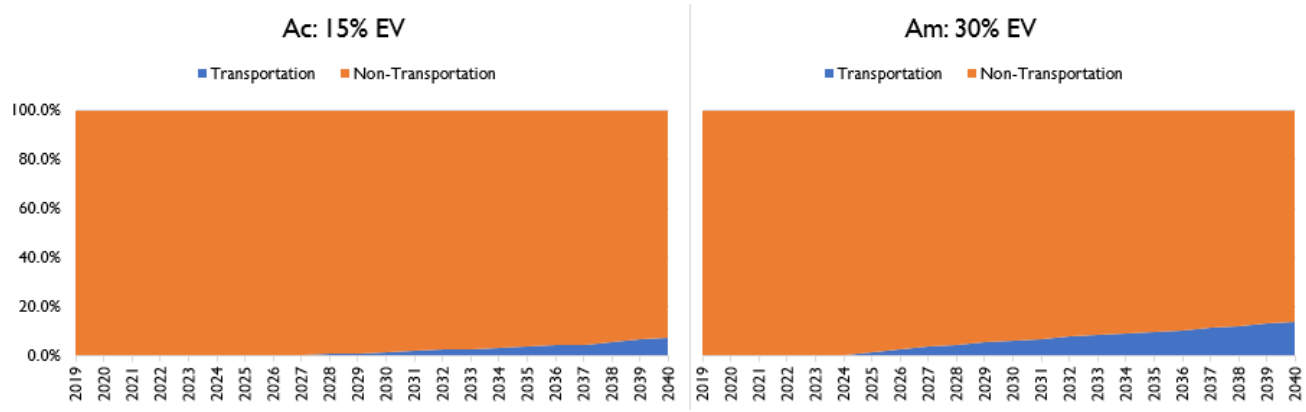


Figure 7.4: The share of transportation in final electricity consumption in A_C and A_M with 15% and 30% of the total vehicles becoming electric is 7% (14,000 GWh) and 14% (27,500 GWh) respectively.

The targets for electrification of transport are set at 15% and 30% of total vehicles in A_C and A_M respectively. Figure 7.4 compares the share of transportation in the final electricity consumption till 2040. The energy demand can be explained in the following way. In transportation sector, A_C envisions a 100% shift to electric buses in public transportation. Approximately around 10,000 buses are under TSRTC[8] as of 2017. This number can be expected to increase to 15,000 soon in the coming decade. A_C envisions a shift of these buses completely to electric. If each bus is assumed to have a 384 kWh BYD k9 bus battery and a charging requirement of 3 times a week (150 times an year), this would lead to an electricity demand for 960 GWh annually. The remaining 35,000 buses will shift to low carbon options of CNG and CBG, or hybrid. The idea is to have no buses running on diesel.

A_M takes targets higher by making all the cars in taxi segment too, electric. The move in this sector has just begun in India in a few cities with some pilot projects[9]. In this case, if 500,000 cars (taxis) with 50 kWh battery pack each are assumed with a 2 time charging requirement per week, then Its not far when economics of these will be clearly spelled out for easy decision-making. If such a case happens, then 2,500 GWh more electricity will be needed. Adding the demand from electrified buses and cars, this takes the total required electricity in transportation sector to 3,460 GWh. What if all the 50,000 buses are electrified (it is assumed that the older diesel ones are disposed and all the news buses are made electric) then the demand increases by

[7]By taking the approach of calculating total energy of a source by multiplying with its capacity factor C_f we will arrive at a much higher values for coal power plants since they have higher installed capacity. Therefore it is assumed that they have to be running sub optimally, i.e., less than their possible C_f in order to achieve the clean energy shares in the total energy mix. For the rest of the sources, the C_f values are: Natural Gas = .75; Biomass = .75; Nuclear = .9.

[8]TS Road Transport Corporation: The public sector company that owns and runs the fleet of buses for public transport in the state.

[9]OLA Cabs Pilot project in Nagpur: Ola Cabs launched a pilot project in the city of Nagpur in 2016 when it ran only electric 2 and 3 wheelers and later added 4W for ride sharing and ride hailing services.

3,200 GWh. In this way if 15% (2.65 million) and 30% (5.3 million) of all the vehicles are electrified, the the demand requirement is shown in figure 7.4.

However, for both the scenarios, this implies a large infrastructure for storage capacity to be needed. Battery storage of Lithium ion is the most promising with abundantly available natural resources too for scaling up. For 50,000 buses, at least 19.2 GWh of storage device capacity will be needed. And for 500,000 cars with 50 kWh battery pack, at least 25 GWh of batteries will be needed. Currently Pb Acid battery technology is dominant for power and transportation applications (Interview #11). This figure of 45 GWh includes the battery for transportation sector and not yet for mega-scale electricity grid storage.

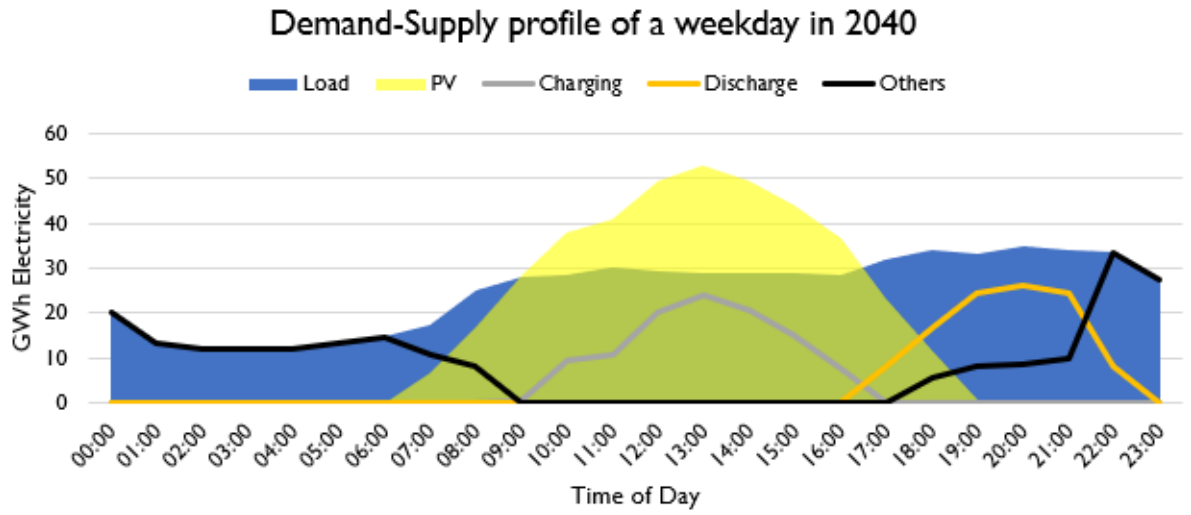


Figure 7.5: A supply-demand profile of a typical day in 2040 for A_M where the total energy from PV is more than 70% in the mix.

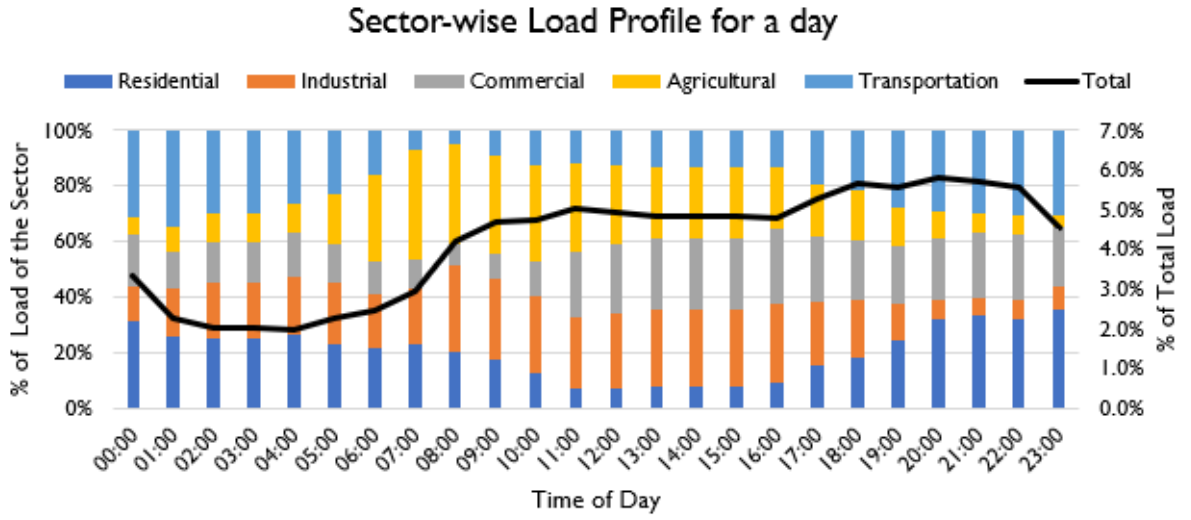


Figure 7.6: The share of total electricity consumed of the the 5 major sectors is given for a 24 hour period in 2040. On the left hand axis, the % of the load from the respective sector in that hour of day is shown. The right hand axis (for the black curve) gives the % of total load for an hour of the day.

While a dynamic optimisation has not been carried out, a high level abstraction can be done to assess the storage capacity needed. The peak demand is expected to go upto nearly 30 GW in 2040. And with the excess of solar energy generated during the day, for example, storage could provide enough energy from peak hours in the evening till night time. In figure 7.5, an example of a demand-supply situation in 2040 is shown where different sources serve the load. The sector-wise shares are shown in 7.6. Total load in the

day is taken at 600 GWh. This is calculated from the projected values in E_{ALT} (the profile is constructed for only one day and is not an optimized one). It gives an idea of how the electricity consumption pattern may look like in 2040. In figure 7.5 only batteries are assumed for storage in grid-scale which are powered by PV.

Figure 7.7 gives the sector wise break up of total electricity consumption in 2040 and compares it with 2017. It was mentioned earlier in chapter 6 that residential segment will experience the highest increase in electricity consumption followed by offices and other buildings (commercial sector) that will experience the next highest increase in consumption. Accordingly the percentages are assumed.

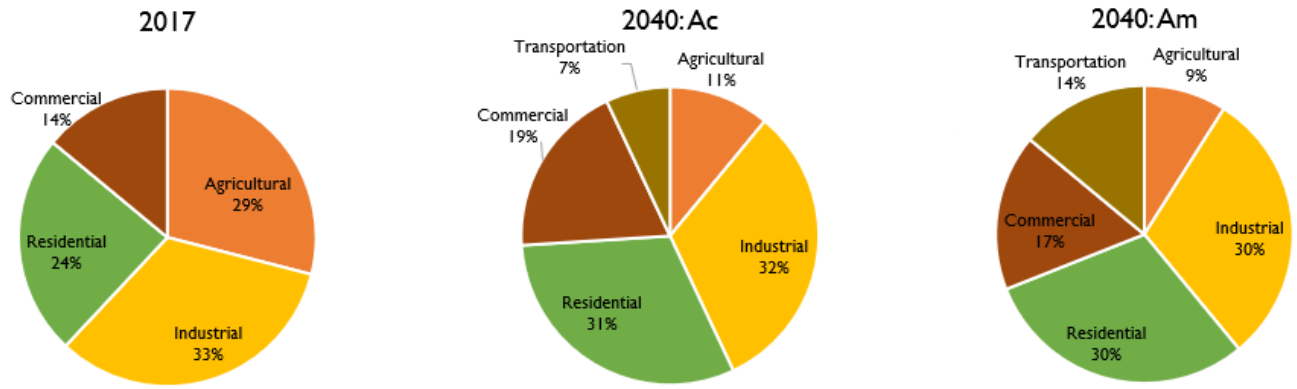


Figure 7.7: Comparing sector-wise electricity shares in 2017 and 2040.

Part III

Backcasting Analysis

8 Analysing Barriers

We are squarely in the middle of the greatest energy transition in history. The era of fossil fuels is over, and the only question now is when the new era will be fully upon us. Economics make its arrival inevitable: Clean energy is less expensive.

Jeremy Leggett

Summary

A detailed analysis of the main barriers,which could act as significant obstacles for achieving the vision, is made in this chapter. The inputs flow mainly from the interviews and thorough analytical discussion is made in some cases. 5 major barriers are discussed and one additional factor of how people can play a role is briefly pointed out.

8.1 Nature of Barriers

While the desired vision was explained in the earlier chapter, it is necessary to understand what barriers are in place that hinder us from achieving the vision. Understanding these will help us in backasting analysis much better. Barriers, especially in terms of institutional, structural, policy and legislative rigidities, or some in terms of political unwillingness, some in terms of lack of financial capacity, etc., have to be looked into. At the same time, there are some drivers too. The most important ones are identified after the interviews and literature study. Some of them were briefly introduced and discussed in the section ?? on PESTEL analysis. This section discusses them in detail. The next section then does a backcasting analysis of *what, how and who*, i.e, what needs to be done, how can it be done and who has to do it. It also gives possible solutions of how the barriers can be addressed. Not addressing them will make the vision, a much bigger challenge than it already is.

What constitutes a barrier? A *barrier is something such as a rule, law, or policy that makes it difficult or impossible for something to happen or be achieved.* In some cases it could also be the existing regime of the socio-technical systems, that hinders or inhibits the way forward. Therefore, what hinders us, or acts as an obstable, from reaching the desired Vision can be considered as a barrier. Thus the barriers that will be discussed here were chosen in such a way that are systemic in nature, meaning that they are spread or affect throughout, system-wide, affecting the economy, market or society as a whole. They have not been labelled or classified as barriers under the headings of each vision element since they are over-arching and affect many areas holistically. The detailed understanding of the barriers are presented here-under.

8.2 Limited view of Decarbonization

Decarbonization is much more than just adding more PV based capacities to the grid. It encompasses addition of RE, reduction of coal power, using alternatives to coal like gas, and electrifying transport, among others. But the state's limited view of decarbonization do not have any of these.

One of the first and foremost alarming problem is the expected 8 GW of coal power in the next 4 years. The decision for this were taken within the last five years and during the same period too, TS installed more than 3.6 GW of solar power and ranks one of the top states in the country in terms of solar installations. While the state government wants to decarbonise, it has no plans to go beyond 5GW of Solar PV (Interview #2). While TSREDCO[1] agrees with the government's commitment to promote RE, this comes as a limited view of decarbonization, that has no other targets beyond 5GW of Solar PV and coal power is promoted much more than Solar PV, whose vast potential outstrips any other source. TSREDCO's stance on this is that to cater to growing needs of ramping power to industrial, domestic baseload and projected EV demand in the non-solar hours, coal power is the only option to look forward to (Interview #2).

Interview #7 suggested switching to gas to solve the problem of power ramping and catering in non-solar hours. While switching to gas can offer a low carbon solution, its availability has often been the major road block. Even if it can be procured, the import dependency shows vulnerability in terms of energy security and can be hampered by global geo-politics[2]. Therefore, gas can only be an intermediate respite if sufficient technology and supply are already in place. If not, it is more sensible to explore and adopt cleaner technologies.

[1] TS Renewable Energy Development Corporation is the state's RE, energy efficiency and conservation and R&D promoter of projects

[2] Similar to the current India-Iran oil trade where India was procuring crude oil at significantly low prices until the US sanctions were hit.

There is no information available to suggest that the other options were fully explored. But from interview #9 it was suggested that there is a lack of understanding of how the battery storage technology works and the associated business model around this, on part of the transmission, distribution companies or TSREDCO, which could be a hindrance to adopt. There are several examples[3] world-wide and within India where Battery storage is used for a peaker plant[4], or as a must run power plant (in addition to several pilot projects). The apprehension raised by TSREDCO regarding lack of technologies available to serve baseload, clearly a battery storage option was not satisfactorily explored.

Further, the targets of SPV that were set are not intrinsically motivated but mandated by policy since they plan upto only 5GW of solar PV by 2022 considering the Renewable Purchase Obligation (RPO) needs and the state power needs (Interview #2). RPO is a mandate set by the Ministry of Power from the central government that dictates a percentage of total electricity consumed by a large consumer or an Electricity Distribution Company (to sell to its consumers), to come from renewables[5] (Mishra, 2018). These targets were set by the central government and thrusted upon states to be achieved.

A similar point, regarding the legislation of central government driving the states, can be made about battery storage technologies. It was pointed out in Interview #2 that there is no policy that mandates the use of Lithium ion or any other battery storage technologies and pilot projects will be taken up when such a directive is given. This reflects a lack of intrinsic desire for change within public institution and the acceptance of the comfort that existing regime offered.

There's an increasing pressure globally to push for renewables and also bring down on coal use, which is a big challenge in itself. With a large upcoming coal capacity and investment lock in period of more than 30 years per a coal power facility, the financial health of the power sector in the coming decades is a point of concern. In the future, the govt may see a huge backlog of coal plants to dis-invest, or liquidate or get rid of, by all the means possible. As long as the motivation is mandated by law and not intrinsically desired, alternative sustainable solutions will not be prioritised. Sometimes, this is despite the favourable economics and advantages of decentralisation, offered by the cleaner solutions. Therefore, the idea of decarbonizaiton has to be expanded to include greater renewables beyond the mandate.

8.3 Tariff Determination

While the Electricity Act, 2003, discussed in section ??, had been a game-changer during its introduction, it has been 15 years since then and new reforms are rushing to be welcomed and replace the older ones. There is however a large institutional resistance especially to that one aspect which has a large political impact is electricity tariff determination. A tariff must be designed in a way so as to recover cost of capital investment in generating, transmitting and distributing equipment, cost of operation, supplies and maintenance of equipment, cost of metering equipment, billing, collection costs and miscellaneous services & should provide with a satisfactory return on the total capital investment, according to Electricity Act, 2003 (J.N. Rai, 2013).

[3] US Department of Energy, Global Energy Storage Database

[4] a power plant that runs during peak power only due to the costs involved setting up

[5] Currently, the RPO is set at 17% of the total electricity consumed. This is further divided into solar and non-solar obligations. The current obligation is to have atleast 6.75% of total energy to come from solar based sources and this will increase in steps up to 10.5% till 2022. Accordingly, non-solar obligation too will increase till the same value and the total RPO will be at 21%

8.3.1 Problem with Low Tariffs

Currently the electricity tariffs in India in general are very low compared to the unit price in many countries (Interview #3). The problem with such low prices is that they dont truly reflect the costs incurred in the entire value chain of electricity generation. In the absence of cost reflective tariff structure, state power utilities are continuously making losses. Further, frequent political intervention does not allow state commission (TSERC) to timely revise tariff structure. Therefore, the companies that operate in this space do not work on sound economic principles. Thus, this is the major reason why only public sector companies work in this space since private companies cannot continue by constantly making losses. As a result additional private investment is stifled in this space since the rules, prices and therefore costs are dictated by actors beyond the control of businesses that are willing to invest.

However, raising them could therefore pose a challenge for the implementing agencies as well the government in power since it could prove unpopulistic or hurt the consumers who cannot afford the higher prices. For example, if the prices were set to reflect the supply-demand situation (or time of use tariffs[6]), higher income households are better able to respond to the price differentials for a positive financial outcome because they have access to and can afford efficient and programmable appliances that could use lesser energy. Disadvantaged households spend a proportionately higher percentage of their income on energy costs (despite using less energy overall than other households) and so are more exposed to the negative impacts of time-varying pricing (J.N. Rai, 2013).

8.3.2 Imapct on DISCOMs

It can thus be seen that if the aspirations to grow and have a future with a new systems and technologies that work differently from the current systems need to be nurtured, new set of rules and policies that can support, aid and help thrive the new investments are needed. Current tariff determination policies therefore is one of the foremost barriers that stops us midway in aspiring to our vision. It inhibits and slows down the growth needed in this sector. One of the major impacts due to this is felt by DISCOMS[7] (Electricity Distribution Companies). DISCOMs procure the electricity from either generator directly or from transmission companies and sell them to consumers and bill them. In this process they pay the generator a certain price per unit to procure the amount of electricity needed and sell them to the consumers, at lower tariff per unit, thus facing low profits or only losses. This problem gets compounded further when cross subsidies (free of charge electricity supply to agricultural sector) are in place.

The losses incurred by DISCOMS throughout the country due to low tariffs was so enormous that the central government created a scheme, UDAY[8], where the debts incurred were borne by the central government and state government in a 75:25 ratio. It may not have achieved the success it hoped but is a mixed bag in general even after many years. This is because, even though the central govt. has taken a share in the financial burden the losses kept mounting since the the tariff determination structure did not change and new losses kept mounting. (Interview #6) To encourage more RE in the total mix, these DISCOMs were mandated to procure more RE under Renewable Purchase Obligation (RPO) as explained earlier, which made the cost of procuring electricity even higher.

[6] ToU Tarrifs: They are offered or imposed on customers primarily by the electricity industry to improve the operation of electricity systems, but are also often promoted by pricing regulators with the objective of increasing economic efficiency. Time-varying pricing could be seen as a mechanism for sharing some of the price risks between the electricity retailer and the customer.

[7] With respect to DISCOMs in Telangana, the information on losses is taken from the 17th Annual Report, Financial statements chapter: balance sheet of financial year 2017 and 2016 which show losses.

[8] Ujjwal DISCOM Assurance Yojana

8.3.3 Case A - Computing Losses in procurement and sale of electricity

Table 8.1: Example to demonstrate the costs incurred, revenues generated and profit/loss made by DISCOMs for 1000 kWh of electricity purchased and sold. All values in INR. (15% of Distribution losses are accounted in the last column, so purchase of 1000 units implies a sale of 850 units.)

Source	Units	Procuring electricity $\frac{Cost}{unit}$	Total Cost (INR)	Total $\frac{Cost}{unit}$ incurred	Revenues per 100 units sold	Profit/ Loss	Profit/Loss per 1000 units (incl. 15% losses)
Case 1							
Coal	1,000	2.00	2,000	2.00	202.50	2.50	21.25
Case 2							
Coal	800	2.00	1,600	2.26	202.50	-23.5	-199.75
Solar	200	3.30	660				
Case 3							
Solar	1,000	3.30	3,300	3.30	202.50	-127.5	-1,083.75

An example is provided in table 8.1 to demonstrate the losses a DISCOM makes in procuring electricity and selling it as 3 cases. Case 1 includes the sale of only coal based electricity. Case 2 involved a 20% mix of Solar and case 3 with electricity from solar only. The per unit price of electricity sold to consumers (tariff) is INR[9] 1.45/unit for 0-50 units and INR 2.60/unit from 51-100 units (Source: TSERC). This slab of 100 units represents nearly two-thirds of total consumers (Govt. of Telangana, 2018). The rest of the consumers consume higher units and the tariffs are accordingly higher. However, DISCOMS make very low profits or only losses from the majority of consumers. It can be seen that selling only coal based power is very marginally beneficial for the DISCOMs in comparison to Solar. While the prices of RE are falling, the existing structure does not incentivise DISCOMs to procure more electricity from solar. Despite the lower prices of coal, the profits made in Case 1 per 1000 units sold are so low that they can be just sufficient to buy less than one kilogram of onion[10].

Since electricity is a concurrent subject and the state government can set its own rules, this too had not been done in Telangana and therefore the DISCOMS in TS too faced similar financial losses. While their financial health can be considered better than what it was earlier, it is no where closer to how a sound business must run. Operating between buying power from utilities and selling it to customers on a loss making basis, DISCOMS are both the strongest as well as the weakest link in the value chain. Strongest, if they are provided the right business environment and weakest, when they are at the receiving end of constant loss making decisions because of not having a say in the setting of rules in their own business.

8.3.4 Case B: Case for Roof top PV for a household consumer

A second example is given that can illustrate how low tariffs weakens the vision of achieving more rooftop PV. Since a consumer already pays a very low price, the economic benefit per kWh that can be obtained by shifting to roof-top is very low. Consider a 3 kW roof-top on the roof of a house. The modules costs come to INR 136,500[11], inverter[12] costs to INR 70,000, installation costs to INR 15,000 and annual maintenance to INR 1000. Therefore, total initial costs of the system come to INR 221,500. The total energy generated is around $4,950kWh$ annually. If a 25 year time period is considered at a 4.5% discount rate, the cost of

[9] Indian National Rupee. 1 EUR = 75 INR

[10] Taken from the Reserve Bank of India's basket of goods prices that is used to compute Consumer Price Index (Inflation)

[11] At INR 65,000 per kW and a 30% subsidy

[12] including one replacement after 15 years

the electricity can be calculated by equation 11 which comes down to INR$\frac{5.32}{kWh}$ (Refer to Appendix A for the equation). Given the costs involved and the size of the PV system considered, we can assume that this household is in a higher socio-economic household. Therefore the electricity consumption is higher and the higher tariffs are applicable.

Assume that the household consumes 400 units per month of electricity on an average (4800 units per year). The price charged by the DISCOMS progressively increases as explained earlier but starts at INR 5 for 0-200 kWh, INR 7.2 for 201-300 kWh and INR 8.5 for 301-400 kWh. These values are much higher than from the earlier example since the average consumption per month is much higher. The monthly PV generation covers only the day time load which is approximately 30% of the total day load (obtained from figure 3.15). This implies an annual 1,707 units of PV electricity consumed. The remaining electricity of nearly 3,000 units is consumed from the grid. Table 8.2 shows the total costs involved and calculates the Pay back time period. Case 2 and Case 3 shown in the table correspond to PV system with and without batteries. While these calculations are simplified, they show the scale of the issue. A 9-12 yr pay back period is a very long time for the scale of the investment considered, despite not considering the rate of inflation that is currently around 2.5%. To put it in perspective, European countries with lesser PV potential than Telangana have a much lower pay back times varying from 7 years in Spain to 12 years in Norway purely due to differences in electricity prices, subsidies, taxes and feed-in tariff regimes (Whitlock, 2019).

Table 8.2: Calculations to show and compare the Pay back Periods for a Rooftop PV system and battery for a house. (All values in INR)

Case 1: Total consumption only from grid		
Source	#Units	Costs (INR)
Grid	4,800	30,840

Case 2: With a Rooftop PV System		
Source	#Units	Costs (INR)
PV	1,707	0
Grid	3,093	16,980
Maintenance: PV		-1,000
Savings: Case 1 - Case 2		12,860
Initial Investments		-221,500
Pay Back Period		∼12 yr

Investment Costs include PV Modules, Inverters, installation charges and battery (for case 3).

Case 3: With Rooftop PV & Battery Storage		
Source	#Units	Costs (INR)
PV+Storage	4,800	0
Grid	0	0
Maintenance: PV + Battery		-1,000
Savings: Case 1 - Case 3		29,840
Initial Investments		-341,500
Pay Back Period		∼9 yr

Therefore improvising tariff structure not only helps debt ridden DISCOMs to function more efficiently but also plays a crucial role for roof-top PV to make a better business case and explore its vast potential.

8.4 EV Policy Paralysis

This problem was briefly discussed in PESTEL analysis earlier. However the nuances of the problem will be presented here and discussed in more detail. The demand for oil is expected to increase continuously for the next decade. There are plans to push efforts in exploring mass scale EV adoption. However, the efforts look misguided and unconclusive due to contradictory tentative plans that are being constantly discussed. While it can be said that the government is thinking out aloud, the stakeholders want to make themselves heard in this discussion.

NITI Aayog has recently opened the stage for opinions from stakeholders when it mentioned that only electric 2 and 3 wheelers should be sold from 2024 and ban ICE 4 wheelers from 2030 (ET Bureau, 2019). However, there is a strong lobbying against this led by Hyundai and Honda, along with Bajaj Auto and TVS

Motor, two of not only India's but world's largest 2 and 3 wheeler manufacturing companies (Dash, 2019). It follows from the government's earlier mandate to move towards BS 6 pollution norms (similar to Euro 6 vehicular pollution norms) 4 years earlier than planned that resulted in more than 10 $ billion investments by the automakers in India to comply to those norms and also work on alternate fuel technologies that would slash pollution levels significantly over the existing BS4 norms.

However this new immediate move to go all electric got the automakers worrying since it would need much longer time to get pay back on these investments already made and also shows an unstable road ahead of the government (Interview #11). New developments are unfolding within short times in this space as the government is vacillating on an integrated EV policy. As the subject comes under the central government Ministry of Transport and Ministry of Heavy Industries, state governments do not have a role to play immediately, however, they can independently provide sops to boost either sale or setting up manufacturing units. But due to the central government's uncertain policy steps, state governments have refrained from taking any action[13].

8.5 Losses & Efficiency

The transmission and distribution losses together account for nearly 19% of the total power losses in the state (Source: Ministry of Power). The target set by central Ministry of Power was to be at 15%. Despite investments of more than $4 billion in the last five years, the losses are yet to be arrested. This means that 1 unit of energy saved at user's end is 1.2 units of energy avoided. The potential of savings that can be obtained in this area is immense. Precious amounts of energy is lost in transportation from one point to another. Decentralised installations can help is keeping the losses to a minimum to to the smaller distances involved. For example, the energy demand for agriculture will boom in the short term and the same for rural households will grow in the short and long term and an example was shown in table 6.1. This demand can be met through greater off-grid projects and micro-grids that can be set up to cater to them instead of serving through coal based power. This can keep the power losses (and therefore associated commercial[14] losses) lower.

It was discussed in Chapter 6 that buildings sector energy consumption will grow the most and the fastest led by space cooling demand requirements. Energy conservation within building code implementation can lead to nearly 34% less energy use. Net Zero energy buildings is another domain that has not been explored. Further, with more energy efficienct cooling systems, immense savings are possible. Bureau of Energy Efficiency (BEE) is the nodal agency in the country that oversees efficiency regulations for electrical appliances, by rating a device from 1 to 5 stars with 1 being the least efficient and 5, the most efficient. In the July of 2019, Energy Efficiency Services Limited[15] along with a leading AC manufacturer released the most energy efficient ACs each of which can annually save 2.9 MWh in comparison to the most efficient ACs sold in the market. If a 100,000 of them are sold, they can collectively save nearly 300 GWh of electricity at the consumption end. The same at the generation end can be 357 GWh. This is nearly .63% of the total electricity consumption of Telangana in 2017.

Currently, Air conditioners below 3 stars are not allowed for sale and the AC market is still yet to grow. This boom is likely to happen already with increasing heat waves and hotter summers year-on-year. Tremendous amount of opportunity is lost if not utilized.

[13] This is the status quo at the time of writing this report as of 9 September 2019

[14] Included in the AT&C or Aggregate Commercial and Technical losses which indicates the difference between the energy input in the distribution network and revenue collected for the same

[15] EESL is an energy service company (ESCO) of the Government of India and is the world's largest public ESCO. It was formed under Ministry of Power to facilitate energy efficiency projects.

8.6 Creation and making access to Financial capital

One of the most important question that has to be answered is financing the transition. While there are barriers involved in accessing capital needed to raise to fund clean energy projects, electrifying the fleet of public transportation, providing subsidies to manufacturers or end users, what precedes these question is that of how to obtain the large capital that is needed for achieving this vision? It was already discussed earlier that in developing and emerging economies, available capital goes into providing the necessary infrastructure that the citizenry was wither deprived of or dilapidated remnants of older regime. It is also necessary for raising social and human capital most importantly in the form of education and health care, which are some of the primary provisions that governments in general are tasked to provide.

In 2017, the state spent nearly 50% of its annual expenditure on agriculture, irrigation, healthcare, rural development, education, and social welfare activities like employment guarantee schemes, housing for the poor, etc. The fiscal deficit of the state's annual budget is hovering around 3.5% to 4%. With such competing priorities, governments in general in India, are pressed to prioritize the available scarce finance (Interviews #4, #5, #7). In such a context, the the priority is therefore on providing what is necessary at the lowest possible costs to the exchequer and not on lowest externality costs.

Further, an example can be given with respect to roof-top PV funding issues. A challenge for the slow deployment of rooftop solar PV, apart from lower tariffs, is the limited availability of financing. Rooftop projects, being smaller in size compared to utility-scale projects, banks/financial institutions face significant challenges, one of which is collateral security from small enterprise or residential customers. Debt funding (money borrowed, in this case from banks) available through domestic sources is at a very high interest rate, which makes the projects financially unviable. Since the sector is still gaining maturity in terms of size and generation (capacity utilisation factors), the funding risk is a major barrier faced by financial institutions (Amit Kumar, 2018). In this sense, obtaining capital for the realization of the vision and finding ways of making that capital accessible at the right time to those in need by addressing the associated barriers, are both crucial to be looked into.

8.7 People driving the change

Transition from a conventional coal based power system to a Renewable energy system entails a monumental transition in policy, infrastructure and user behaviour; most importantly they are spread out over a long time-frame. It is a well known fact that while India is the third largest global green house gas emitter, the per-capita emission is one of the lowest, largely owing to its high population and a significant population living in energy poverty. However, while this is going to change in the future when there will be sufficient energy accessibility and affordability, the per-capita emissions will rise subsequently polluting the cities. Due to this, the current political willingness in this democratic set-up favours energy accessibility and affordability and not on sustainability.

Most people are aware of the changing environment, water scarcity problems, the unseasonal rains that wreak havoc through floods, heat waves making every summer hotter than the previous one, etc (Interview #13). Recently in August 2019, the floods in southern and western parts of India in Kerala, Karnataka and Maharashtra were, without doubt, aggravated by short-sighted development that ignored the consequence of exploiting the Western Ghats in the manner this has happened and the poor urban planning that followed. However, all these events are not linked well in the minds of people. 'We are not a mature society to protest for rights violation in case of clean air or water'(Interview #5).

While India has had a significant impact in the past with respect environmental activism on deforestation,

construction of dams in ecologically sensitive regions, water pollution, etc., it was perhaps because they are tangible and visible resources unlike air that is, in comparison not strictly tangible natural resoure that has no price, yet. Should rights and activism based approach counter the regime and lead to the vision that also intends to improve the quality of air through sustainable energy and cleaner transportation? This aspect is perhaps the most important since people are at the centre of decision making on the use of the products. The way energy is generated and used, food is grown, water is consumed, or land is utilised, have all consequences on the environment and therefore climate change. Therefore changing behaviour must be a crucial focus (Interview #13).

There is a significantly large population that is coming out of poverty and many others who have just begun to enjoy the fruits of economic prosperity. 'While it is not right in asking them to pay more to fund a cleaner future, we have to figure a way out to pass this additional cost to those who can afford'(Interview #5). It is therefore important to pay attention to the thought of what role people can play.

9 Backcasting Analysis: STRAPSETT

> We are squarely in the middle of the greatest energy transition in history. The era of fossil fuels is over, and the only question now is when the new era will be fully upon us. Economics make its arrival inevitable: Clean energy is less expensive.
>
> Jeremy Leggett

Summary

Backcasting analysis is made which provides pathways called STRAPSETT: Strategic Transition Pathways towards Sustainable Energy Technologies for Telangana. Possible solutions are offered to address the barriers stated earlier.

Now that the major barriers are discussed, this chapter will try to address some of them and facilitate enablers in the form of suggestions and recommendations to the stakeholders to achieve the vision. The backasting analysis done here for A_C and A_M together paves way for STRAPSETT: *Strategic Transition Pathways towards Sustainable Energy Technologies for Telanagana*. While what needs to be done, which is explained here, is the same for both A_C and A_M, however the rate at which they have to be done varies significantly, especially in terms of targets to be achieved in the given time. Figures 9.1 and 9.2 show the percentages of the power capacities year-wise for A_C and A_M respectively. The use of the word decarbonization in this analysis implies the journey of the transition to low or zero carbon emissions and not a completely decarbonised end state.

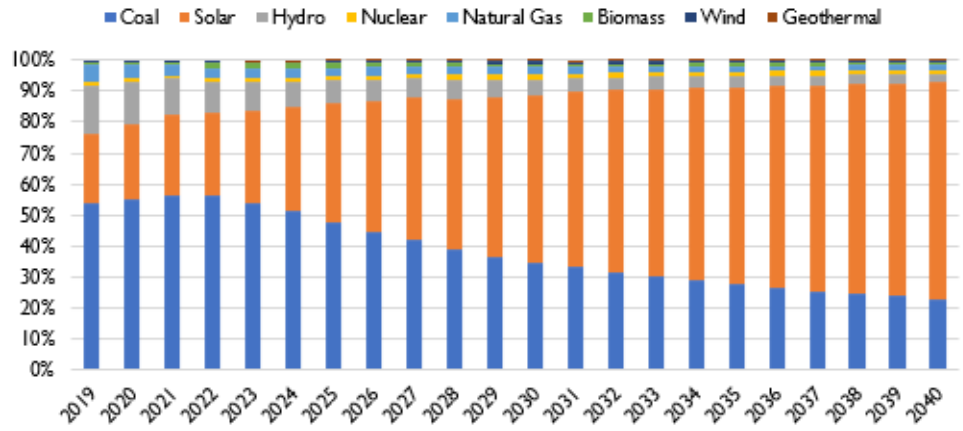


Figure 9.1: The cumulative total shares of installed capacities year-by-year in A_C.

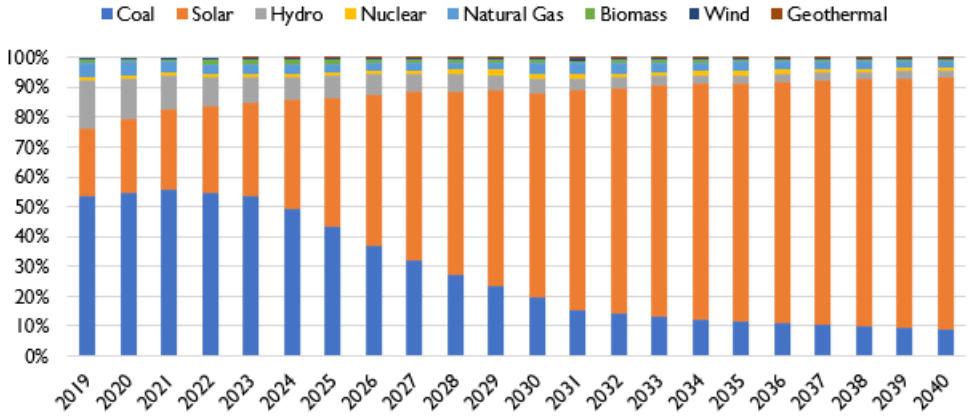


Figure 9.2: The cumulative total shares of installed capacities year-by-year in A_M.

9.1 Financing the vision

The first question in the mind that comes after seeing the targets in the vision is, *Who pays for it*? Or where does the necessary capital flow from? Should the entire PV modules and storage capacity be manufactured here or a share of it be imported? Which one is cheaper? (And which one requires lesser energy in the process?) Financing energy transition is a subject of discussion around the world and is not a novel encountered problem. Different countries adopted different strategies to address is. In China for example, the severe problem of air pollution in the city of Shenzhen forced the municipality and the Chinese federal government to act and they converted all public transportation buses to electric within less than 4 years. They implemented this in major cities and today have nearly 421,000 electric buses which is 99% of the world numbers. This

was of course possible through generous subsidies from the government (Li and Strachan, 2017; Eckhouse, 2019).

Generally in India, bank debt has been the primary source of domestic currency capital for infrastructure projects. With competing demands on this limited pool of capital (which is highly regulated by the Reserve Bank of India), the bond market could potentially be a critical source available for making debt funds available to finance energy transition (Dutt et al., 2019). Bond is an instrument that is used by governments or companies to raise large amounts of capital through promising an interest rate on them to the investors/buyers of the bond and paying the money back to them once the time period of the bond ends. In this regard, green bonds are an attractive option to look at (Interview #4). Green bonds are a category of bonds usually raised specifically for clean energy projects. Both the government as well as private companies can use this as a tool to raise capital for projects.

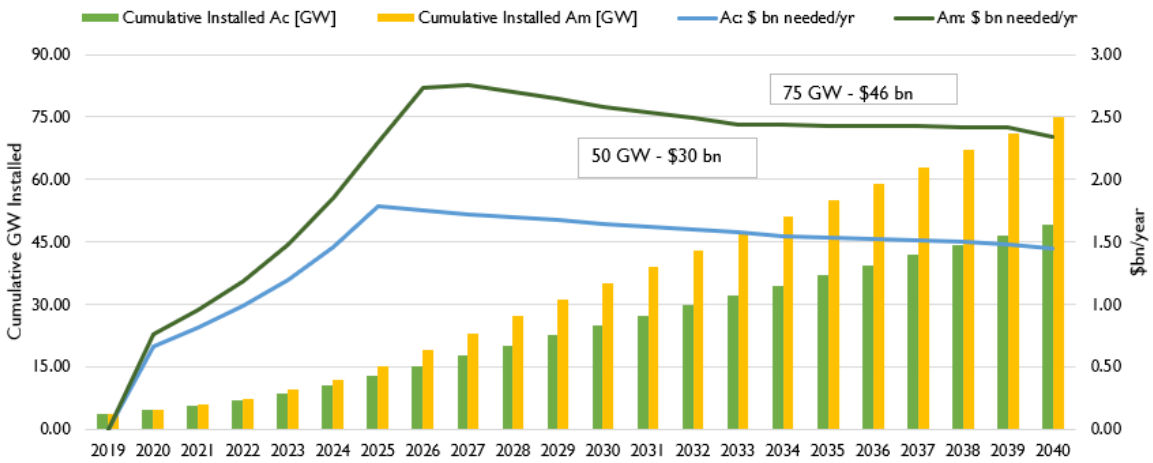


Figure 9.3: Showing the GW of PV needed in both cases and comparing their costs in A_C and A_M.

From the figure 9.3 for example, the capital needed[1] for 75 GW of PV in A_M is about $46 bn. This is excluding the additional transmission and distribution infrastructure necessary for it. In a geographic location like India blessed with abundant solar energy, utility scale projects are seeing extremely low prices for electricity with fiercely increasing competition and the high volumes of energy possible to generate due to the local conditions. Due to this, India is already the world's cheapest solar power producer at $793 per kW for a utility scale project installation (International Energy Agency, 2018). As a result, significantly large investments are coming from private sector too because of the lucrative profits that they offer.

A similar analysis could be done by including the total costs for PV, storage and the transmission infrastructure shown in figures 9.4 and 9.5. We can see that, in the beginning, less than $1 billion will be needed per year in raising the required infrastructure. The costs go higher to nearly $2.4 billion and $3.5 billion in A_C and A_M respectively. This slower growth in the beginning is planned to have the state build the necessary capacity before it can be accelerated. The total investment needed is about $39 billion in A_C and $60 billion in A_M. It represents one third and one half of the total state GDP of 2018 (120 billion US$). If this amount is averaged over the next 21 years, it represents, less than 0.5% of the state GDP every year, including the year 2026 in A_M where $3.6 billion is needed.

The split up can be seen where PV takes a major share of the total costs, followed by battery storage, and then T&D (Transmission & Distribution) infra. Over and above this, additional costs will be incurred over the investment required to set up the facilities. However, it should be noted that the money will be coming from state government as well from private investment which will have a bigger share as is being seen now in terms of ownership of PV plants. New storage projects are seeing interest from private companies. It would

[1]Refer section B.3 in Appendix B for assumptions used.

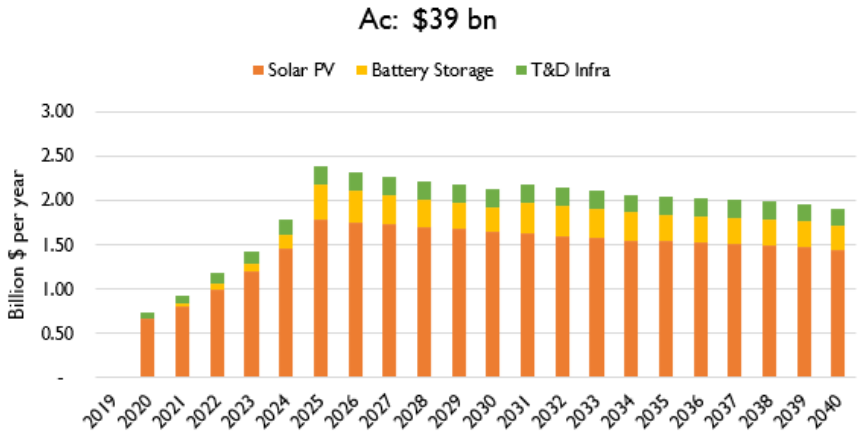


Figure 9.4: It would cost around 39 billion US$ over a 21 year timeline for A_C that amounts to less than 1% of the state's GDP in terms of capital needed per year. The share of PV in the total capital is more than 75%.

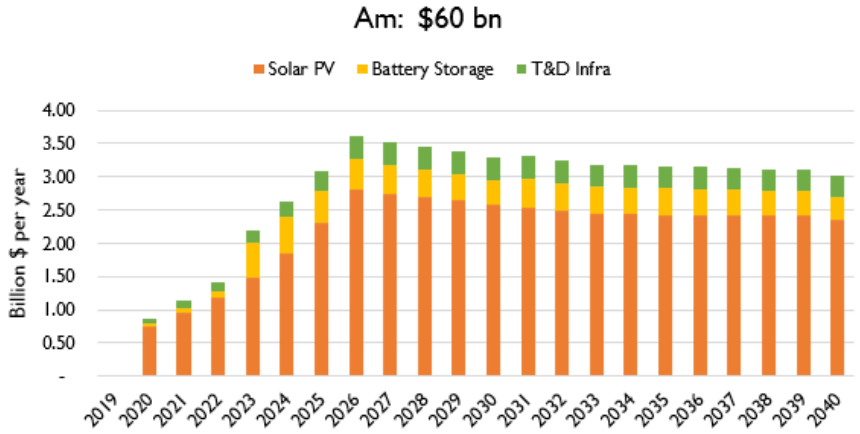


Figure 9.5: The capital needed in A_M is 60 billion US$ and the share of PV is the nearly same as in A_C in the total capital.

be desirable for the investment in T&D to also come from both the above sources unlike the current model where only the DISCOMs which are under the state govt. bear the load. Therefore, there is a significant capital hunger that can possible be explored from green bond market.

India's corporate bond market is still in nascent stages and the bond market in general needs significant policy advances to be made for it to reach market maturity (Dutt et al., 2019). However it has improved in the last few years and realising this as an opportunity for accessing capital for RE projects, a number of issuances were made by Indian financial entities and public sector entities. In the electric mobility sector, the issuance of green asset-backed securities[2] by financial institutions presents a ready avenue for issuance of green bonds to finance the purchase of EVs by mobility provider. Of course, the readiness to issue bonds also depends on the issuer's credit worthiness, which in simple terms implies the suitability of the issuer to receive financial credit based on their reliability to pay back. India Credit Rating Agency[3] rated Telangana state government A+, which gives the TS government an excellent option to raise capital through green bonds and eventually as the bond market matures, have more private companies do the same. Therefore, this presents an reasonably exciting opportunity to look at and explore.

[2]Green Asset backed Securities: Green ABS are financial instruments that help raise capital by mortgaging an asset for security of the capital amount raised, in this case if the capital finances low carbon initiatives, climate change related projects, etc.

[3]ICRA Limited was set up in 1991 by leading financial/investment institutions, commercial banks and financial services companies as an independent and professional investment Information and Credit Rating Agency. The international Credit Rating Agency Moody's Investors Service is ICRA's largest shareholder.

Sufficient information and awareness on the up and growing new technologies is also needed for these financial agencies. Lenders (banks and financial institutions) should be made aware of the specific requirements and characteristics of RE projects so that they can take informed decisions, resulting in reduced risk perceptions, and hence better terms of finance. Beyond same, sector specific financing mechanism (low cost money based refinancing, interest subvention etc.) need to be structured avoiding the possibilities of market distortions (NITI Aayog et al., 2016).

9.2 Tariff Management

The problems associated with lack of a proper tariff structure and the barriers it poses were discussed sufficiently earlier. Therefore, structuring reforms such that utility tariffs are reflective of true costs and system-wide efficiencies (or inefficiencies) is the need of the hour. It was mentioned earlier that DISCOMS are at the receiving end of the outcomes of changes in tariffs made by forces outside their control. Therefore, strengthening of DISCOMS is at the heart of tariff management. It has to be realised that moving towards a transformative way of energy system entails similar level changes in the current system without which this entire exercise is a wasteful use of time. DISCOMS are the strongest link in the electricity value chain and giving them independence in managing their business is the most basic requirement if the power sector has to develop. This, infact has held back a number of missed opportunities. Who can make this happen? TSERC, the power regulatory organization of the state. Some of the ways of doing it are discussed.

9.2.1 Time of Day Tariff

Time of Day (or TOD) tariff is a tariff structure in which different rates are applicable for use of electricity at different time of the day in the morning, noon, evening and night. This can contribute positively towards RE integration when by, for example, charging the cost of energy from PV at lower prices in the day time when it is in abundance and charging it at higher price during peak times when the energy is expected to come from battery storage charged from additional PV power during the day. In this way, this could also help the peaker storage plants planned for the future scenarios to recover costs and function economically.

9.2.2 Temporal Pricing

This is a form of TOD based pricing that is applicable for large solar power producers who directly connect their solar farms to the grid. The energy generated by them is purchased by DISCOMs and sold to consumers. Generally sunlight is available for 9-11 hours in the day during which energy generation takes place. After that, there is no generation, and therefore no usage of distribution infrastructure. But solar farm owners pay the DISCOMs for utilizing the infrastructure for 100% of the time in a 24 hour time even if they utilize less than 50% of the time. An alternative to this must be adopted through a temporal pricing, i.e., depending on the time the infrastructure is used, solar farm owners to be billed accordingly. (from Interviews #3 and #7)

9.2.3 Eliminating Cross subsidies

Cross subsidies refer to the free power provided to agriculture sector. By eliminating them, half the financial restraints disappear and bad debts will not get compounded (Interview #3). Supply of electricity to agricul-

ture sector can be done by dedicated feeders[4]. Separation of electricity feeders for agriculture from domestic and industrial load would be a measure in favour of grid security. Separate feeders would enable servicing of agricultural demand during the hours of high solar generation. This would enable improved minimum loads for conventional power and greater integration of renewable energy(NITI Aayog et al., 2016). This is the advantage of decentralised renewable sources that is not being leveraged.

Instead of giving free power, farmers can be enabled to share the cost of buying solar pumpsets, for example in a 25:75 proportion, in which the DISCOMS can be made a part of and therefore can eventually lower the losses or recuperate much faster. This is an effective option that has not yet been looked into (Interview #7). Another option can be to provide free power only during peak solar energy generation timings during the day and charge them for rest of the time. Or the tariff can be regulated to reflect the share of solar energy during the day time as a percentage of the tariff. If 50% of the energy during a point in the day time comes from solar, then the tariff can be charged at 50% of the stipulated tariff. While these are less than ideal, they can be explored since they could have lesser political resistance with reduced losses for DISCOMS.

9.2.4 Financial Health of DISCOMs

If the financial health of DISCOMS improve with better tariff structure, this can give a greater scope for them to invest in improving the distribution infrastructure which contributes to nearly 15% of the losses in addition to transmission losses of 3.5%. The better their financial health, the stronger the distribution operations become and more robust the business ecosystem transforms to. As a result, DISCOMS themselves could invest in decentralised PV and own them thereby bringing the procurement costs to nearly 0 and can reap benefits. There are some suggestions made to amend the Electricity Act to unbundle DISCOM network and business operations too which will definitely improve the operational efficiency, as has been seen in many countries around the world (Interview #7).

The bigger benefits could be entry of private companies in the DISCOM business that can further improve economic efficiency and bring the prices down. As of now, by legislation, private companies can be allowed to form a DISCOM however, given the current boundaries within which they operate, businesses has shied away from any investment. Despite unbundling the electricity value chain in 2004, till date not a single private company has come up in this space, this shows the high economic unviability (Agrawal et al., 2017). This can go on to have a great potential since, if nearly 50 GW worth of investments are needed by 2040 and if the current systems continue to operate in the conventional way, it is not only difficult but the transition becomes economically unviable due to the unsoundness of the business operations which will also compound the bad debts. The total energy volume is expected to triple by 2040 and this should be considered as an opportunity for new generation DISCOMS to work on only clean energy procurement and sale.

9.2.5 Feed in Tariffs

Currently only net metering is in place that does not sufficiently benefit a building with roof-top PV that generates more than it consumes from the grid. That is, if a roof top PV system generates 100 units and the building consumes 50 units of electricity from the grid and the PV system each, the additional 50 units are wasted and are not compensated to the owner of the PV system. However, with a gross metering in place, the billing would deduct the units of electricity consumed from the grid and pay a price per unit of electricity (from PV system) that is fed onto the grid. In such a case, the DISCOM is responsible to pay the PV system owner for the gross consumption (positive if units fed into grid is higher than units consumed

[4]Feeders are the power lines through which electricity is transmitted in power systems. Feeder transmits power from Generating station or substation to the distribution points.

from the grid). Therefore, a Feed-in-Tariff should be eventually introduced once the electricity tariffs have been rationalised. This would therefore help the consumers of electricity to become prosumers.

Irrespective of A_C or A_M, these measures are needed to improve the power sector. They technically, operationally and economically improve the functioning of the system and thus strengthen DISCOMs as well as to convert the consumers to prosumers.

9.3 Low Carbon Transition in Transportation

A state govt. agency interviewed (TSREDCO) was of the opinion opinion that the business sector in clean energy space is poised to grow well (Interview #2). But is being stunted due to a lack of a proper vision through stable policies from the government. In the area of EVs, this was clearly explained. For Telangana, it was seen in figures 6.5 and 6.6 that despite being a small share in the total number of vehicles in the state, diesel consumption is nearly 3 times more than that of eptrol consumption. The kilometers driven for diesel vehicles is significantly higher than that of gasoline ones. This presents an area of opportunity where the vision can be concretised through action. As explained before, TSRTC[5] can set a goal of achieving 100% electrification of all their current 10,000 and projected 15,000 diesel buses by 2040. In fact, a target that is much earlier is definitely possible. Apart from this, the current buses that have a significantly long time line can be retrofitted with CNG, CBG or HCNG[6] kits that significantly bring down the pollution levels in the interim. It is evident from the central government that their frequent goal post shifting has not given any favourable response from the industry, TS must make use of this gap in the low carbon transition of its public transportation system.

IOC, that is tasked with the responsibility of the fuel's availability, has further clarified about the availability of these alternate fuels to the states that first ask for it. Therefore TS should go for these alternate fuels and make them a part of the supply chain since these do not need additional large capital. One of the major concerns with diesel combustion is the release of PM 2.5 and not carbon dioxide emissions. PM 2.5 are fine particulate matter released during the fuel combustion process into air which have impacts on climate and precipitation that adversely affect human health, in addition to direct inhalation[7]. While gasoline vehicles release greater quantum of carbon dioxide emissions, diesel vehicles are chiefly responsible for these harmful carcinogenic (in some cases) particulate matter. In certain industrial areas and rush hour peak traffic in Hyderabad, for example, a PM 2.5 value of more than 120 $\frac{\mu g}{m^3}$ (on a weekday, in August. Source: US AQI station data) was measured. The safe limit was below 40. Shifting all the public transportation buses to low carbon alternatives can therefore show a significant in the quality of air in cities.

To continue the pathway for A_M, a similar strategy should be implemented for the diesel powered taxi segment that is growing at a breakneck pace. The encouraging news here is that in the FAME subsidies given in phase 1 and now being given in phase 2 mainly benefitted the fleet aggregators (Interview #9 and #10). The same extends not just for cars, but also for 2W and 3W that are offered for either delivery or logistics market. Fleet aggregators are companies who provide vehicles in bulk numbers as a service to individuals, corporations or governments on lease for a long period of time. This comes under a business segment called Mobility-as-a-Service (MaaS). They have the largest kilometers driven per day and going electric makes sense all the more. How much economical? Ola Cabs, a ride sharing and hailing provider, piloted a project in the

[5] The state owned public transporter

[6] Compressed Natural Gas, Compressed Bio-gas, Hydrogen mixed Compressed Natural Gas which have developed as alternate fuels.

[7] Worldwide exposure to PM2.5 contributed to 4.1 million deaths from heart disease and stroke, lung cancer, chronic lung disease, and respiratory infections in 2016. Source: Wolrd Health Organization

city of Nagpur by providing only electric 3W and 4W, clocking more than 7.5 million kilometers. It has produced a comprehensive report (Arora and Raman, 2019) with definitive conclusions after operating nearly for 18 months from which the following 2 points are taken.

1. The success of electric mobility is hinged on leveraging shared mobility
2. Vehicle segment prioritization with an eye on TCO[8] viability is at the heart of EV adoption drive across the country.

What these 2 points means are that while high upfront costs, lack of charging infrastructure and perception of uncertainty in the performance of a battery powered vehicle may hold back rapid adoption of e-mobility for private users, fleet operators are potential early adopters due to business sensitivity to operating costs. The report mentions that "...when an electric four-wheeler is compared to an ICE powered 4W - it provides operational savings of INR 3.07/km and INR 4.57/km to fleet operators and private owners respectively. The high upfront costs get recovered in five years for a fleet operator, which takes almost 11.5 years when driven for private use". Therefore due to these low operating costs, commercial and public utility vehicles have more compelling economics when compared with private / passenger-owned vehicles.

In chapter 4 microalgae was considered to calculate the potential of bio-diesel. Further research is required in this area to show how much of it can be actually considered and used for making biodiesel. There are no plans on ground yet and so this must be thoroughly explored, given the vast potential is carries.

One thing to be remembered here is that decarbonization efforts in electricity should precede the decarbonization efforts in transportation sector.

9.4 Creation of capacity

With the capital from green bonds, the guaranteed demand growing exponentially for both PV as well as storage technologies, it is necessary to have a security for their capacity to manufacture to keep the system costs lower and keep import dependency at bay. STRAPSETT envisions that while shift to clean energy technologies must happen and the oil import dependy must come down, this should be the case when the domestic manufacturing capabilities for these new technologies should be strengthened. As of 2018, 90% of the solar panels in India are imported from China. This state of affairs should not continue.

A sufficient manufacturing capabilities need to be set. The National Storage Mission[9] document released by NITI Aayog earlier in February 2019 expects nearly 3,500 GWh battery storage market potential in India if leveraged, pegged at $300 bn. According to it, "domestic battery manufacturing to supply the transition to EVs is an important market opportunity would bring economic and social benefits from reduced oil imports, improved public health, and increased integration of renewable energy supplies into the electric grid". This analysis estimates that 25 to 40% of the total economic opportunity represented by battery manufacturing for India's EV ambitions can be captured in India even under the least favorable scenario, where India imports all lithium-ion cells and assembles these cells into battery packs.

Telangana should grab the opportunity here to set up the domestic manufacturing capacity in this context for both storage as well as solar PV modules. By enabling large manufacturing base for local manufacturers, competition can be expected to lower the prices. Developing battery pack manufacturing capacity, initially scaling supply chain and then scaling end-to-end manufacturing capacity for batteries, particularly focusing on battery cell capacity, and eventually capitalizing on research and development is the strategy that has to be adopted (NITI Aayog and Rocky Mountain Institute, 2017). With demand coming in from EVs as well,

[8] Total Cost of Ownership: in simple words TCO is the cost of a full operating lease of the vehicle over its total lease duration
[9] NSM shows the potential of battery storage technologies possible and sets a roadmap to achieve it.

investing in storage manufacturing capacity is necessary. A split up of GWh of storage capacities needed (cumulatively) is shown in figure 9.6.

(Interviews #9, #10) Battery storage should be extensively promoted using strong credit and subsidy mechanisms at manufacturer's level instead of market level for end user. This promotes greater efficiency through competitive markets. Policy should also promote incentives for battery storage at household and community levels in-addition to large grid level storage since this is a highly untapped market and has got a lot of potential through the residential roof top PV. Community level implies large apartments or gated societies with high density of people. Tapping into this market can also be an effective way of dealing with Demand side management related issues in the future.

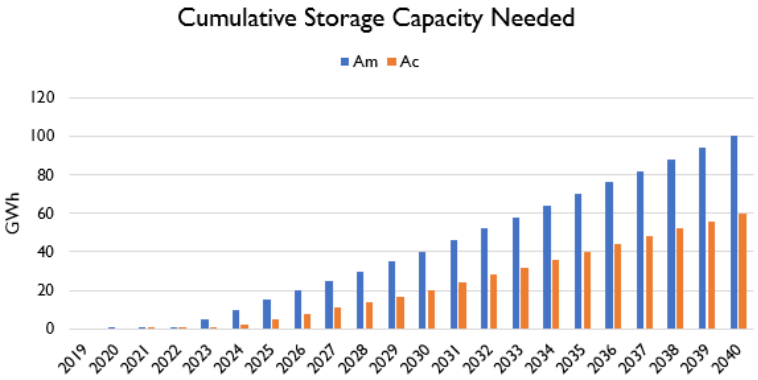


Figure 9.6: Cumulative Storage Capacities needed in GWh in A_M and A_C.

Like installed capacity target, state should also set a manufacturing capacity target for both PV and storage, or else imports will continue to flood the market. For A_C the target is 60 GWh and for A_M the target is 100 GWh. This includes for both electricity as well as transportation sector. In A_C it can be seen that atleast 3 GWh per year will be needed from 2025 that will increase to 4 GWh per year. In A_M even more rapid growth will be needed starting at 5 GWh per year and then increasing to 6 GWh per year.

Finally, all non-financial support options should be made available like project development, policy support, legislative enablers, and coordinated implementation ecosystem. Such interventions are critical to reach the targets. The ecosystems should also ensure that all direct and indirect incentives should get reflected in the tariff of RE at the procurement end. Further the incentive design and procurement mechanism should be specific to the characteristics of resource and technology under consideration.

9.5 Closure of Coal power

While this was briefly discussed in the interviews, the collective opinions resonate on one point: coal free scenario is not planned any time soon. Nevertheless it is important to address this point, explore and offer alternatives possible.

An important task of decarbonization that has to be done if the A_M pathway is adopted is the shut down of nearly 8 GW of coal power plants. How can this be achieved? The role of coal power needs to be re-thought of. Gradual subsitution of fossil fuels with RE is usually the way forward. However, it is not an easy task to do so. The Power Ministry's (of the Central government) thrust on increasing the Renewable Purchase Obligation (RPO) as discussed earlier is a method of decarbonization by increasing the total share of RE in the energy mix. However the cost of procuring electricity for the DISCOMs will increase leading to even further losses. But the prices of RE are gradually dropping. Therefore, Power Ministry's idea of decarbonization must go beyond increasing the RPO and must extend to closure of coal power plants, which then complements the RPOs. Politicians should create the conditions technically, economically and politically feasible to achieve the closure. The major hindrance here is from within the government itself since the power plants are owned by the state government and central government companies.

Alternatives like carbon taxes and cap-and-trade system[10] should be explored. This is because a carbon market can be cheaper way (than pursuing RPO) since producers of coal power have the flexibility to respond to a price on carbon with emissions reduction strategies that minimise their costs. This flexibility is constrained when electricity sector-specific targets are introduced through mandating RPOs. It was earlier demonstrated with example that if renewable electricity costs are higher than the average cost of electricity, a higher share of RE makes electricity costlier. But, if the price of RE drops to such an extent that it gets cheaper than coal power and if carbon tax makes coal power pricier than RE, then an advantageous situation is obtained where coal meets natural closure eventually. Further, the use of a cap-and-trade system could limit the availability of coal power thereby creating a scarcity which incentivises DISCOMs to push more RE. (This assumes a situation with improved tariff rates to effectively make the closure happen.)

9.6 Role of Citizens

The social and economic incentive for change for an individual and community must be explored by providing people with sufficient knowledge on the right practices. A multi-stakeholder engagement led climate literacy and awareness program must be initiated. Discussions on sustainable practices must be made mainstream in the press and also at public discussions. Improved awareness at the policy and government level, at the community and neighbourhood level, in institutions, as well as fostering individual and personal actions is necessary. Customer awareness about energy efficient appliances too must be a part of this climate literacy and increase.

9.6.1 Climate Literacy & Action in Pune

In 2018, in the city of Pune in India, a number of concerned citizens, subject matter experts and 2 organizations[11] got together and organized a workshop on 'Climate Literacy & Action in Pune'. It focussed on the following 2 key questions: If Pune aims to become Carbon Neutral by 2030,

1. What are the key sectors of interest, and the key actions to be taken in these sectors?
2. How can the public be engaged in these actions at individual and collective levels?

They prepared a report with a definitive framework and proposals for action plan for public engagement. Education for 'Climate Positive Action'empowers people to change the way they think and work towards a sustainable future. A widespread discussion leading to action, of making choices about products and services and how they are designed, for people to have a decent life, which energy makes possible âĂŞ what type of roads, buildings, land use, public infrastructure do people need in cities, what type of transportation system, waste and water management system, what happens with hills, streams and rivers, and what are our sources of electricity. The idea is to strike a chord with individual and collective notions, practices and responses on actions that can be either carbon neutral or carbon negative, in other words actions that can create a positive climate impact.

[10] Emissions trading or cap and trade system is a market-based approach to controlling pollution by providing economic incentives for achieving reductions in the emissions of pollutants.

[11] 1. Pune International Centre; 2. Centre for Environment Education.

9.6.2 Rally for Rivers

An example of a highly successful movement from the people is '*Rally for Rivers*'. It was headed by a Not-for-Profit NGO Isha Foundation along with 25 scientists & lawmakers and a university. It was launched in September 2017 to revitalize India's rapidly depleting rivers. Thousands of people volunteered and personally drove over 9300 kms through 16 states to raise awareness about the dire situation of perennial rivers drying up. It became the largest public-endorsed, mass awareness campaign in the recent times, and supported by over 162 million people, it has become the world's largest ecological movement. It provides a comprehensive solution to save India'rivers, and is unique in its structure as a primarily economic program with a significant ecological impact. They prepared the 'Revitalization of Rivers in India'draft policy with recommendations to the national and state governments and handed it to the Prime Minister Narendra Modi. They are now focusing on rapid implementation of the solution through detailed studies and on-the-ground action in several states. The proposed plan is to plant trees that would cover a border two-thirds of a mile wide and stretch on either side of the country's major rivers, which is the simplest way to revitalize the waterways, since planting trees can increase rainfall and replenish groundwater supplies[12].

9.6.3 Project Drawdown

Project Drawdown is a research organization that reviews, analyses, and identifies the most viable global climate solutions, and shares these findings. It 'partners with communities, policy-makers, non-profits, businesses, investors, and philanthropists to identify and deploy science-based, effective climate solutions, as quickly, safely, and equitably as possible'. Their solutions are spread across the fields of Energy, Food, Women & Girls, Buildings, Land use, Materials, and Transport. According to Project Drawdown Report Hawken (2017), for example, education of young girls has the 6th highest potential of bringing down carbon emissions in the form of family planning, educated choices, and delayed marriage, globally.

The report ranks the action based on the potential amount of emissions it can offset. For example, at a global level, Refrigerant materials rank 1, wind turbines at 2, food waste at 3, forest management at 5 and solar modules at 10 and so on. It develops an action plan most suitable to a particular region or country by collaborating with institutions working there. This work connects the issues affecting climate change on a higher plane of systems thinking perspective and helps create action plan that is regionally suitable. Aspects like water management, land management, food waste, etc., are much more localized issues which require local actions. People at regional levels can be involved with these action plans and participate in formulating, implementing and driving change at grass roots level.

[12] Source: Isha Foundation and National Geographic News

10 Conclusions, Recommendations & Reflections

> There is perhaps no better demonstration of the folly of human conceits than this distant image of our tiny world. To me, it underscores our responsibility to deal more kindly with one another, and to preserve and cherish the pale blue dot, the only home we've ever known. It is the only world known so far to harbor life. There is nowhere else, at least in the near future, to which our species could migrate.
>
> Carl Sagan, American Astrophysicist

Summary

This chapter consists of 3 sections. Firstly starting with the conclusion that establish a connection with the research question and the sub questions. The second section discusses the set of recommendations that are suggested which flow from the backcasting analysis. Finally, the last section reflects on the overall work done in this report methodologically and feasibility of the suggested pathways.

10.1 Conclusions

The objective of this thesis is to analyse the status quo of the energy system in the state of Telangana and suggest pathways necessary to set it towards energy transition for the electricity sector. A vision was developed with a timeline till 2040 and the barriers in place were analysed. A backasting analysis was made and pathways were developed. In this concluding section, the research questions will be briefly revisited. Since this thesis required a vision developed on future normative scenarios, backcasting approach was chosen as it fit the requirement.

The first research question sought to understand how is the current energy system organised, how energy consumption takes place and who the major stakeholders are. This was sufficiently addressed in chapters 3 and 5. First the economy of the state was discussed to provide a socio-political context of the chosen location. Then it was shown that coal power is still the dominant source of energy for power sector and the share of various sectors in the economy was discussed. In terms of only electricity consumption, Industrial sector consumes the highest at 33% closely followed by agriculture at 29%. Then residential sector at 24% followed by the remaining sectors in smaller shares. In terms of total energy consumption, transportation takes half the share, followed by industrial, agricultural and residential sectors. A PESTEL analysis discussed various macro level factors affecting the state and energy sectors. The major stakeholders are public sector companies in the state and the interviewed stakeholders were briefly introduced.

The second research question required the calculation of the potentials of various renewable energy sources available, that was done in chapter 4. Source by source, the potentials of solar, wind, hydro, biomass and geothermal were analysed. The total renewable energy sources potential was 194,000 GWh dominated by solar PV at 96.5%, followed by the others in very small percentages. In Solar PV, 3 types of categories were analysed: utility scale, roof-top PV and others (comprising PV on highways and waterbodies).

The third research question sought to analyze how a future demand for energy would be for both electricity and transport sectors. It was shown in chapter 6. The future growth rates of electricity, petrol, diesel and other alternate fuels was calculated by considering changes in economic growth rates since it was related to energy consumption. Then taking 2017 data as the base case, the energy demand was forecast till 2040 through 2 growth scenarios, one in a BAU way and another in a more moderate alternative (ALT) growth. There are significant differences in the total energy consumption in both the scenarios, 530 TWh and 320 TWh. Electricity consumption increases to 320 TWh & 197 TWh while fuel demand in transportation is projected to increse to 209 TWh and 132 TWh, in BAU and ALT scenarios respectively. The percapita energy consumption was found to nearly double in 2040 in comparison to the 2017 values.

The fourth research question sought to understand how the total power capacity and the energy share in the system change over the years if there is an increasing share of renewables adding to the system. It was shown in chapter 7 that this can be done in 2 ways. The target of 50% and 75% of renewable energy in the mix by 2040 is considered. Further there is a target to achieve 60 GWh and 100 GWh of storage capacity in A_C and A_M respectively. In chapter 9 it was shown how the achievable targets keep changing with every year and thus the configuration of the power system is shown.

The last research question required to understand what pathways can be developed for a sustainable energy future by the desired timeline. These were developed from the vision, analysis of the barriers and backcasting analysis in chapters 7, 8, and 9. There are 2 pathways A_C and A_M, both of which correspond to the 2 different targets. A_C envisions a 50% RE in the electricity sector and 15% of total vehicles to get electrified including all public tranport buses and the remaining large diesel consuming vehicles to adopt alternative low carbon fuel technologies. A_M more ambitious desires a 75% RE in electricity and 30% of electrification in transport sector. However, for both of these major changes in terms of revising the tariff structures, improving the working conditions of DISCOMs, raising capital through initially state supported green bonds mechanism,

sufficient creation of capacity, and gradual closure of coal power plants must be accomplished. Importantly people should made a part of the transition and it should not be thrusted on to them.

10.2 Recommendations

Two pathways A_C and A_M were developed. This thesis explicitly recommends pathways for achieveing A_M, because of the potential it has in terms of greater decarbonization involved in both electricity and transportation sector. The targets set are ambitious but can also provide greater welfare by significantly reducing the externalities involved. However, the choice will rest with the state government.

10.2.1 Restructuring Tariff Policy

The first step to be taken is to immediately start with restructuring of the tariffs since it was shown to have the biggest impact not only to improve the financial health of DISCOMs and help them run with greater operational efficiency, but also to improve the economic benefit possible that could lead to greater adoption of roof-top PV. This helps provide confidence to both PV module and storage businesses that this market will improve. The policy of restructuring tariffs will further act as an indication on the part of the government to usher in even stronger policies in the future in support of clean energy and improving power sector. After this, then Feed in Tariffs (FiTs) can be introduced to promote more rooftop PV to make prosumers out of regular consumers of electricity.

The state of Gujarat, for example, has shown that politically this can be achieved by raising tariffs, eliminating cross subsidies and still being able to provide power with 100% reliability. The elections that were recently concluded in June 2019 in Telangana has given nearly 90% majority of the legislature to the ruling political party, TRS[1]. Therefore they have absolute majority and political appeasement through free power can take a backseat. Thus, tariff restructuring is possible and can be done with political willingness.

Who should act:

The state electricity regulation commission, TSERC is the agency empowered to do this. The tariff proposals of DISCOMs must be taken into account while doing so by actively involving them in the due process.

10.2.2 Raising and providing access to Capital

Taking advantage of its A+ credit rating of the state government, it must pave way to raise capital through green bonds and show this as an attractive way forward for businesses operating in the space of clean energy. Eventually as the bond market will improve and mature, not only can more capital be raised but this can also act as a reasonably attractive option for the government to fall back on as and when needed. It can raise capital through green bonds by setting up a Special purpose vehicle[2] (SPV), set up only for the clean energy purposes and energy transition. Another way is to contintue its existing successful Public Private Partnership[3] (PPP) model of project financing and implementation where government can raise its share of

[1] Telangana Rashtra Samiti

[2] A special purpose vehicle is formed for a particular purpose or an activity. Its powers are limited to what might be required to attain that specific purpose and it ceases to exist when the purpose is attained. The operations are limited to the acquisition and financing of specific assets.

[3] PPP is an arrangement between a govt. or govt. owned entity on one side and a private sector entity on the other, for the provision of public assets and/or public services, through investments being made and/or management being undertaken by the private sector entity, for a specified period of time. Source: Ministry of Finance

the capital from green bonds.

The capital raised should also cater to the subsidies that have to be provided to these manufacturers and also to retail customers. For example, subsidies on home storage systems, roof-top PV modules, and electric cars. Especially in EVs, subsidy should mainly be provided based on the kilometers travelled rather than the purchase, which can effectively reward the user.

Who should act:

The Ministry of Finance under the state government of Telangana must look into facilitating this. It must, along with the Council of Energy, Environment and Water (CEEW #5) and banking & financial institutions to create detailed plans for creating the right instruments for raising capital for clean energy transition projects.

10.2.3 Infrastructure

Then comes framing the policies that helps in setting up of large scale infrastructure of Solar PV and battery storage facilities. Unlike the earlier (current) regime where the asset ownership of power plants or their manufacturing units rests with the government, the transition should see a greater use of competitive market based instruments. It was seen that A_M requires 4 GW of PV and 6 GWh of battery storage per year. In order to require $2 billion or more worth of infrastructure every year this engine of continuous flow of capital must go on and the role of the government is simply to facilitate this to happen and let competition between businesses drive the market. This also requires requirement of large areas of land for the purposes of setting up the facilities and infrastructure to be made available for competent manufacturers at attractive prices, apart from providing the land needed for large scale solar parks.

Who should act:

Office of the Chief Minister of TS must initiate the work on creation of right framework and Department of Industrial Policy and Promotion should support them administratively. TSTRANSCO with its vast experience in power infrastructure can play a key role in planning and management.

10.2.4 Electrifying Transportation

While the transition from ICEs to EVs has promising gains in terms of significantly lowering air pollution in the cities and generally improving air quality, this tranisition is also one of the most challenging ones. Electrifying the fleet 40,000 buses phase by phase by 2040 is an achieveable target. From the storage capacity that will eventually be developed from the early 2020's decade, it can provide the much needed battery storage devices for the buses. If some of existing bus fleets have a much longer lifetime, then they must be shifted away from diesel to alternatives like CNG, that can be retrofitted and diesel must be replaced with bio-diesel. All the future buses procured must not be diesel-run. While fuel cell alternatives are being developed, they must be encouraged once their commercialisation is possible.

With subsidies flowing based on kilometers travelled, taxis and fleet aggregators can benefit the most in terms of reaching parity and getting returns on the higher capital paid upfront for the initially expensive vehicles. Since more than 70% of the vehicles are 2 wheelers running on petrol, incentivising this segment of buyers is necessary. Once the market reaches a stabilization phase in terms of diffusion of EVs and it can be shown they can sustain on their own and grow better than ICE based vehicles, then subsidies can eventually end.

Who should act:

Central Ministry of Power and Ministry of Transport should support with setting up of the charging infrastructure and rolling out subsidies. Indian Oil Corporation (IOC) should help in improving the infrastructure for alternate fuels and must continue its current expansion of fuel stations to install EV charging facilities. IOC and the state's ministry of power must explore opportunities involved with bio-fuels, especially through microalgae. TSRTC should actively engage with manufacturers of buses and batteries, and R&D institutions. TSTRANSCO should engage with IESA (#9).

10.2.5 Efficiency Improvements

Improvements in the power grid must be stressed to increase their efficiency and bring down the losses. Current losses at 15% imply that 1 unit saved at consumer's end is equivalent to .85 units avoided at generators end. This can make the grid cleaner and cities less polluted. The most important savings that can be realised come from buildings sector since they are projected to have the highest increase in energy demand in the future, mainly from electricity. Net Zero Energy Buildings (NZEB) or Carbon Neutral buildings should be pushed for along with reasonable pay back time periods involved. Since Air Conditioners are expected to contribute for the major increase in buildings electricity demand, highly efficient ACs should be promoted. Energy Efficiency Services Limited (EESL) launched the most energy efficient AC in India recently, each of which can save 3,000 kWh of electricity annually from consumer's end. This represents a saving of 3,530 kWh at the generator's end. This presents us with an excellent opportunity in terms of energy savings.

Who should Act:

A team comprising of Bureau of Energy Efficiency, Ministry of Power (state and central governments), Ministry of New and Renewable Energy and TSREDCO should create a high level list of required interventions that can provide significant energy efficiency improvements. Then detailed plans must be made for urban and rural regions. The Energy Conservation and Building Code (ECBC) that sets energy consumption and efficiency targets for all buildings must be made mandatory throughout the state in all the municipalities. Grid infrastructure needs to be modernised by TSTRANSCO and DISCOMs as the current level of power losses are not acceptable.

10.3 Reflections

This section reflects on the methodology, its limitations, possible new approaches, and feasibility of STRAPSETT.

10.3.1 Methodological Reflections

Quist's generic participatory backcasting approach was adopted. This involved 5 major steps. First the strategic problem orientation was sufficiently done by geographic and economic analysis of the region followed by explaining the current power sector. Then a PESTLE analysis was done to improve this analysis by connected the macro-economic aspects to energy. Then the available renewable energy resources were discussed and their potentials were calculated. Finally the stakeholders in the system were discussed and the relationships of they key ones is shown.

Secondly, analysis of the future demand was projected along with the discussion of various causal factors associated, for both power and transport sectors. A Business as Usual and an alternative growth scenarios were built. The alternative scenario projects a 3 fold growth in the total energy consumed for power sector. The share of electricity in transport sector is projected to grow by 15%. Similarly, for the fuel consumed,

while petrol and diesel and projected to grow in the short run and eventually fall in the long run, alternate fuels are expected to increase because of the upcoming policy measures in place.

Then a desirable vision was created after briefly discussing the outcomes of interviews with stakeholders and literature survey on the supply side of the energy system as to what needs to be achieved. Then the vision was explained in detail and the targets were elaborated year by year. 2 possible ways of achieving this vision were discussed. One which envisions a 50% share of RE in the energy mix and another, a 75%.

The barriers hindering the realisation of the vision were analysed in detail and a backasting analysis was done that showed how to achieve the vision and also offered possible solutions to address the barriers by developing pathways.

Heavy use of forecasting is made to determine the possible future power and fuel demand, increase in the number of vehicles, possible requirements for battery storage in transport and power sector, and others.

The RE resources required to achieve the clean energy targets in the vision are available in plenty and in fact more than required. In terms of the 2040 energy demand the available solar energy potential is nearly equal to it, which means, with sufficient storage technologies to address the intermittancies, a 100% RE based system can be technically explored.

It is clear that BAU policies are insufficient to achieving this vision of transition to low carbon and cleaner energy system and it requires changes in political, technological, financial and societal factors. Political willingness to facilitate change at such a large scale, building the required technological competence and necessary infrastructure, creation of capital and providing access to this, and finally social and cultural changes in the society that can aid the transition are all needed to collectively work together and operate.

Green bonds are an effective instrument for capital creation. Public and private sector, both can raise capital for clean energy purposes and energy transition.

While closure of fossil fuel facilities is necessary, it has to be done gradually starting with dirtiest facilities. Then through carbon pricing or cap-and-trade systems, which either make the coal pricier or create scarcity of power by limiting coal based energy, greater adoption of RE can take place. To make this happen, first and foremost changes in tariffs will be needed, before which any other action can only delay the transition further.

Decarbonization in power sector should precede that of transport sector for an effective emission reduction strategy.

Methodology Limitation:

The role of stakeholders was limited to extraction of information and opinions on several issues, and not on developing an elaborated action plan. Their opinions were pivotal in the analysis of barriers, creating of vision and backasting analysis. But a future plan of action, which was the next step in Quist's framework, was not made possible. This is partially due to the work being done remotely from the chosen location and not in person. The interviews conducted were over phone and e-mail. As a result, much traction was not possible.

Further, this framework requires stakeholders who have strong stakes in the process and who can make things happen either through policy or through execution. Not all the interviewed actors had strong stakes, some had low to medium level stakes. Actors #1, #2, #6, #7 and #8 came from public sector organizations that have considerable influence on the system. Actors #3, #9, #10 and #11 came from private sector organizations whose stakes were dependent on what the earlier category could do. And #13 was an environmental activist. So the stakes are not evenly balanced.

Novelty:

1. The energy demand projections were made to assess the future energy requirements in which 2 possible scenarios were projected. One is a BAU growth scenario and another is a more moderate and an alternative to BAU scenario. However, the targets elaborated in the vision and backcasting analysis made, referred only to this alternative scenario and not for the BAU. This is because backcasting is used to work towards an alternative future when the BAU is highly undesirable. Therefore the targets in the vision must reflect an alternative to BAU along with required changes in the system, if an energy transition is to happen. Therefore the 2 supply side scenarios emerge (from vision) are developed for one future demand. But the 2 differ in terms of Renewable Energy percentages and offer alternatives to achieve the same future (demand) through 2 pathways.

   For instance in the master thesis of ? where a backcasting was done for the Spanish island of Galicia, only one BAU demand scenario was build and a backcasting was done to show how the supply side can be achieved with the right interventions. But this thesis shows 2 alternatives for demand side and builds 2 possible pathways to achieve, but only for the future that is an alternative to BAU.

2. The novel aspect about the method used to develop the vision (figure 7.1) is that it acts as a guiding system or a framework and not the target to be achieved per se. It was developed this way because the outcomes from the responses of the interviews repeatedly discussed the barriers and the problem with status quo, but not a target of clean energy over a long term future. Further, even the state government had no targets for a holistic vision for a transition or decarbonization. Therefore, it was necessary to develop a guiding framework that would enable and facilitate a transition. After this, 2 targets were developed, first one reflected from the interviews and second one, an alternative which was significantly more ambitious.

   For instance in the Novel Protein Foods project, Quist (2013) describes the vision as the idea of protein foods from non-animal sources having a 20 times lower environmental burden than (pork) meat. And he further elaborates the future vision as a novel protein foods replacing 40% of Dutch meat consumption in 2035. Therefore, to begin with, the vision was explicitly normative. But in this thesis, the targets were set after explaining the guiding framework around which these targets have to be achieved, viz., the vision with 5 elements in figure 7.1.

10.3.2 Adopting a different approach

It must be noted that this is a first of its kind of work made on the chosen location where a desired vision and targets for a 20 year time line were set for achieving a more sustainable energy scenario than the present. This transition sees the share of energy from coal drop to 25% of the total electricity mix from the current 90%. With thorough barrier analysis, future energy demand forecasts, and yearly defined targets to achieve, this can serve as a reference for any future work that can be taken up, either within the university this work is undertaken or elsewhere. Further, the possibility here lies in the fact that this work provides pathways from one approach while a number of other approaches could also be possible that are yet to be explored.

In this thesis, backcasting is done purely from an energy perspective. Problems like energy transition are aptly called wicked problems due to the inertia, slow pace of change and inter-connected nature with several fields and stakeholders. They require greater co-orinated efforts from various fields. For example, circular economy, urban mobility, urban planning and land management, and human behaviour are a few aspects deeply connected with energy transition. A more holistic approach towards low carbon transition could be adopted through 'design thinking'and 'general systems thinking'methods.

Design Thinking is an iterative process in which it is sought to understand the people, challenge assumptions, and redefine problems in an attempt to identify alternative strategies and solutions that might not be instantly apparent with initial level of understanding. It provides a solution-based approach to solving

problems and has a human-centered core. Systems Thinking works on a premise that complex systems share organizing principles which can be discovered and modeled mathematically. It is a holistic approach that analysis and focuses on the way that a system's constituent parts interrelate and how systems work over time and within the context of larger systems.

The use of either of these approaches could look at the problem of decarbonization and energy transition from a much more connected point of view and could require entirely different methods than the one used in this thesis. However, it can significantly increase the scope of a master thesis in such a case.

10.3.3 Limitations

The following are some of the limitations faced and constraints within which this thesis was done.

1. Modelling: The model used was a simplified one which is a linear growth model and is not optimised. A stochastically optimised model is desirable. However the current model used is closer to a deterministic one which therefore returns much higher values of the end results. For example, the future energy demand projections, GW of PV needed, GWh of storage needed, amount of investments needed, etc. Further, significant level of abstraction was assumed due to lack of availability of data or due to increasing complexity. Be it area calculations for PV potential, uniform tilt angle assumption for the whole state, non-optimised calculations for determining the storage capacity needed to complement with the installed solar capacity, etc.
2. Stakeholders: All major stakeholders were not possible to be reached for discussion and/or interviews. While the interviewed stakeholders are 13, initially 22 agreed for the interview, however, eventually refused to do so despite frequent follow ups. As a result significant time was lost. Having some more important ones like TSERC, TSRTC, ARAI would add quality to the backcasting analysis. Further, a second round of interviews to share the results of the backcasting analysis was not possible with all stakeholders. Another note on the limitation was the reluctance on the part of the interviewees to share opinions on some of the questions asked, especially those from public sector companies. Finally, the author of this thesis felt more experience is needed to schedule and organize interviews and also to frame questions and take down notes.
3. The inter-relationships between academia and industry were not sufficiently explored. While their interaction is limited, it could have been addressed as a driver in knowledge improvement. The role of innovation too, was not explored much or suggested. It was briefly discussed in one interview and not with others.
4. The use of energy in this thesis has been restricted to coal, solar PV, wind, biomass and geothermal sources in the electricity sector; and petrol, diesel and CNG in the transport sector. The use of gas has not been considered for purposes other than CNG for transport, but it is used for cooking in residential and commercial sectors. Kerosene use, while it has come down, is still prevalent but has not been considered due to lack of data availability on the highly fragmented (market) use. It is used for lighting and cooking in poor households. Since this thesis planned for a sustainable electricity future, change in cooking practices from gas or kerosene to electricity is not envisioned anywhere in the future. Therefore, it is not considered. Transport sector excludes aviation fuel consumption.

10.3.4 Is STRAPSETT ambitious?

If the Strategic Energy document from NITI Aayog[4] is considered, then STRAPSETT is definitely ambitious. If an emissions based climate action perspective is chosen, then the actions needed to be taken with a number of competing priorities seem sufficiently large. The average percapita CO_2 emissions of an Indian citizen is profoundly low at 1.57t compared to that of a Chinese at 6.57t, or a Dutch at 9.23t, or an American at 14.95t, or a Qatari at 30.77t[5]. While data at a much more granular level for TS is not available at any sources, it can be assumed 1.3 times more given the average per capita energy consumption is higher than India's. Still, the number is relatively lower and these pathways that can help TS in leapfrogging towards affordable, accessible and sustainable forms of electricity is indeed an ambitious growth.

10.3.5 Is STRAPSETT achievable?

Financially:
It was shown that both A_C and A_M require financial capital which will be less than or nearly 1% of state GDP for every year till 2040. However, this is a value from the simplified calculations made. As explained earlier, these numbers resulted from a deterministic model will be higher than an optimised model. Therefore, the capital needed per year could be much lesser than discussed before. If that is the case, then is this achievable? Definitely yes. However this total capital does not flow only from the government but mainly from private enterprises.

Technically:
From a technical point of view, the difficulty of reduced inertia was not addressed in the thesis. However it is to be remembered that the power grid of the entire country is integrated in one and Telangana is a part of this grid. Therefore it can be expected that the balance can still be maintained with increased non-inertia based sources. A challenge could be lack of sufficient skilled man-power at the moment. But this can be addressed with co-ordinated efforts over a long 20 year time line.

Politically:
But the real challenge is not financial or technical, but political. Is there a willingness to change the tariff structures, shut down coal plants, and facilitate energy transition? Therefore the question assumes a political significance. But the more important question is *what does it take to achieve them* and not *if it is possible* since the necessity transition to a cleaner energy technologies has been established globally beyond doubt and discussion. However, in the slow moving sector of energy with the government at the centre as a significantly large player with stakes in all elements of value chain, can the transition happen at the speed that it is required?

Given the option of choosing A_C or A_M to the government, the negotiations would begin to have neither of them but they may eventually opt for a pathway closer to A_C. It should also be noted that complete phasing out of coal has not been suggested. Alternative energy technologies are already mature and await encouraging policies. Low carbon transition pathways must be adopted to steer through energy transition without any delay.

[4] NITI Aayog (2017)
[5] Values from (International Energy Agency, 2018)

Bibliography

Agrawal, A., Kumar, A. and Rao, T. J. (2017), 'Future of Indian Power Sector Reforms: Electricity Amendment Bill 2014', *Energy Policy* 107(October 2016), 491–497.
URL: *http://dx.doi.org/10.1016/j.enpol.2017.04.050*

Air Quality Index (2018), 'World Air Quality Index'.
URL: *http://aqicn.org/city/mexico/mexico/camarones/*

Alok Medikepura, A. (2017), 'India and China together can lead the Fourth Industrial Revolution. Here's how | World Economic Forum'.
URL: *https://www.weforum.org/agenda/2017/11/india-and-china-together-can-lead-the-fourth-industrial-revolution-here-s-how/*

Amit Kumar, A. B. (2018), Rooftop Solar in India, Technical report, PWC.
URL: *https://www.climateinvestmentfunds.org/sites/cif_enc/files/rooftop_solar_pv_in_india_ctf_pwc._v8pdf_0.pdf*

Andhra Pradesh State Electricity Board (1998), Chapter 4: Case Study Andhra Pradesh Power Sector : A Profile, Technical report, Andhra Pradesh State Electricity Board, Hyderabad.

Ang, B. and Goh, T. (2018), 'Bridging the gap between energy-to-GDP ratio and composite energy intensity index', *Energy Policy* 119, 105–112.
URL: *https://www.sciencedirect.com/science/article/pii/S0301421518302544#bib3*

Ang, B. W. (2006), 'Monitoring changes in economy-wide energy efficiency: From energy-GDP ratio to composite efficiency index $', *Energy Policy* 34, 574–582.
URL: *www.elsevier.com/locate/enpol*

Archer, D., Almansi, F., DiGregorio, M., Roberts, D., Sharma, D. and Syam, D. (2014), 'Moving towards inclusive urban adaptation: approaches to integrating community-based adaptation to climate change at city and national scale', *Climate and Development* 6(4), 345–356.
URL: *https://doi.org/10.1080/17565529.2014.918868*

Arora, N. and Raman, A. (2019), 'Beyond Nagpur: The promise of electric mobility'.

Balasubramanian, A. (2016), 'The wastelands in india', (July 2015).

Bhardwaj, A., Joshi, M., Khosla, R. and Dubash, N. K. (2019), 'More priorities, more problems? Decision-making with multiple energy, development and climate objectives', *Energy Research and Social Science* 49(November 2018), 143–157.
URL: *https://doi.org/10.1016/j.erss.2018.11.003*

Bilal, A. (2019), 'How long before India achieves self-sufficiency in sourcing solar power equipment?'.
URL: *https://energy.economictimes.indiatimes.com/news/renewable/how-long-before-india-achieves-self-sufficiency-in-sourcing-solar-power-equipment/69843176*

Blok, K. and Nieuwlaar, E. (2016), *Introduction to Energy Analysis.*, 2 edn, Taylor and Francis.

Börjeson, L., Höjer, M., Dreborg, K. H., Ekvall, T. and Finnveden, G. (2006), 'Scenario types and techniques: Towards a user's guide', *Futures* 38(7), 723–739.

Buckley, T. and Shah, K. (2019), India's Grid Transmission Infrastructure Needs Further Modernisation, Urgently Growth in Renewable Energy Investment Slowing Due to Grid Limitations, Technical report.
URL: *http://ieefa.org/wp-content/uploads/2019/01/IEEFA-India_Grid-investment_January-2019.pdf*

Central Electricity Agency (2019), All India Installed Capacity of Power Stations (Utilities), Technical report, Central Electricity Agency.
URL: *http://www.cea.nic.in/reports/monthly/installedcapacity/2019/installed_capacity-03.pdf*

Central Electricity Authority (2019), All India Installed Capacity of Power Stations (Utilities), Technical report, Central Electricity Authority.
URL: *http://www.cea.nic.in/reports/monthly/installedcapacity/2019/installed_capacity-03.pdf*

Cherp, A., Vinichenko, V., Jewell, J., Brutschin, E. and Sovacool, B. (2018), 'Integrating techno-economic, socio-technical and political perspectives on national energy transitions: A meta-theoretical framework', *Energy Research and Social Science* 37, 175–190.
URL: *https://www.sciencedirect.com/science/article/pii/S2214629617302815*

Chiu, D. (2018), THE EAST IS GREEN: CHINA'S GLOBAL LEADERSHIP IN RENEWABLE ENERGY The East Is Green: China' s Global Leadership in Renewable Energy, Technical report, Centre for Strategic & International Studies.
URL: *https://csis-prod.s3.amazonaws.com/s3fs-public/171011_chiu_china_Solar.pdf?i7ofouep_pGOS3iWhvwUlBNigJM*

Dasgupta, S., De Cian, E. and Verdolini, E. (2016), *The political economy of energy innovation*, United Nations University World Institute for Development Economics Research.
URL: *https://www.researchgate.net/publication/299769102_The_Political_Economy_of_Energy_Innovation?channel=d*

Dash, D. (2019), 'Niti Aayog: Niti's new road map: Only electric vehicles to be sold after 2030, Energy News, ET EnergyWorld'.
URL: *https://energy.economictimes.indiatimes.com/news/power/nitis-new-road-map-only-electric-vehicles-to-be-sold-after-2030/69835088*

Dept. of Land Resources and National Remote Sensing Centre (2011), Wastelands atlas of India. Change Analysis Based on Temporal Satellite Data of 2005-06 and 2008-09, Technical report, Ministry of Rural Development, Govt. of India.

Directorate of Economics & Statistics (2017), Telangana Statistical Year Book: 2017, Technical Report 45, Directorate of Economics & Statistics, Hyderabad.

Dutt, A., Soman, A. and Chawla, K. (2019), Financing India ' s Energy Transition A Guide on Green Bonds, Technical Report June, Centre for Energy Finance, CEEW.

E. Wesley F. Peterson (2017), 'The Role of Population in Economic Growth', *SAGE* .
URL: *https://doi.org/10.1177/2158244017736094*

Eckhouse, B. (2019), 'The U.S. Has a Fleet of 300 Electric Buses. China Has 421,000 - Bloomberg'.
URL: *https://www.bloomberg.com/news/articles/2019-05-15/in-shift-to-electric-bus-it-s-china-ahead-of-u-s-421-000-to-300*

EPTRI and MoEFCC (2016), Transport sector of Telangana, Technical report, Environment Protection Training & Research Institute.

ET Bureau (2019), 'Govt mulling ban on petrol, CNG two and three-wheelers'.

URL: *https://economictimes.indiatimes.com/industry/auto/auto-news/govt-mulling-ban-on-petrol-cng-two-and-three-wheelers-nitin-gadkari/articleshow/70076804.cms*

Ferrant, S., Selles, A., Le Page, M., Herrault, P. A., Pelletier, C., Al-Bitar, A., Mermoz, S., Gascoin, S., Bouvet, A., Saqalli, M., Dewandel, B., Caballero, Y., Ahmed, S., Maréchal, J. C. and Kerr, Y. (2017), 'Detection of irrigated crops from Sentinel-1 and Sentinel-2 data to estimate seasonal groundwater use in South India', *Remote Sensing* 9(11).

Fotis, P., Karkalakos, S. and Asteriou, D. (2017), 'The relationship between energy demand and real GDP growth rate: The role of price asymmetries and spatial externalities within 34 countries across the globe', *Energy Economics* 66, 69–84.
URL: *https://linkinghub.elsevier.com/retrieve/pii/S0140988317301913*

Friedrich, J., Ge, M. and Pickens, A. (2017), 'World's Top 10 Emitters, and How They've Changed | World Resources Institute'.
URL: *https://www.wri.org/blog/2017/04/interactive-chart-explains-worlds-top-10-emitters-and-how-theyve-changed*

Gleick, P. H. (2004), ' W Ater U Se ', *Annual Review of Environment and Resources* 28(1), 275–314.
URL: *http://apps.isiknowledge.com/full_record.do?product=WOS&search_mode=GeneralSearch&qid=7&SID=3EpI*

GOI (2017), 'Energy Statistics 2017', *MoSPI Govt. of India* (24), 1–109.

Goldie-Scot, L. (2019), A Behind the Scenes Take on Lithium-ion Battery Prices | Bloomberg NEF, Technical report, Bloomberg New Energy Finance.
URL: *https://about.bnef.com/blog/behind-scenes-take-lithium-ion-battery-prices/*

Government of India (2015), India's Intended Nationally Determined Contribution: Working Towards Climate Justice, Technical report, Ministry of Environment, Forests & Climate Change.
URL: *https://www4.unfccc.int/sites/submissions/INDC/Published Documents/India/1/INDIA INDC TO UNFCCC.pdf*

Government of India (GoI) (2002), 'Annual Report (2000-01) on The Working of State Electricity Boards and electricity departments'.

Government of Telangana (2015), POWER FOR ALL: Telangana State, Technical report.
URL: *https://powermin.nic.in/sites/default/files/uploads/Power_For_All_4_12_Final_Telangana_Signed.pdf*

Govt. of China (2015), China's INDC, Technical report, Department of Climate Change, National Development & Reform Commission of China.
URL: *https://www4.unfccc.int/sites/submissions/INDC/Published Documents/China/1/China's INDC - on 30 June 2015.pdf*

Govt. of Telangana (2018), Socio-Economic Outlook-2018, Technical report, Planning Department, Hyderabad.

Grubler, A., Wilson, C. and Nemet, G. (2016), 'Apples, oranges, and consistent comparisons of the temporal dynamics of energy transitions', *Energy Research & Social Science* 22, 18–25.
URL: *https://www.sciencedirect.com/science/article/pii/S2214629616301980?via%3Dihub*

Gupta, S., Patil, V., Himabindu, M. and Ravikrishna, R. (2016), 'Life-cycle analysis of energy and greenhouse gas emissions of automotive fuels in India: Part 1 âĂŞ Tank-to-Wheel analysis', *Energy* 96, 684–698.
URL: *https://www.sciencedirect.com/science/article/pii/S036054421501573X#fig16*

Hafez, A., Soliman, A., El-Metwally, K. and Ismail, I. (2017), 'Tilt and azimuth angles in solar energy appli-

cations âĂŞ A review', *Renewable and Sustainable Energy Reviews* 77, 147–168.
URL: *https://www.sciencedirect.com/science/article/pii/S1364032117304677#bib126*

Halcrow Group Ltd (2008), Breaking the Trend Visioning and Backcasting for Transport in India & Delhi (VIBAT INDIA & DELHI), Technical report, Asian Development Bank, New Delhi.
URL: *https://www.adb.org/sites/default/files/project-document/68254/39578-reg-dpta.pdf*

Hannesson, R. (2009), 'Energy and GDP growth', *International Journal of Energy Sector Management* 3(2), 157–170.
URL: *http://www.emeraldinsight.com/doi/10.1108/17506220910970560*

Harinarayana, T. and Kashyap, K. J. (2014), 'Solar Energy Generation Potential Estimation in India and Gujarat, Andhra, Telangana States', *Smart Grid and Renewable Energy* 05(11), 275–289.
URL: *http://www.scirp.org/journal/sgrehttp://dx.doi.org/10.4236/sgre.2014.511025http://dx.doi.org/10.4236/sgre.2014.511*

Hawken, P. (2017), *Drawdown: The most comprehensive plan ever proposed to reverse global warming*, kindle edn, Penguin Books Ltd.
URL: *https://www.drawdown.org/*

Hermans, L., Enserink, B., Kwakkel, J., Thissen, W., Koppenjan, J. and Bots, P. (2010), *Policy Analysis of Multi-Actor Systems*, Boom Lemma Uitgevers, The Hague.

Higgins, K. L. (2013), Economic growth and sustainability âĂŞ are they mutually exclusive?, *in* 'Financial Whirlpools', Elsevier.
URL: *https://www.elsevier.com/connect/economic-growth-and-sustainability-are-they-mutually-exclusive*

Holtz, G., Alkemade, F., de Haan, F., Köhler, J., Trutnevyte, E., Luthe, T., Halbe, J., Papachristos, G., Chappin, E., Kwakkel, J. and Ruutu, S. (2015), 'Prospects of modelling societal transitions: Position paper of an emerging community', *Environmental Innovation and Societal Transitions* 17, 41–58.
URL: *https://www.sciencedirect.com/science/article/pii/S2210422415000441?via%3Dihub*

Hossain, J., Sharma, D., Mishra, N. K., Ansari, M. Z. and Kishore, V. V. N. (2016), 'Re-assessment of wind energy potential with new technology in India', *Wind Engineering* 40(4), 379–397.

Hultman, N. E., Malone, E. L., Runci, P., Carlock, G. and Anderson, K. L. (2011), 'Factors in low-carbon energy transformations: Comparing nuclear and bioenergy in Brazil, Sweden, and the United States', *Energy Policy* 40, 131–146.
URL: *www.elsevier.com/locate/enpol*

IBEF (2019), 'Power Sector in India: Market Size, Industry Analysis, Govt Initiatives | IBEF (Govt. Trust)'.
URL: *https://www.ibef.org/industry/power-sector-india.aspx*

IIHS (2015), Cities as Engines of Inclusive Development, Technical report.
URL: *http://iihs.co.in/knowledge-gateway/wp-content/uploads/2015/07/IIHS-RF_CitiesasEnginesofInclusiveDevelopment_Final_Reduced-size.pdf*

Institute of Energy (2019), 'IRENA Forecasts 59% Solar PV Price Reduction By 2025 - Energy News - Institute of Energy of South East Europe'.
URL: *http://www.iene.eu/irena-forecasts-59-solar-pv-price-reduction-by-2025-p2740.html*

International Energy Agency (2018), CO_2 Emissions from fuel combustion: Statistics, Technical report, International Energy Agency.
URL: *www.iea.org/*

International Renewable Energy Agency, T. (2018), *RENEWABLE POWER GENERATION COSTS IN*

2018, IRENA, Abu Dhabi.
URL: *www.irena.org*

IPCC (1998), PRINCIPLES GOVERNING IPCC WORK, Technical report, United Nations, Vienna.
URL: *https://www.ipcc.ch/site/assets/uploads/2018/09/ipcc-principles.pdf*

IPCC (2014), Climate Change 2014: Synthesis Report AR5, Technical report.
URL: *http://www.ipcc.ch.*

IWTMA (2018), IWTMA Report 2018-19, Technical report.
URL: *http://www.indianwindpower.com/pdf/Statewise-Installed-Capacity.pdf*

JLL Global Research (2019), City Momentum Index 2019: Technology , Transparency and Transformation, Technical report.

J.N. Rai, J. R. (2013), 'Tariff Setting In the Indian Power Sector-An Overview', *IOSR Journal of Electrical and Electronics Engineering* 6(1), 97–108.
URL: *http://www.iosrjournals.org/iosr-jeee/Papers/Vol6-issue1/N06197108.pdf*

Kavlak, G., McNerney, J. and Trancik, J. E. (2018), 'Evaluating the causes of cost reduction in photovoltaic modules', *Energy Policy* 123, 700–710.
URL: *https://linkinghub.elsevier.com/retrieve/pii/S0301421518305196*

Kern, F. and Smith, A. (2008), 'Restructuring energy systems for sustainability? Energy transition policy in the Netherlands', *Energy Policy* 36(11), 4093–4103.
URL: *https://www.sciencedirect.com/science/article/pii/S030142150800308X?via%3Dihub*

Khosla, R. and Bhardwaj, A. (2019), 'Urbanization in the time of climate change: Examining the response of Indian cities', *Wiley Interdisciplinary Reviews: Climate Change* 10(1), 1–13.

Koride, M. (2018), 'Telangana top power consumer in India'.
URL: *https://timesofindia.indiatimes.com/city/hyderabad/telangana-top-power-consumer-in-india/articleshow/66476728.cms*

Lamb, W. F., Callaghan, M. W., Creutzig, F., Khosla, R. and Minx, J. C. (2018), 'The literature landscape on 1.5 ÂřC climate change and cities', *Current Opinion in Environmental Sustainability* 30, 26–34.
URL: *https://doi.org/10.1016/j.cosust.2018.02.008*

Lauber, V. (2016), 'The politics and economics of constructing, contesting and restricting socio-political space for renewables âĂŞ The German Renewable Energy Act', *Environmental Innovation and Societal Transitions* 18, 147–163.
URL: *http://dx.doi.org/10.1016/j.eist.2015.06.005*

Li, F. G. and Strachan, N. (2017), 'Modelling energy transitions for climate targets under landscape and actor inertia', *Environmental Innovation and Societal Transitions* 24, 106–129.
URL: *https://www.sciencedirect.com/science/article/pii/S2210422416300764?via%3Dihub*

Lu, L., Xue, L. and Zhou, W. (2018), 'How Did Shenzhen, China Build World's Largest Electric Bus Fleet? | World Resources Institute'.
URL: *https://www.wri.org/blog/2018/04/how-did-shenzhen-china-build-world-s-largest-electric-bus-fleet*

Mardani, A., Streimikiene, D., Cavallaro, F., Loganathan, N. and Khoshnoudi, M. (2019), 'Carbon dioxide (CO2) emissions and economic growth: A systematic review of two decades of research from 1995 to 2017', *Science of The Total Environment* 649, 31–49.
URL: *https://www.sciencedirect.com/science/article/pii/S0048969718331930*

Mata, T. M., Martins, A. A. and Caetano, N. S. (2010), 'Microalgae for biodiesel production and other applications: A review', *Renewable and Sustainable Energy Reviews* 14(1), 217–232.
URL: *https://www.sciencedirect.com/science/article/pii/S1364032109001646*

MINISTRY OF LAW AND JUSTICE (Legislative Department) (2003), 'Electricity Act, 2003'.
URL: *http://www.cercind.gov.in/Act-with-amendment.pdf*

Ministry of New & Renewable Energy (2008), National Policy on Biofuels, Technical Report 14, MNRE.

Ministry of New & Renewable Energy (2018), 'A target of installing 175 GW of renewable energy capacity by the year 2022 has been set'.
URL: *http://pib.nic.in/newsite/PrintRelease.aspx?relid=180728*

Ministry of Power (2019), 'FAME II Policy'.
URL: *https://www.fame-india.gov.in/WriteReadData/userfiles/file/FAME-II Notification.pdf*

Miola, A. (2008), Backcasting approach for sustainable mobility, Technical report, European Commission, Luxembourg.
URL: *http://publications.jrc.ec.europa.eu/repository/bitstream/11111111/7659/1/backcasting final report.pdf*

Mishra, T. (2018), 'Centre sets renewable purchase obligation for FY22 at 21% - The Hindu BusinessLine'.
URL: *https://www.thehindubusinessline.com/news/centre-sets-renewable-purchase-obligation-for-fy22-at-21/article24175501.ece*

MoSPI Govt. of India (2018*a*), 'Energy Statistics 2018 Central Statistics Office Ministry of Statistics and Programme Implementation Government of India', 2018, 101.
URL: *http://mospi.nic.in/sites/default/files/publication_reports/Energy_Statistics_2018.pdf*

MoSPI Govt. of India (2018*b*), India in Figures 2018, Technical report, Central Statistics Office.

Mukherjee, S. (2018), 'CNG likely to make up 50% of vehicle sales by 2030 on govt's infrastructure push'.
URL: *https://economictimes.indiatimes.com/industry/auto/auto-news/cng-likely-to-make-up-50-of-vehicle-sales-by-2030-on-govts-infrastructure-push-report/articleshow/66684485.cms?from=mdr*

Naidu, C. V., Dharma Raju, A., Vinay Kumar, P. and Satyanarayana, G. C. (2017), 'Perceptible changes in Indian summer monsoon rainfall in relation to Indian Monsoon Index', *Global and Planetary Change* 157, 83–92.
URL: *https://www.sciencedirect.com/science/article/pii/S0921818117300346*

Natural Resources Defence Council, Council for Energy Environment & Water and Institute for Governance & Sustainable Development (2015), REDUCING STRESS ON INDIA ' S ENERGY GRID, Technical Report July.

New Indian Express (2018), 'Telangana's IT sector recordsÂă25 per cent growth in two years- The New Indian Express'.
URL: *http://www.newindianexpress.com/states/telangana/2018/mar/20/telanganas-it-sector-records-25-per-cent-growth-in-two-years-1789693.html*

Newman, P. (2018), *The Renewable Cities Revolution*, 2 edn, Elsevier Ltd.
URL: *http://dx.doi.org/10.1016/B978-0-08-102074-6.00015-2*

Ng, A. (2009), 'Backcasting performance of the emerging renewable energy sector in China', *Journal of Technology Management in China* 4(1), 53–66.
URL: *http://www.emeraldinsight.com/doi/10.1108/17468770910942834*

Nicholas, S. (2018), 'Enter the dragon: China's renewables growth goes global'.
URL: *https://www.eco-business.com/opinion/enter-the-dragon-chinas-renewables-growth-goes-global/*

NITI Aayog (2017), Energizing India, A Joint Project Report of NITI Aayog and IEEJ, Technical report, NITI Aayog.
URL: *http://niti.gov.in*

NITI Aayog and Rocky Mountain Institute (2017), India's Energy Storage Mission: A Make-in-India Opportunity for Globally Competitive Battery Manufacturing, Technical report.
URL: *http://www.rmi.org/Indias- Energy-Storage-Mission*

NITI Aayog, International Energy Agency and Asian Development Bank (2018), Workshop-Report-2018-The-Indian-Power-Sector-Low-Carbon-Strategy-for-Renewable-Energy-Integration.

NITI Aayog, Prayas Energy Group, Center for Study of Science Technology and Policy and Shakti Sustainable Energy Foundation (2016), Report of the Expert Group on 175 GW RE Target by 2022, Technical report, NITI Aayog.

Nixon, J. D., Dey, P. K. and Ghosh, S. K. (2017), 'Energy recovery from waste in India: An evidence-based analysis', *Sustainable Energy Technologies and Assessments* 21, 23–32.
URL: *http://dx.doi.org/10.1016/j.seta.2017.04.003*

Office of the Registrar General & Census Commissioner (2011), Census India 2011 Decadal Changes Report, Technical report, Ministry of Home Affairs.
URL: *http://www.censusindia.gov.in/2011census/PCA/A-2_Data_Tables/00 A 2-India.pdf*

Piketty, T. and Goldhammer, A. (2014), *Capital in the twenty-first century*.

Prateek, S. (2018), 'Feed-In Tariffs to Make a Comeback in India for Small Solar and Wind Projects - Mercom India'.
URL: *https://mercomindia.com/feed-in-tariff-solar-wind/*

PRS Legislative Research (2018), Telangana Budget Analysis 2017-18 Background: Telangana's Economy, Technical report, PRS Legislative Research.
URL: *http://www.prsindia.org/uploads/media/State Budget 2017-18/Telangana Budget Analysis 2017-18.pdf*

PVSYST Directory (2014), 'Albedo Values'.
URL: *http://files.pvsyst.com/help/albedo.htm*

Quist, J. (2007), Backcasting for a sustainable future, PhD thesis, Delft University of Technology.

Quist, J. (2013), *Handbook of Sustainable Engineering*.

Quist, J. and Vergragt, P. (2006), 'Past and future of backcasting: The shift to stakeholder participation and a proposal for a methodological framework', *Futures* 38(9), 1027–1045.
URL: *https://www.sciencedirect.com/science/article/pii/S0016328706000541*

Raghuwanshi, C. S. S. D. R. K. (2017), 'Agricultural Waste to Energy for Rural India: A Smart way to Clean Energy', *International Journal of Science and Research (IJSR)* 6(4), 2441–2445.
URL: *https://www.ijsr.net/archive/v6i4/25041701.pdf*

Rajamani, L. (2000), 'The Principle of Common but Differentiated Responsibility and the Balance of Commitments under the Climate Regime', *Review of European Community & International Environmental Law* 9(2).
URL: *https://onlinelibrary.wiley.com/doi/pdf/10.1111/1467-9388.00243*

Robinson, J. (1990), 'Futures under glass: A recipe for people who hate to predict'.

Robinson, J. B. (1982), 'Energy backcasting: A proposed method of policy analysis'.

Rotmans, J., Kemp, R., Van Asselt, M. (2001), 'More evolution than revolution: transition management in public policy', *Foresight* 03(01), 1–17.

Saghafi, F., Aliahmadi, A., Noori, S. S. G. and Hourali, M. (2013), 'Offering the reference model of backcasting approach for achieving sustainable development', *Journal of Futures Studies* .
URL: *https://www.researchgate.net/publication/287247948_Offering_the_reference_model_of_backcasting_approach_fo*

Sahu, G. (2008), LEAD Law Environment and Development Journal VOLUME 4/1 IMPLICATIONS OF INDIAN SUPREME COURT'S INNOVATIONS FOR ENVIRONMENTAL JURISPRUDENCE, Technical report.
URL: *www.lead-journal.org*

Salih, T. M. (2003), 'Sustainable economic development and the environment', *International Journal of Social Economics* 30(1/2), 153–162.
URL: *https://www.emeraldinsight.com/doi/10.1108/03068290310453655*

Sarolkar, P. B. (2018), Geothermal Energy in India: Poised For Development, Technical report, Stanford University.
URL: *https://pangea.stanford.edu/ERE/pdf/IGAstandard/SGW/2018/Sarolkar.pdf*

Saxena, S. (2012), Pathways to a sustainable transport future (Delhi 2030) : developing and applying a futures decision making framework, PhD thesis.

Schleussner, C.-F., Rogelj, J., Schaeffer, M., Lissner, T., Licker, R., Fischer, E. M., Knutti, R., Levermann, A., Frieler, K. and Hare, W. (2016), 'Science and policy characteristics of the Paris Agreement temperature goal', *Nature Climate Change* 6(9), 827–835.
URL: *http://www.nature.com/articles/nclimate3096*

Schwarze, R., Meyer, P. B., Markandya, A., Kedia, S., Maleki, D., de Lara, M. V. R., Sudo, T., Surminski, S., Anderson, N., Olazabal, M., Grafakos, S. and Dobardzic, S. (2018), Economics, Finance, and the Private Sector, *in* C. Rosenzweig, P. Romero-Lankao, S. Mehrotra, S. Dhakal, S. Ali Ibrahim and W. D. Solecki, eds, 'Climate Change and Cities: Second Assessment Report of the Urban Climate Change Research Network', Cambridge University Press, Cambridge, pp. 225–254.
URL: *https://www.cambridge.org/core/books/climate-change-and-cities/economics-finance-and-the-private-sector/FE9C4F7E12DFDDA39F9C3765F1701966*

Shadikhodjaev, S. (2017), IndiaâĂŤCertain Measures Relating to Solar Cells and Solar Modules, Technical Report 1.
URL: *https://www.wto.org/english/tratop_e/dispu_e/456r_e.pdf*

Sharan, P. S. and David, K. (2017), '© Associated Foundation (AARF) GEOTHERMAL ENERGY IN INDIA - A PERSPECTIVE VIEW', *International Research Journal of Natural and Applied Sciences* 4(1), 107–117.

Sharma, N., Smeets, B. and Tryggestad, C. (2019), The decoupling of GDP and energy growth.
URL: *https://www.mckinsey.com/industries/electric-power-and-natural-gas/our-insights/the-decoupling-of-gdp-and-energy-growth-a-ceo-guide*

Singh, A. K., Boruah, D., Sehgal, L. and Ramaswamy, A. P. (2017), 'Feasibility study of a grid-tied 2MW floating solar PV power station and e-transportation facility using âĂŸSketchUp Pro' for the proposed smart city of Pondicherry in India', *Journal of Smart Cities* 2(2).
URL: *http://ojs.udspub.com/index.php/jsc/article/view/100/pdf*

Singh, H. S. (2018), 'Most tribals use firewood for fuel'.
URL: *https://www.thehindu.com/news/national/telangana/most-tribals-use-firewood-for-fuel/article22723865.ece*

Singh, S. (2019), 'Solar power: India becomes lowest-cost producer of solar power, Energy News, ET EnergyWorld'.
URL: *https://energy.economictimes.indiatimes.com/news/renewable/india-becomes-lowest-cost-producer-of-solar-power/69565769*

Smart Power India (2019), 'Rural Electrification in India - Customer behaviour and demand', (February).
URL: *http://www.smartpowerindia.org/media/1230/report_rural-electrification-in-india_customer-behaviour-and-demand.pdf*

Smets, A. H., Jäger, K., Isabella, O., van Swaaij, R. A. and Zeman, M. (2015), *Solar energy: The physics and engineering of photovoltaic conversion, technologies and systems*, UIT Cambridge, England, Delft.
URL: *https://op.lib.kobe-u.ac.jp/opac/opac_link/bibid/3000026383*

Smith, A., Stirling, A. and Berkhout, F. (2005), 'The governance of sustainable socio-technical transitions', *Research Policy* 34(10), 1491–1510.
URL: *https://www.sciencedirect.com/science/article/pii/S0048733305001721*

Solar R&D Division (Government of India) (2014), State wise Estimated Solar Power Potential in the Country, Technical Report 22.
URL: *http://mnre.gov.in/file-manager/UserFiles/Statewise-Solar-Potential-NISE.pdf*

Srivastava, S. (2018), 'The case for power discom privatization'.
URL: *https://www.livemint.com/Opinion/CfhWUvgC9sFZUtfmQD2xQM/Opinion–The-case-for-power-discom-privatization.html*

Tank, V., Bhutka, J. and Harinarayana, T. (2016), 'Wind Energy Generation and Assessment of Resources in India', *Journal of Power and Energy Engineering* 04(10), 25–38.
URL: *http://www.scirp.org/journal/doi.aspx?DOI=10.4236/jpee.2016.410002*

Thapar, S., Sharma, S. and Verma, A. (2016), 'Economic and environmental effectiveness of renewable energy policy instruments: Best practices from India', *Renewable and Sustainable Energy Reviews* 66, 487–498.
URL: *http://dx.doi.org/10.1016/j.rser.2016.08.025*

The Automotive Research Association of India (2018), Emission Standards: BS VI, Technical Report November 2018, ARAI.

Trabish, H. K. (2018), 'Can the price of rooftop solar keep falling? | Utility Dive'.
URL: *https://www.utilitydive.com/news/can-the-price-of-rooftop-solar-keep-falling/539612/*

TSGENCO (2019), 'TSGENCO Installed Capacity'.
URL: *https://www.tsgenco.co.in/getInfo.do*

UNFCCC (1992), UNITED NATIONS FRAMEWORK CONVENTION ON CLIMATE CHANGE, Technical report, United Nations.
URL: *https://unfccc.int/resource/docs/convkp/conveng.pdf*

UNFCCC (2015), ADOPTION OF THE PARIS AGREEMENT - Paris Agreement text English, Technical report, United Nations, Le Bourget.
URL: *https://unfccc.int/sites/default/files/english_paris_agreement.pdf*

UNFCCC Report (2017), 'China and India Lead Global Renewable Energy Transition | UNFCCC'.
URL: *https://unfccc.int/news/china-and-india-lead-global-renewable-energy-transition*

United Nations (2015), 'The UN Sustainable Development Goals'.
URL: *http://www.un.org/sustainabledevelopment/summit/*

United Nations (n.d.), 'Conference of the Parties (COP) | UNFCCC'.
URL: *https://unfccc.int/process/bodies/supreme-bodies/conference-of-the-parties-cop*

Vaish, B., Srivastava, V., Singh, P., Singh, A., Singh, P. K. and Singh, R. P. (2016), 'Exploring untapped energy potential of urban solid waste', *Energy, Ecology and Environment* 1(5), 323–342.

Vergragt, P. J. and Quist, J. (2011), 'Backcasting for sustainability: Introduction to the special issue', *Technological Forecasting and Social Change* 78(5), 747–755.
URL: *https://www.sciencedirect.com/science/article/pii/S004016251100062X*

Whitlock, R. (2019), 'PV - European payback times for solar power fell in 2018 finds new report - Renewable Energy Magazine, at the heart of clean energy journalism'.
URL: *https://www.renewableenergymagazine.com/pv_solar/european-payback-times-for-solar-power-fell-20190221*

Woodcock, J., Edwards, P., Tonne, C., Armstrong, B. G., Ashiru, O., Banister, D., Beevers, S., Chalabi, Z., Chowdhury, Z., Cohen, A., Franco, O. H., Haines, A., Hickman, R., Lindsay, G., Mittal, I., Mohan, D., Tiwari, G., Woodward, A. and Roberts, I. (2009), 'WHO COLLABORATING CENTRE Public health benefits of strategies to reduce greenhouse-gas emissions: Urban land transport', *Series Health and Climate Change 2, The Lancet* .
URL: *http://www.iitd.ac.in/ tripp*

World Bank, Sustainable Energy for All and International Energy Agency (2018), 'Energy intensity level of primary energy (MJ/$2011 PPP GDP)'.
URL: *https://data.worldbank.org/indicator/EG.EGY.PRIM.PP.KD?locations=IN*

Part IV

Appendices

A Equations used

A.1 Solar Energy Potential calculation

All the equations are taken from Smets et al. (2015).
The total irradiance on a PV module, G_M^{tot} is the sum of 3 components: Direct, Diffused and Albedo. Subscript M indicates module.

$$G_M^{total} = G_M^{Direct} + G_M^{Diffuse} + G_M^{Albedo} \tag{1}$$

Direct irradiance component is given as,

$$G_M^{direct} = DNI \cdot \cos\gamma \tag{2}$$

Where, DNI = Direct Normal Irradiance, and
γ = angle between the surface (of PV module) normal and the incident direction of the Sunlight, also called Angle of Incidence (AOI).

$$\cos\gamma = \cos a_M \cdot \cos a_S \cdot \cos\left(A_M - A_S\right) + \sin A_M \cdot \sin a_S \tag{3}$$

Where,

a_M - Module Altitude
a_S - Solar Altitude
A_M - Module Azhimuth
A_S - Solar Azhimuth.

Diffused irradiance component is given as,

$$G_M^{Diffuse} = SVF \cdot DHI \tag{4}$$

This is the Isotropic Sky Model. Where, SVF = Sky View Factor,
DHI = Diffused Horizontal Irradiance,

$$SVF = \frac{1 + \cos\theta_M}{2} \tag{5}$$

θ_M = Module Tilt Angle, it is calculated as (Hafez et al., 2017)

$$\theta_M = \varphi_0 \cdot 0.87 \tag{6}$$

Where, φ_0 = Geographical Latitude of the location where PV module is placed.

Albedo Component of Irradiance is given by,

$$G_M^{Albedo} = GHI \cdot \alpha \cdot (1 - SVF) \tag{7}$$

where, α = Albedo coefficient,
GHI = Global Horizontal Irradiation, given by

$$GHI = G_M^{Direct} + G_M^{Diffuse} \tag{8}$$

The solar PV potential (for utility scale, SPV_{utsc}) is calculated from the equation,

$$SPV_{utsc} = G_M^{total} \cdot A_{Wastelands} \cdot p_w \cdot \eta_{module} \cdot LUF \cdot \eta_{BOS} \cdot \eta_{grid} \tag{9}$$

where,

SPV_{utsc}	-	Potential in GWh
G_M^{total}	-	Annual Irradiation received by the module
$A_{Wastelands}$	-	Area of Wastelands
p_w	-	Percentage of $A_{Wastelands}$ considered
η_{module}	-	Efficiency of the solar PV module used (Vikram Solar SOLIVO SMART Model)
LUF	-	Land Area Utilization Factor
η_{BOS}	-	Efficiency of the Balance of System elements
η_{grid}	-	Efficiency of power transmission and distribution in the grid

The solar PV potential (for rooftop, SPV_{rftp}) is calculated from the equation,

$$SPV_{rftp} = G_M^{total} \cdot A_{Buildings} \cdot p_b \cdot \eta_{module} \cdot LUF_{Buildings} \cdot \eta_{BOS} \cdot \eta_{grid} \tag{10}$$

where,
other variables denote the same as explained under equation 9.

SPV_{rftp}	-	Potential in GWh
$A_{Buildings}$	-	Total area covered by the buildings in the state
p_b	-	Percentage of the buildings considered with Roof top PV installed
$LUF_{Buildings}$	-	Land Area Utilization Factor considered for area of roofs of the buildings

A.2 PV system electricity cost calculation

$$C_{PV} = \frac{\sum_{t=0}^{n} \frac{I_t + M_t}{(1+r)^t}}{\sum_{t=0}^{n} \frac{EY}{(1+r)^t}} \tag{11}$$

where, C_{PV} - Cost of the electricity of the PV system $[INR^1/kWh]$,
t - year in which calculation is done,
n - Highest year upto which calculation is taken,
I_t - Investment Costs in year t,
M_t - Maintenance costs in year t,
EY - Annual Energy yield of the PV system $[kWh]$,
r - discount rate assumed

[1]Indian National Rupee, at current prices 1 EUR = 75 INR

TECHNICAL DATA

THIS DATASHEET IS APPLICABLE FOR: SOLIVO SMART GRAND ULTIMA SERIES
REGISTERED AS SOMERA VSMS.72.AAA.03.04 (AAA=340-370)

Electrical Data[1, 2]

All data refers to STC (AM 1.5, 1000 W/m², 25°C)

Peak Power P_{max} (Wp)	340	342.5	345	347.5	350	352.5	355	357.5	360	362.5	365	367.5	370
Maximum Voltage V_{mpp} (V)	38.1	38.1	38.1	38.1	38.1	38.2	38.2	38.2	38.3	38.3	38.4	38.4	38.4
Maximum Current I_{mpp} (A)	8.93	8.99	9.06	9.12	9.18	9.24	9.29	9.35	9.41	9.46	9.52	9.58	9.63
Open Circuit Voltage V_{oc} (V)	46.8	46.8	47.2	47.3	47.4	47.4	47.5	47.6	47.7	47.7	47.8	47.9	48
Short Circuit Current I_{sc} (A)	9.37	9.42	9.44	9.51	9.56	9.61	9.64	9.71	9.78	9.81	9.84	9.85	9.9
Module Efficiency η(%)	17.55	17.68	17.81	17.94	18.07	18.19	18.32	18.45	18.58	18.71	18.84	18.97	19.10
Maximum Voltage V_{max} TS4-L (V)	43	43	43.1	43.1	43.1	43.2	43.3	43.3	43.4	43.4	43.5	43.5	43.5
Maximum Current I_{max} TS4 (A)	12	12	12	12	12	12	12	12	12	12	12	12	12

1) STC:1000 W/m² irradiance, 25°C cell temperature, AM1.5g spectrum according to EN 60904-3
Average relative efficiency reduction of 5% at 200 W/m² according to EN 60904-1 | 2) Power measurement uncertainty is within +/- 3%

Electrical Parameters at NOCT[3]

Power (W)	251.8	253.5	256.0	257.7	259.6	262.0	263.7	265.4	267.7	269.3	272.1	274.7	276.2
V@P_{max} (V)	35.4	35.4	35.7	35.7	35.8	35.9	35.9	36.0	36.0	36.1	36.3	36.5	36.5
I@P_{max} (A)	7.12	7.16	7.18	7.22	7.26	7.31	7.34	7.38	7.43	7.47	7.51	7.53	7.57
V_{oc} (V)	43.3	43.3	43.6	43.7	43.8	43.8	43.9	44.0	44.1	44.1	44.2	44.2	44.3
I_{sc} (A)	7.58	7.62	7.64	7.69	7.73	7.77	7.80	7.86	7.91	7.94	7.96	7.97	8.01
V_{max} TS4-L (V)	43	43	43.1	43.1	43.1	43.2	43.3	43.3	43.4	43.4	43.5	43.5	43.5

3) NOCT irradiance 800 W/m², ambient temperature 20°C, wind speed 1 m/sec

Temperature Coefficients (Tc) permissible operating conditions

Tc of Open Circuit Voltage (β)	- 0.28%/°C
Tc of Open Circuit Voltage TS4-L (β_V_{oc})	0.0%/°C
Tc of Short Circuit Current (α)	0.057%/°C
Tc of Power (γ)	-0.39%/°C
Maximum System Voltage	1000 V
NOCT	45°C ± 2°C
Temperature Range	-40°C to + 85°C

Mechanical Data

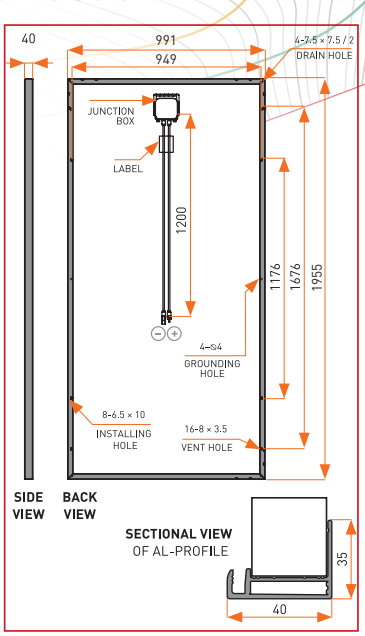
Length × Width × Height	1955 × 991 × 40 mm (76.96 × 39.01 × 1.57 inches)
Weight	21.3 kg (54.67 lbs)
Junction Box	IP67, TS4-base with smart ready covers. (TS4-D; TS4-M; TS4-F; TS4-S; TS4-O; TS4-L)
Cable & Connectors	1200 mm (47.24 inches) length cables, MC4 Compatible/MC4 Connectors
Application Class	Class A (Safety class II)
Superstrate	3.2 mm (0.13 inches) high transmission low iron tempered glass, AR coated
Cells	72 Monocrystalline, 5BB solar cells
Cell Encapsulant	EVA (Ethylene Vinyl Acetate)
Back Sheet	Composite film
Frame	Anodized aluminium frame with twin wall profile
Mechanical Load Test	5400 Pa (Snow load), 2400 Pa (Wind load)
Maximum Series Fuse Rating	15 A

Warranty and Certifications

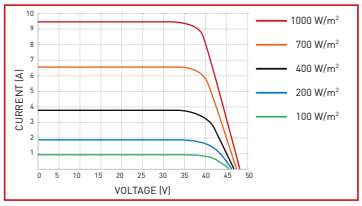
Product Warranty**	10 years
Performance Warranty**	Linear Power Warranty for 25 years with 3% for 1st year degradation and 0.65% from year 2 to year 25
Approvals and Certificates	IEC 61215 Ed2, IEC 61730, IEC 61701^, IEC 60068-2-68^, MCS, CE, CEC (California)^, UL 1703^

VSL/ENG/SC/132

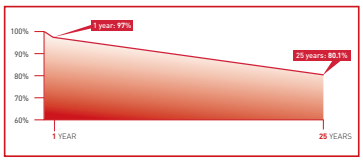
Dimensions in mm



Typical I-V Curves



Performance Warranty



Packaging Information

Quantity/Pallet	25
Pallets/Container (40'HC)	24
Quantity/Container (40'HC)	600

^ All (^) certifications under progress.
** Refer to Vikram Solar's warranty document for terms and conditions.

CAUTION: READ SAFETY AND INSTALLATION MANUAL BEFORE USING THE PRODUCT.
Specifications included in this datasheet are subject to change without notice. Electrical data without guarantee. Please confirm your exact requirement with the company representative while placing your order.

*Vikram Solar is Trademark of Vikram Solar Limited registered in India

flyer-5BB-72-solivo-som-grand ultima-smart 1000V-E-18-R00

vikramsolar
CREATING CLIMATE FOR CHANGE

sales@vikramsolar.com
www.vikramsolar.com

- **India:** Kolkata | Gurugram | Mumbai | Pune Bengaluru | Raipur | Surat | Ahmedabad
- **International:** Germany | USA | Singapore | China | UK LATAM | Japan | Kenya | Uganda

Figure A.1: PV Module Datasheet

B Additional figures and tables

The figure B.1 shows the day wise peak demand profile for the whole year. A peak demand of over 9 GW is observed for TS in 2017. On an average, peaker demand is seen in the months of February, March, July, September (and occasionally October) since this demand is mainly driven by agricultural load for increased water consumption for irrigation purposes. Agricultural load contributes to approximately 40% of the total load in these months (Interview #1). In the rest of the months energy requirement for agriculture sector is significantly less and the demand is dominated by Domestic and Industrial loads.

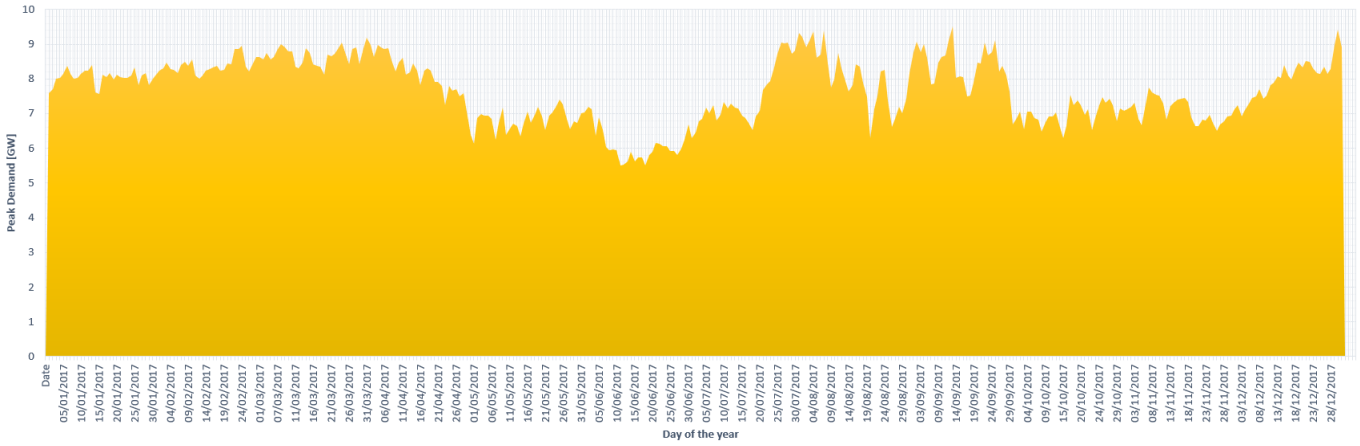


Figure B.1: Day wise peak demand. Max value = 9.191 GW (2017) [GW]

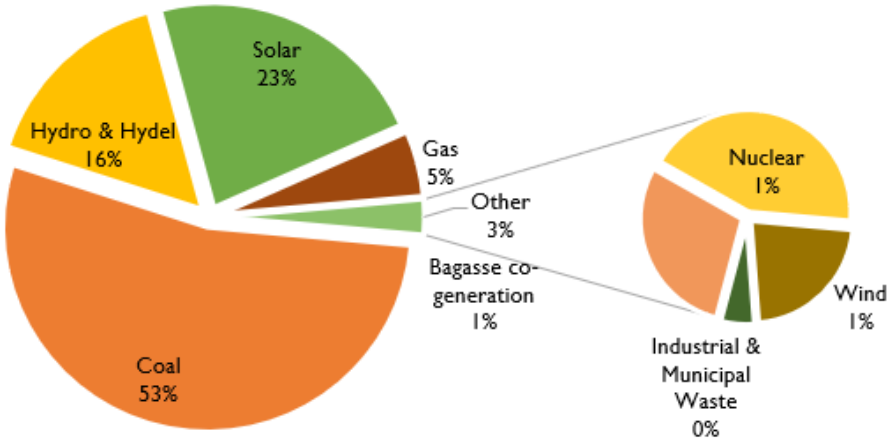


Figure B.2: Installed Capacities as on 1 July 2019. Source: TSTRANSCO.

B.1 Growth Rates and Projections

Table B.1: Year-wise projected values for Electricity (E), Fuel in transportation (F), total energy for the scenario (Sc) and the per-capita energy consumption.

		BAU [TWh]				ALT [TWh]			
Year	Population [millions]	E	F	Sc	Per-capita [kWh/person]	E	F	Sc	Per-capita [kWh/person]
2017	38.50	58	56	114	2,963	58	56	114	2,963
2018	38.88	66	61	127	3,270	66	61	126	3,253
2019	39.26	75	67	142	3,611	74	66	140	3,573
2020	39.64	84	73	157	3,971	83	71	155	3,898
2021	40.03	95	80	174	4,350	93	77	169	4,227
2022	40.32	105	86	192	4,753	102	82	184	4,561
2023	40.60	116	93	209	5,159	111	87	198	4,885
2024	40.89	127	101	228	5,575	120	92	213	5,198
2025	41.18	139	108	247	5,998	129	97	226	5,497
2026	41.47	150	116	266	6,426	138	102	240	5,783
2027	41.77	162	124	286	6,855	146	106	253	6,047
2028	42.06	175	132	306	7,285	154	110	265	6,293
2029	42.36	187	140	327	7,714	162	114	276	6,519
2030	42.66	200	147	347	8,138	169	118	287	6,721
2031	42.97	213	155	367	8,551	175	120	296	6,887
2032	43.19	226	162	387	8,970	181	123	304	7,041
2033	43.41	238	169	407	9,376	186	125	311	7,168
2034	43.63	251	175	426	9,769	190	127	317	7,267
2035	43.85	264	181	445	10,145	194	128	322	7,338
2036	44.07	276	187	463	10,508	196	129	325	7,384
2037	44.30	288	193	481	10,859	198	130	328	7,406
2038	44.52	300	199	498	11,194	199	131	330	7,403
2039	44.75	311	204	515	11,507	198	132	330	7,374
2040	44.98	322	209	531	11,799	197	132	329	7,321

Table B.2: Growth in the consumption of Gasoline, Diesel and Alternate Fuels as percentage and TWh values year-on-year. G: Gasoline; D: Diesel; AF: Alternate Fuels (CNG, CBG, HCNG); α: Efficiency improvements in fuel use; β: growth rate; F: Total (fuel) energy use.

		BAU gr %		BAU Energy [TWh]			ALT gr%			ALT Energy [TWh]			
Year	α	G_β	D_β	G	D	F_BAU	G_β	D_β	AF_β	G	D	AF	F_ALT
2017	1.00%	15.00%	10.00%	14	42	56	15.00%	9.50%		14	42		56
2018	1.00%	14.50%	9.45%	16	46	61	13.95%	9.00%		15	45		61
2019	1.00%	13.50%	9.30%	17	50	67	12.97%	8.46%		17	49	0.1	66
2020	1.10%	13.00%	9.25%	20	54	73	12.07%	7.95%		19	52	0.1	71
2021	1.20%	12.50%	9.00%	22	58	80	11.22%	7.48%	0.40%	21	55	0.2	77
2022	1.30%	12.00%	9.00%	24	62	86	10.44%	7.03%	0.80%	23	58	0.4	82
2023	1.40%	11.50%	8.75%	26	67	93	9.70%	6.61%	1.60%	25	61	0.8	87
2024	1.50%	11.00%	8.60%	29	71	101	9.03%	6.21%	2.40%	27	64	1.2	92
2025	1.60%	10.50%	8.45%	31	76	108	8.39%	5.84%	3.20%	28	67	1.7	97
2026	1.70%	10.00%	8.20%	34	81	116	7.81%	5.49%	4.00%	30	69	2.2	102
2027	1.80%	9.50%	8.00%	36	86	124	7.26%	5.16%	4.80%	32	72	2.8	106
2028	1.90%	9.00%	7.80%	39	91	132	6.75%	4.85%	5.60%	33	74	3.4	110
2029	2.00%	8.50%	7.60%	41	96	140	6.28%	4.56%	6.40%	35	76	4.0	114
2030	2.10%	7.90%	7.45%	44	101	147	5.84%	4.28%	7.20%	36	77	4.6	118
2031	2.20%	7.60%	7.30%	46	106	155	5.43%	4.03%	7.49%	37	79	5.0	120
2032	2.30%	7.30%	6.90%	48	110	162	5.05%	3.78%	7.79%	38	80	5.3	123
2033	2.40%	7.00%	6.60%	50	115	169	4.70%	3.56%	7.40%	39	80	5.7	125
2034	2.50%	6.80%	6.30%	53	119	175	4.37%	3.34%	7.60%	40	81	6.0	127
2035	2.50%	6.60%	5.90%	55	123	181	4.06%	3.14%	7.65%	40	82	6.4	128
2036	2.50%	6.40%	5.65%	57	127	187	3.78%	2.95%	7.70%	41	82	6.8	129
2037	2.50%	6.20%	5.45%	59	130	193	3.51%	2.78%	7.80%	41	82	7.3	130
2038	2.50%	6.00%	5.25%	61	134	199	3.27%	2.61%	8.00%	41	82	7.7	131
2039	2.50%	5.75%	4.95%	62	137	204	3.04%	2.45%	8.10%	41	82	8.2	132
2040	2.50%	5.50%	4.75%	64	140	209	2.83%	2.31%	8.00%	42	82	8.7	132

Table B.3: ALT Scenario: Quantum of fuel use in billion litres and thousand tonnes of CNG (assumed as an alternate fuel). Total Vehicles in millions.

Year	Gasoline (billion liters)	Diesel (billion liters)	CNG ['000 tonnes]	Vehicles (millions)
2009	0.68	2.65		4.32
2010	0.75	2.79		4.89
2011	0.83	2.94		5.54
2012	0.89	3.23		6.23
2013	0.90	3.43		6.93
2014	1.01	3.34		7.68
2015	1.13	3.40		8.48
2016	1.29	3.72		9.32
2017	1.47	4.04		10.16
2018	1.66	4.36		10.98
2019	1.86	4.68		11.74
2020	2.06	4.99	6.5	12.52
2021	2.26	5.30	11.83	13.30
2022	2.46	5.60	25.03	14.07
2023	2.66	5.89	52.76	14.83
2024	2.86	6.16	83.09	15.57
2025	3.05	6.41	115.99	16.30
2026	3.23	6.65	151.37	17.02
2027	3.41	6.87	189.10	17.71
2028	3.57	7.06	228.99	18.39
2029	3.72	7.24	270.87	19.03
2030	3.85	7.39	314.78	19.66
2031	3.97	7.52	337.52	20.27
2032	4.07	7.62	361.20	20.86
2033	4.16	7.71	385.79	21.42
2034	4.24	7.76	411.26	21.95
2035	4.30	7.81	437.97	22.48
2036	4.35	7.84	465.97	23.00
2037	4.39	7.85	495.27	23.50
2038	4.42	7.86	525.89	24.00
2039	4.44	7.85	557.87	24.48
2040	4.45	7.83	591.21	24.94

Table B.4: The ratio of change in energy consumption to the change in GDP considered as a multiplier to calculate future energy growth.

Year	EGR multiplier	Year	EGR multiplier
2014	1.43	2028	0.94
2015	1.28	2029	0.94
2016	.88	2030	0.94
2017	0.98	2031	0.93
2018	0.97	2032	0.93
2019	0.97	2033	0.93
2020	0.97	2034	0.93
2021	0.96	2035	0.92
2022	0.96	2036	0.92
2023	0.96	2037	0.92
2024	0.95	2038	0.92
2025	0.95	2039	0.91
2026	0.95	2040	0.91
2027	0.94		

B.2 Yearly Installed Capacities projected

Table B.5: Scenario A_C: Yearly Installed Capacity in GW for all sources.

Year	Coal	Solar	Hydro	Nuclear	Nat. Gas	Biomass	Wind	Geothermal	Total
2019	8.56	3.6	2.5	0.19	0.83	0.15	0.10	0.00	15.9
2020	10	4.4	2.5	0.19	0.83	0.15	0.10	0.00	18.2
2021	12	5.5	2.5	0.19	0.83	0.15	0.10	0.00	21.3
2022	14	6.8	2.5	0.19	0.83	0.5	0.15	0.00	25.0
2023	15	8.4	2.5	0.4	0.83	0.5	0.15	0.12	27.9
2024	16	10.3	2.5	0.4	1	0.5	0.15	0.12	31.0
2025	16	12.8	2.5	0.4	1	0.5	0.15	0.12	33.4
2026	16	15.2	2.5	0.4	1	0.5	0.15	0.12	35.9
2027	16	17.6	2.5	0.4	1	0.5	0.15	0.12	38.3
2028	16	20.0	2.5	0.8	1	0.5	0.15	0.12	41.1
2029	16	22.5	2.5	0.8	1	0.5	0.35	0.12	43.7
2030	16	24.9	2.5	0.8	1	0.5	0.35	0.12	46.1
2031	16	27.3	2	0.8	1	0.5	0.35	0.19	48.1
2032	16	29.7	2	0.8	1	0.5	0.35	0.19	50.6
2033	16	32.1	2	0.8	1	0.5	0.35	0.19	53.0
2034	16	34.6	2	0.8	1	0.5	0.35	0.19	55.4
2035	16	37.0	2	1	1	0.5	0.35	0.19	58.0
2036	16	39.4	2	1	1	0.5	0.35	0.19	60.4
2037	16	41.8	2	1	1	0.5	0.35	0.19	62.9
2038	16	44.2	2	1	1	0.5	0.35	0.19	65.3
2039	16	46.7	2	1	1	0.5	0.35	0.19	67.7
2040	16	49.1	2	1	1	0.5	0.35	0.19	70.1

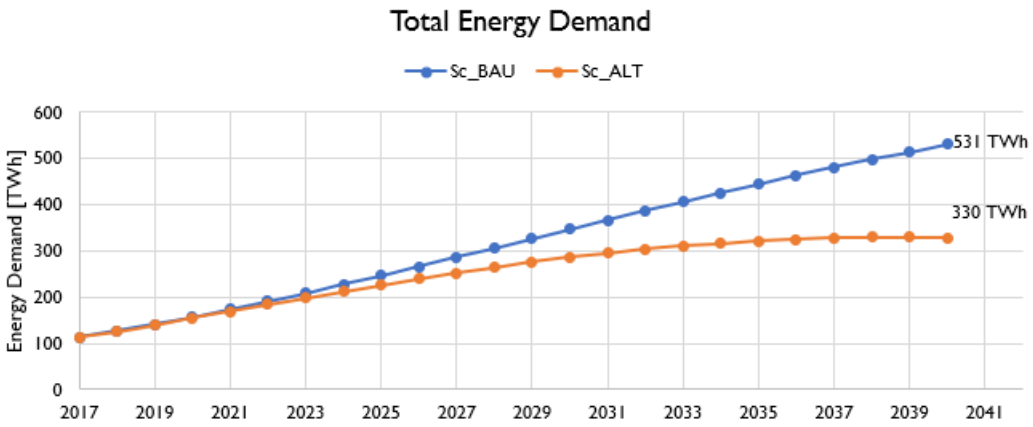


Figure B.3: Total energy demand in both scenarios including electricity and fuel.

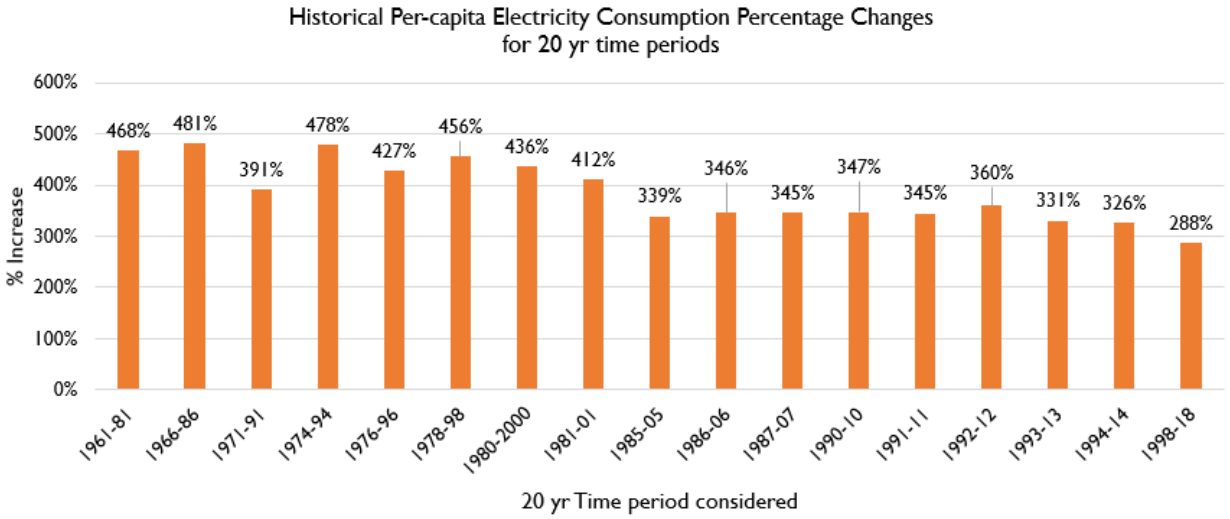


Figure B.4: Historical Percapita Electricity Consumption taken for 20-year periods observed till 2018. The trends shows a very slow but gradually falling percentages.

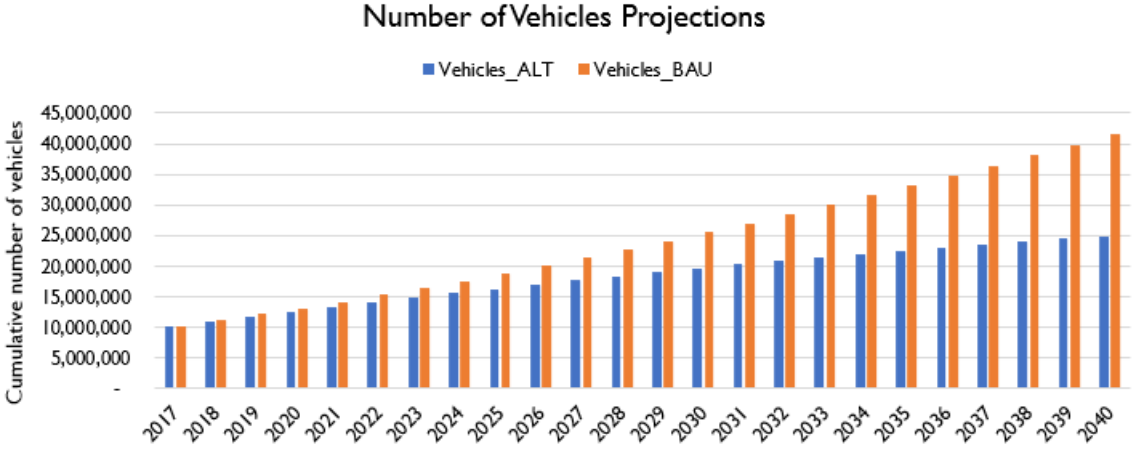


Figure B.5: Scenarios for projected increase in the total number of vehicles

B.3 Cost Assumptions

The assumptions for calculating the capital made (in section 9.1) are given below.

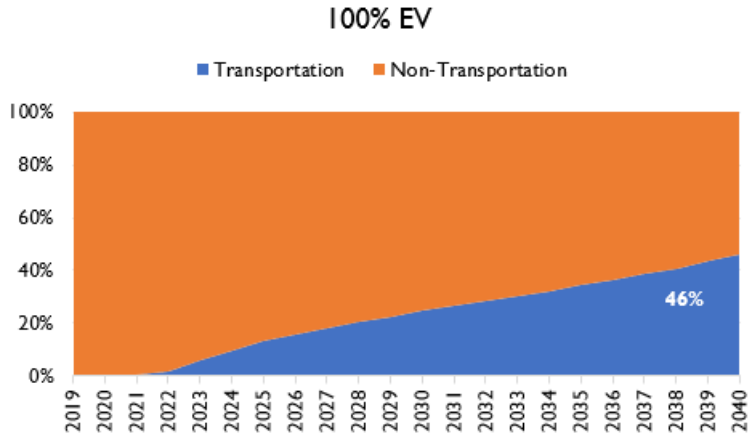


Figure B.6: What if 100% of the vehicles go electric by 2040? Share of electricity from transportation in a 100% EV scenario.

Table B.6: Scenario A_M: Yearly Installed Capacity in GW for all sources.

Coal	Solar	Hydro	Nuclear	Nat. Gas	Biomass	Wind	Geothermal	Total
8.56	3.6	2.5	0.19	0.83	0.15	0.1	0	15.9
10	4.6	2.5	0.19	0.83	0.15	0.1	0	18.3
12	5.8	2.5	0.19	0.83	0.15	0.1	0	21.6
14	7.4	2.5	0.19	0.83	0.5	0.15	0	25.5
16	9.4	2.5	0.4	0.83	0.5	0.15	0.12	29.9
16	11.9	2.5	0.4	1	0.5	0.15	0.12	32.6
15	15.1	2.5	0.4	1	0.5	0.15	0.12	34.8
14	19.1	2.5	0.4	1	0.5	0.15	0.12	37.8
13	23.1	2.5	0.4	1	0.5	0.15	0.12	40.8
12	27.1	2.5	0.8	1	0.5	0.15	0.12	44.1
11	31.1	2.5	0.8	1	0.5	0.35	0.12	47.3
10	35.1	2.5	0.8	2	0.5	0.35	0.12	51.3
8	39.0	2	0.8	2	0.5	0.35	0.19	52.9
8	43.0	2	0.8	2	0.5	0.35	0.19	56.9
8	47.0	2	0.8	2	0.5	0.35	0.19	60.9
8	51.0	2	0.8	2	0.5	0.35	0.19	64.9
8	55.0	2	1	2	0.5	0.35	0.19	69.0
8	59.0	2	1	2	0.5	0.35	0.19	73.0
8	63.0	2	1	2	0.5	0.35	0.19	77.0
8	67.0	2	1	2	0.5	0.35	0.19	81.0
8	71.0	2	1	2	0.5	0.35	0.19	85.0
8	75.0	2	1	2	0.5	0.35	0.19	89.0

1. For Solar PV, the cost per kW value is taken at 800 $\frac{\$}{kW}$ from International Renewable Energy Agency (2018). A learning rate of 20% with 10x increase in the total capacity installed is taken from Trabish (2018), Kavlak et al. (2018) and Institute of Energy (2019).

2. For Battery storage, Lithium ion battery costs are considered. The current price of 250 $\frac{\$}{kWh}$ is assumed. Input by Interview #9. The learning rate of 18% with doubling of total capacity installed is taken from Goldie-Scot (2019).

3. The capital needed for Transmission and Distribution Infrastructure is taken from Government of Telangana (2015) and Buckley and Shah (2019) at 91 million $\frac{\$}{GW}$. A learning rate of .5% per year is assumed.

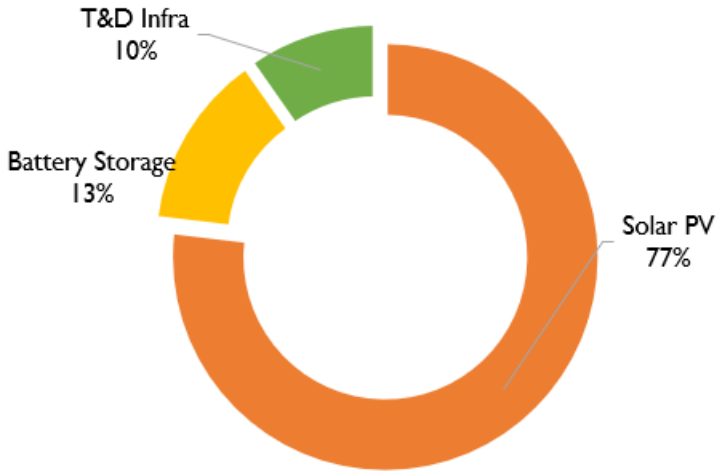


Figure B.7: Share in the total capital for PV, Storage and Transmission and Distribution Infrastructure. The % values are the same for both A_C and A_M.

C Stakeholders

This part of appendix will give additional information about the other major actors involved, the names of the interviewees and the transcripts in brief. The table below in figure C.1 shows the methods available for actor analysis. In this thesis, the policy analysis activities for which stakeholder analysis is done is restricted to research & analyze and design & recommend.

Policy analysis activity	Actor analysis can help to ...
Research and analyze	Mobilize knowledge and information from a broad actor base, which is likely to improve the quality of the problem analysis
Design and recommend	Create ideas for alternative strategies and tactics by mapping options and interests of different actors. This helps to identify common ground and shared fundamental values, to identify ways in which different actors can contribute to these shared values, and to identify needs and possibilities for compensation or mitigating measures to satisfy particular actors
Advise strategically	Assess the feasibility and potential to implement policy options, by mapping the positions, interests, resources, and relations of actors, providing insight into the opportunities and threats that actors pose for problem solving
Mediate	Map conflicts, identify potential coalitions of actors, and propose a road map for a negotiation process, including agenda items and participants in various stages of discussion
Democratize	Ensure that all the important actors are included in the policy process, and/or that their views and concerns are incorporated in the problem analysis. From a normative point of view, this supports a more legitimate problem analysis
Clarify values and arguments	Include the full range of values and arguments in a problem analysis, which aids a problem analysis that is recognized and accepted by different parties, offering a better basis for agreement and cooperation concerning policy options

Figure C.1: Possible contributions of actor analysis to policy analysis activities. Source: Hermans et al. (2010).

C.1 Interviewees

The interviews were conducted over telephone. Interviewees #3, #4, #5, #7, and #9 took nearly one hour or more. And the rest between 30-45 minutes. #1 and #2 were conducted over e-mails. #12 did not provide consent to publish their details. Certain interviewees requested anonymity in terms of their name and

Table C.1: List of Interviewees

#	Name	Designation	Organization
1	Amarnath Sriram	Chief Divisional Engineer	TSNPDCL
2	A Prasad	CEO	TSREDCO
3	Subrahmanya Pulipaka	CEO	NSEFI
4	Pustav Joshi	Programme Manager	x
5	Shalu Agarwal	Programme Lead	CEEW
6	Akshay Dewan	General Manager, Operations	PXIL
7	Venkateswaran	General Manager, Plant Head	NTPC
8	Akshay Sarwade	Regional Manager	IOC
9	Dr Rahul Walawalkar	President & Executive Director	IESA
10	Girish Shivakumar	Business Development Manager	MEML
11	Rahul Lamba	Consultant	NewMo Management Consulting
12	J V	x	x
13	Kajal Maheshwari	Environmental Activist	x

organization and so they are omitted.

Some of the *power flows* of the actors above is given below. Continuous lines indicate direct influence and dashed lines indicate indirect influence. One sided arrows show the direction of influence from one to another and two sided arrows show bidirectional influences.

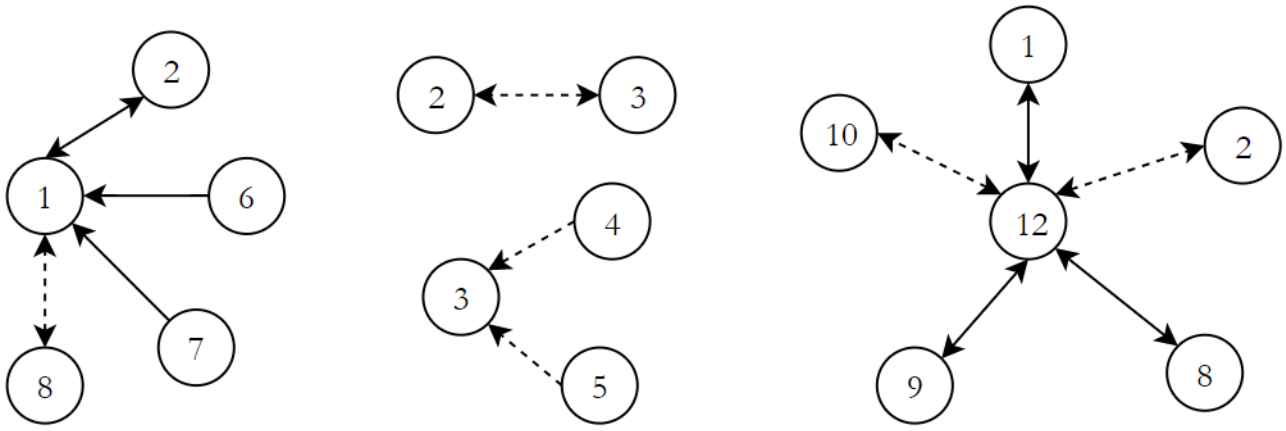


Figure C.2: Direct and indirect, uni- and bi-directional Powerflows among the stakeholders interviewed.

C.2 Interview Transcripts

The transcript of the interviews has been given below in brief with questions and answers. Most of the answers are given briefly as noted down during the interview. (#1, #2, #3, etc., represents interviewee numbers allotted earlier in table C.1). The conversations of 8 interviews were recorded (as audio files) and transcribing of the discussion in the form of minutes of the meeting is made. Certain parts of the conversation were re-heard for the purposes of understanding the interviewer better and notes were made. The transcripts presented here are a concise version of the discussion that took place. While most of the discussions presented

here are chosen from the point of view of the value that they add to the discussion, certain others are omitted due to lack of coherence and to avoid repeatedness.

Not all the questions were asked to everyone, however actors from similar fields faced common questions. For example, most questions for #4 and #5 were common since their organizations are research think tanks; similarly, some questions for #1 and #2 were common since they both were from similar state government organizations; #3, #5, #6, #7 had some common questions due to their background and experience working in the power sector; #9, #10, #11, #12 had some common questions due to their field of work in mobility and its inter-connectedness with storage technology sectors.

C.2.1 Electricity, Grids, and Finance

1. *What is your Opinion on reaching to a 100% RE scenario for a city or a state (for example, Telangana)?*

   #3 Impractical anytime soon without immense amounts of additional funding from national and international agencies and thousands of skilled manpower.

   #4 100% difficult and impractical. Won't happen anytime soon, not atleast by 2050;

   - Haven't figured out solving the storage problem on a mega scale yet. Storage seems too nascent for now.
   - Competing financial priorities of the government.
   - Politically not motivated (not for the masses yet). Majority wants energy, they don't care if its clean or not.
   - Policy paralysis => power is a concurrent subject and incidents like Andhra Pradesh currently renegotiating PPAs.
   - Lack of maturity of the electricity system to evolve into a more competition and market forces driven system and therefore a more govt regulated system.

   #5 For India, around 50% perhaps by 2050.

   #9 will be very challenging. More than technical is financial. To have consumers and policy makers to agree is difficult. Are people ready to pay for this to happen?
   Do you see willingness from govt?
   Central govt., yes. Not state.

   #10 Difficult from a grid management perspective. Distribution management will be a challenge. As RE goes high, there are more curtailing. This will just remain a vision on paper till new tech are implemented?

2. *The policies and actions of (state and central governments) look paradoxical. Both RE and coal power plants are encouraged. Also, excess power is lying vacant and there's a rise in stressed infrastructure (Non- Performing Assets or NPA). The investment lock in period for a coal power plant is more than 30 years. What happens to the financial health of power sector in the next decades? There's a lot of pressure already building up to push for renewables and bring down on coal use from around the world. Will the govt be staring at a huge backlog of coal plants to dis-invest, or liquidate or get rid of, by whatever means possible?*

   #2 Telangana is newly formed state. Still the per capita power consumption of the state if 1507 kWh as against the National Avg Power consumption of 1122kWh. The upcoming lift irrigation projects and the industrial domestic growth and the EV demands needs the base load in the non solar hours hence

the thermal is found as the only source to meet the base load and for ramping. But Govt of Telangana is having the highest focus on the RE. The current RE share in the installed capacity of Telangana is 27% which is very high as compared to other states and also Telangana is continuing as No. 1 state in the country in solar.

#4 Coal free India is not on the cards till 2050 or beyond. (National govt is clear on that) Coal will continue to play a major role since we need storage. Coal is imported from Australia, Indonesia and South Africa. Even by switching to gas, foreign dependency still remains. Govt wants to push EV since it wants to reduce crude imports. Policies of other countries also impact India. For example, India was getting crude oil from Iran great prices and due to the US sanctions, this is not the case any more. Market forces will drive coal out, only to a certain extent. Not more.

#5 Agriculture sector is important for economy and power. If farmer distress and irrigation issues increase, then this would lead to greater power problems. Solar pumps will be promoted more. They are good from energy point of view but bad from that of water. Need to find ways to incentivise state govt to participate in integration. Its not just more solar. Cannot discount political compulsions.

#7 Reasons why there is excess capacity and NPAs in coal power sector:
Country went over ambitious to let many pvt players set up a number of coal power plants without any PPAs. However these companies were alloted coal mines at much cheaper prices through inefficient ways and not through the appropriate competitive bidding. Eventually as corruption charges were proven against the authorities that made this happen, these coal mines were de-allocated by the supreme court of India. The coal companies thus had to source coal from other sources (open-market) that increased the price of the electricity. Eventually, this couldn't stand the competition and soon they were forced to go bankrupt. Thus, this gave rise to an excess vacant capacities which were also NPAs. However, that is not the case with TS. For the next 15-20 yrs in India (and TS), coal plants will not shutdown. Next best alternative for India to serve baseload is Nuclear power.

3. *So what is the way out? Shouldn't more efforts be aimed towards increasing renewable power instead of coal? Is TS prepared for an energy transition?*

   #7 For TS: They should go for large scale solar PV, connect it with their irrigation requirements and use that instead of Coal. So that PV can be used exclusively for pumping requirements.
   thereby Delinking load requirements with the main grid (powered by coal). Instead of giving free power, enable farmers to share the cost of buying solar pumpsets. (20:80 ratio).

4. *What do you think about India's RE target of 100GW of installed Solar Power by 2022?*

   #7 May be 2025-26. It has slowed down relatively. The policies have to be revisited. Problems mainly related to transmission of power from solar parks. PLF is about 18-20% throughout India (for fixed axis, w/o tracker. They change inclination season to season. Axis tracker are not popular.)
   Transmission: Power grid corp. If power trans happens between states, then PGC pays. If within states then state TRANSCO itself pays. However, 18-20% PLF is not economical for transcos. TS has well distributed instead of large solar parks since they use existing transmission line capacities; and there is no sudden loss of power in the load profile.

5. *What are the major challenges for Grid Operator/Discom at present and for the coming 10-15 years? Especially for integrating vRE into the grid?*

   #3 Major complaint from Grid Operatorss: Intermittancy of REs. transmission and distribution capacities left under utilized. Highly destabilizing the grid. Another problem Grid Operators facing:

Deviation Settlement Management (DSM) - solar power plant owners are penalised if their solar farm produces lesser than what they promised, 15 days before. It depends on a particular percentage.

#7: 1. Kothagudem and ramagundam power plants are very old. Kothagudem is setting up new units. 2. Payments from Transcos not on time. Transcos are also constrained since govt is not released the money for free power to agri. Payment is in bits and pieces. 3. When solar and wind are high, coal backs down. And when they are low, coal ramps up. Current ramp rate is is 4-5%. Plans to increase 20%.

6. *What is the biggest challenge you see for the entire energy system transition (including electricity, transportation, etc)?*

   #5 1. A. Demand-supply problem in the short term. b. Ability to upgrade the whole grid infra to make it flexible and smart. c. Integrating centralised storage systems in a manner. (Institutional reforms) 2. Electricity markets will change drastically. (Organizational changes) 3. Lot of DSM - participation of consumers - Cooling devices in the future - so how to make consumers more aware and active. 4. Agricultural SEctor

7. *What are the current challenges in the power sector that are impacting trading operations?*

   #6 Discoms are not able to comply to RPO obligations. NMEEE - REC is a part of it. Certain RPOs are assigned to every state => state assigns to captive/industrial consumers. Some big consumers keep defaulting since this market is highly regulated. Base price of solar trading is Rs 1/kwH. Goes upto 3.30 Rs/unit. Due to these reduced prices discoms want to operate in their own state.

   Andhra pradesh: solar + storage - 1MW for 4 hours: 4MWh project. Project was scrapped due to lack of funds. Greenco - 3000 MWh deal with AP. (solar + Li ion) AP, TS, TN - smarter states with better power plans. Northern india - colder - NMC - Nickel Magnesium Cobalt.

8. *How are Renewables affecting the trading real time prices?*

   #6 Not much. Exchanges operate on variable load. Base load is already met from coal plants. 90% of the energy is met from entitlements - long term PPA, or medium terma etc. remaining is traded frome exchanges. 1000 MW – 10% is 100MW. But the thing is Renewables are must run. They go first in merit order. RE are more of obligation to put in by govt to reduce coal dependency. It is just a price saving option. Installing or having RPOs is a burden.

   Solar private players: Generators go into PPA with large consumers. Information dissemination is there but no one knows how tech operates.

9. *If in future, renewables occupy 50% share in energy mix in TS. then how does exchange operations change?*

   #6 It is good for exchange. It will not affect the prices much. And the rest from conventional sources. But renewables alone wont be able to alone supply the total increase in energy consumption. Variable source cannot feed variable demand.

10. *Which months have the highest and which months have lowest demand? And why?*

    #1 In Northern Power Distribution Company Limited Peak Demand months are âĂŞ
    -Highest Demand Months- September, October & March. As TSNPDCL is dominated by Agricultural load (Approx.40% of Load), in above mentioned months water requirement for agriculture crops is significant which leads to increase in energy consumption in overall.
    -Lowest Demand Months- May, June, July August. In these months energy requirement for agriculture sector is very less. In these months demand dominated by Domestic and Industrial loads.

11. *What solutions are currently being implemented to the address the intermittancy /variability, while power feeding from solar and wind, to the grid?*

    #3 National Storage Mission, Feb 2019. Li ion. Govt is bullish. Integrating storage in the grid is also a challenge: Lack of inertia. Storage may not entirely solve the problem. Its never feasible to have storage that can continuously supply power for such a long time. Its not economically feasible. Hydrogen: timeline - 2022 from IOC and ONGC

12. *What are your thoughts on greater privatisation of distribution network? What are the challenges and the way out?*

    #3 Why private players don't come in? They are loss making and loss is really huge.
    UDAY too was not successful. Banks never agreed.
    Solutions: 1. Remove cross subsidy (free power to agro sectors), half the problems are gone, bad debts will not get compounded; 2. Residential tariffs to be OT based, variable pricing as per time of the day. Since solar doesn;t consume infra for 60% of the day. S, price of electricity to be made sensitive. Variable pricing to be done depending on duration of the day. Despite 5-6 yrs of RE growth, a lot more hasn't been done due to political will.

    #5 Challenges are mainly Political. However customer dissatisfaction rose where privatization took place. First provide evidence/confidence that privatisation can actually help.
    What if: a part of power share to be privatised.

    #7 It is certainly possible. Pilot in Orissa didn't work well. Delhi is a good example. Calcutta electric supply undertaking, Bombay (BEST) distribution. Other states: Problem of the government, rather than private players. Govt must make circles for pvt players. More of a policy decision rather than non-viability.
    In AP, for example, distribution is privatised in some small regions. It is working well, but many problems arose due to it.

13. *Do you think that if states and municipalities get greater autonomy in handling investment and decision making in power systems, would it make the energy transition faster?*

    #5 Certainly there will be a greater role for state level govt in the future. Municipalities participating: Why not? But some state, central and municipality laws clash. It has to be cleared, provisioned.
    Bangalore and Chennai has rain water harvesting compulsion stuff, for example. New kind of business practices too needed.
    More autonomy/incentives to states and cities should work.

14. *Telangana has a potential of more than 20GW (according to NISE) of Solar power which is around 85% of the total RE potential. If the future energy infrastructure comprises of this, what is the way forward in terms of how policy can drive the adoption of solar and addressing variability?*

    #3 Policy should focus on distributed gen - more micro, mini,nano grids. Rooftop to have cumulative policies.
    In TS - Kusum Scheme:
    Above all reduce liability on discom.

    Community based storage systems: not sure. Hasn't been done. Solar + storage for rural is done: Chotkei (Orissa) india first nano grid.

    How much can be achieved from this available potential?
    #2 Telangana Govt Is committed to commission 5GW of solar by 2022 considering the RPO needs and the state Power needs.

15. *What are your opinions on bio-based energy sources being sustainable?*

    #7 Further legislation is required. Example: burning farm stubble causes pollution. Govt policy: this stubble can be sold and burnt with coal. This is working. Is such a thing happening in TS? No policy as such. Including Municipal Waste. Agro waste could be a great source.

16. *Do you have an opinion on any of the following? (How much the following will be needed or useful in India and why they are not implemented yet in India?)*

    #4

    - Green Bonds
      In indian context: Hard to work at the moment in India - general bond market doesnt work well in indian context; only govt agencies publish; if corporate issues, then its viewwed with a lot of suspicion. Since it is viewed as high risk; it is basically unsecured loan. GB market in india will grow, but mainly govt driven;
      India needs to resolve its issues with bond market. Regular bonds to be made green. there is potential.

    - Carbon taxes (CO_2 tax)
      They tried it and it was successful. National clean energy fund was created by taxing coal upto INR 400/ton. 2011/2012. Back then it was lauded across the world. Govt made 70k cr out of it. It was diluted to national clean envt fund and clean ganga movement. And balancing GST books. The cess is still there, but the money is not used for the right purpose. Pseudo carbon taxation; REC; procure more RE and get REC;
      It helped a few industries to lower their footprint; targeted 8/9 industries (iron and steel, cement, hotels and hospitals)
      Generating cos have not transferred to consumers; but pricing of power is strictly regulated. Pricing of power is completely politicised. So power gencos face the biggest pain.
      Bad politics and populist options. Power pricing => Indirect subsidy => achieving political objective.

    - Feed-in-Tariffs
      India had FiT till 3 yr back; removed due to pricing complications due to administrative structural problems.

17. *Residential Roof-top PV sector has the lowest growth in comparison to the rest of solar PV sectors. What are the reasons?*

    #3 WE pay very low electricity tariffs. The incentive to move to solar is very low. So there is no trade off. No RoI. Therefore there is no point. Further residential roof top pv is still slow despite govt subsidy of 30%. Therefore, electricity prices have to be made demand sensitive. Right? Yes. Political will is very weak.

    #4 People haven't figured out the economics yet. Its got nothing to do with FiT. Since most of the power is gen during morning and afternoon, that's not where the peak power is. So they need to use a battery. And introduction of battery will push the economics out for a householder. Pay back period without battery is 12- yr. With battery 9- yr. This is way too long. Hence this is one reason.
    DISCOMS are not willing to set up net metering system. Cost of electricity procurement goes through the roof. They have no incentive do it.
    Cultural issues: People are not willing to give up their rooftops. What if they build a new floor on roof and get more rent? I like open spaces, terrace gardening, kids play, etc. terrace space is highly valued. Most people live in rented houses. Ownership model issues, social and financial security, etc.

What if: roof top pv + battery => FiT during peak time = ? Not sure how that works commercially. Issues are mainly towards economics and biz models.

18. *Why do we not have FiT and/or FiP in India yet? Why isnâĂŹt the govt focusing on incentive based mechanisms for promoting rooftop PV?*

    #3 The problem was that our infra and regulation was for consumers. For prosumers, tariff determination became complex. Electricity being a concurrent subject, laws became quite complicated and clashed. Therefore they switched to Net metering. So consumers are paid only for what they took from grid.

19. *When the power in grid is dominated by RE, how is the inertia in the grid maintained?*

    #7 Very difficult. Coal plants have to manage. Other countries use gas for ramping at peak times instead of coal. Gas is a solution for peak ramping of multiple GW. Cannot visualise how TS can have plenty of RE without gas or storage.

20. *What kind of DSM techniques can help normalise power prices and load balancing problems?*

    #6 Demand forecasting hasn't been too successful. (for exmaple; mumbai- rains delayed by 2 weeks). People are also a big constraint. No one is interested or look at new technologies. People don't bother. Upper level are in control but not much work is accomplished. Customised Energy Solutions.
    This is all a slow moving sector.

21. *What are the conflicting policies and policy based constraints for Solar PV?*

    #3 Mainly for rooftop- they are getting away with net metering and gross metering. Domestic procurement clause: There is very low mfg capacity compared to the rate of growth.

22. *Climate Change is not yet mainstream in the public domain. What can we do about it, especially in urban areas?*

    #3 MD - India Africa youth energy forum. Bringing it to urban context - make youth participatory in it. They are the main drivers. However, Indians are working more than they should if CBDR are to be taken into account.

    #5 Most people are aware of changing environment. Example: Water. Rains. Increased temperatures. But they are not linked well. We are not a mature society to protest for rights violation. Stronger community based action needed. It has to be made an important discussion.

23. *Floating PV:*

    #3 Prices have come down in the last 2 years. Not too high to reject

    #7 NTPC installed floating PV. they are costly for now. (other thought for TS?). Do it more in coastal areas, backwaters, etc.

24. *Learnings from other countries:*

    #3, #4 Incentives and push factors from China. Missed the bus. China's policy of promoting local manufacturing should be promoted fully, Rooftop side, learn from Australia and Germany.

25. *Financing Innovation: Innovation is one of the most undervalued in Indian firms. There are very few firms and govt agencies that work on innovative technological solutions for energy, storage and electric mobility technologies. How do you see innovation taking the driving seat and how should money be invested in driving innovation?*

#4 I dont see that happening. Its cultural thing. There is only state funded research. Innovation is still considered risky. People neither have the capital or patience needed. Social perception very low. We don't encourage it on a financial or even a social level.

26. *What kind of economic, fiscal, or policy incentives help promote Renewables in India, that haven't been worked before?*

    #4 If india wants to become more green (not just renewables), if you want to green the entire economy, or incentivise low carbon activity, the idea, itself makes a huge difference. Every ministry has a different mandate; if we were to come up with a policy to see a common mandate; wrt infrastructure; It would be nice if all ministries has a good common vision to work towards; say 1, 2, or 3 common threads are running and right things are prioritised (sustainability); For example; China can do it. Because of authoritarian. Can india do it? Too many challenges. We need more financial capital. We are short on capital on all fronts?

27. *Your experience from rural problems for energy. If you could change, what are the top 3 things that you would do, to act with urgency, to promote as much renewables as possible by 2040?*

    #5 Look at the new business models disrupting solar energy roof-top (rental/lease/sell excess). I think we need to figure out how to pass the cost of electricity to the ones who can bear it. We should also expose them to alternative solutions.

    #10 RE+storage is ideal. Tech and commercial. What the utilities are doing => renegotiate purchase agreements to change prices. So this may delay invest since investors sentiments are hurt. PPAs are not being honored. TS and AP mainly. Delay in payment to the solar farm developer is a main cause. Way forward: Legal enforcement - separate tribunal. Normalise all current PPAs. Solar wont get tariff higher than coal. Central govt has to provide Viability Gap Funding. All power projects have a share of central govt. Setting up greenfield power projects require a lot more infra and costs. Other big problem: what if they generate a lot more energy? They have to be integrated to national grid.

28. *Do you have a list of top things to be done or planned ?*

    #3 1.Stop grid integration and promote more off grid. Its the main way to go forward.
    2.Skilled work force is needed. Better the skilled forced better the system. Proper streamlined mechanism needed. With certification.

29. *Policy for TS: Solar+storage*

    #3 Challenges of Coal plants; New emission norms are notified. Go to diesel and catalytic converters. Not sure if TS has planned for these environmental norms.

    #6 Major RECs from non solar – bagasse, biomass, wind. Overall net realisation from solar is pretty low.

Currently how is the RE ecosystem in the state? In terms of private participation in Solar, wind, bio-based, storage and other technologies, how is the business atmosphere?

#2 Solar Wind Technology is more stabilized in terms of business. The storage technology looks promising but once the policy is rolled out the actual scenario will be known.

C.2.2 Fuel, Transportation, and Storage Tech

1. *The demand for oil is continuously increasing. How do you see this happening for the future? How long will this trend continue?*

#8 Until 2040 it will continuously increase. Availability is always an issue. Continuously everyday new oil fields are coming up. So future is not too bleak for oil. Largest Oil consumer Us and India (per capita consumption).
We are import dependent: So govt has given free license to buy more oil fields (Indian oil bought in US and Congo). Now marketing cos also buy.
Current import: check PPAC report.

#10 Will happen till 2030. India will peak oil cons.
But after Bs6, fuel gets even more expensive. But macro economic factors are better.

#11 Ans: Segment by segment has to be considered. 2W, 3W - are gaining traction significantly. 2W - low and high speed segments - urban and tier 2 places; Bounce, Riva, etc - ride sharing from metro sharing.
Zomato, Ola, uber - testing electric 2w. They seem happy. But the next 6 mo is going to be still testing and dev.
Erickshaws - India's market exploded. More than 200-300 mfg. No significant player who enjoys 5%. (but max on Pb acid tech). - because its very cheap. Do you see the shift happening to Li? It would take a lot more time. Because the costs would rapidly rise. The subsidies are insufficient - 10k per kwh. There are closely to 1.5 million vehicles. But real figure is much higher (adding unregistered vehicles.)
e-Autos: tech is not yet developed commercially and technically as well. Battery degradation is unclear. No lifecycle tests. Market wants one type of swappable battery for 2w,eautos and ericks. But current rating differences are yet to be reconciled. Ashok leyland and piaggio working.
4W - probably last thing to be electrified. Subsidies are still insufficient to cover the gap. Personally opened will take much longer.
For Ola and Uber - Mahindra everito and tata tigor. 98% of the cars are less than 10L. There is a heavy policy uncertainty at the moment that needs to be sorted by the central govt.

2. *Major challenges in the oil sector that you see and what is to be done about them?*

   #8 1. Increasing pollution related problems => emphasis on oil consumption. Like electrification, Compressed bio gas (90CNG and 10CBG); Satad - govt. initiative: Wastes from (Oct 1 2018 report): CBG from wastes (all). Urging municipalities and corporations to use this along with CNG
   2.Stress on EV; wherever feasible, install charging stations.

   #9 Main challenges facing the technology as well as its commercialization? Explain wrt stakeholders like Transcoms and Discoms. Ans: One of the biggest issue is people are not aware of tech and biz model. Lots of intertia within the system to change, from both tech and human capital.
   Example: Andaman nicobar islands. 5 yrs back also it would be cost effective to have battery storage. But still nothing substantial on ground. So first thing is to show how it can be effectively used. Inform all stakeholders. *There are enough global pilots, so pilots not needed in India. But the time for demonstration is beyond. We are missing the bus. So we just need to address barriers and get started.*
   Test drive example: specify what you want to learn from the criteria - test drive- test speeed, acceleration, etc. But economics don't work: Example residential roof-top pv - that's true. Case by case basis, residential, is not yet.

   #10 (commercialising storage tech) It has to be an enabler due to more renewables. It has to be therefore cost competitive. Penalties will have to be paid till better management is done.

3. *What are the major breakthroughs that you expect to see in the coming short term future/Next big revolution transforming oil industry?*

   #8 BS6 is as good as CNG emissions level. NOx and SOx come down. Furnace oil, light diesel oil, kerosene oil, LPG, LNG, are the fuels used. LSHS - low sulphur heavy stock is now being used.

Furnace oil is now going to be banned.
Light diesel oil is heavy. So shift to lpg or lng (heavier capital). LNG subject to availability.
CGD - City gas distribution => Rolled out in many cities like Pune, Mumbai, Goa working now. 100 districts LORs given. Hyderabad also WIP.
All retail outlets to run on solar energy only : Apr 2020 targets

4. *Govt has introduced mandatory ethanol blending in major cities across India. But it is not implemented across all outlets.*

   #8 5.8% blending all over india, for 2018-19. Due to non availability of ethanol. (90:10 suggested). Lack of rainfall => no sugarcane => no ethanol. (sugar production shouldn t be affected).

5. *Bio diesel upscaling: what kinds are available (future) and to what extent can they be upscaled?*

   #8 Biodiesel imported from Singapore (at kakinada and vizag). Jatropha is a failed project. 5 and 10% blending. (fuel quality obtained wasn't satisfactory). Nearly 5000 crores loss. Bio-diesel has a very bleak future. But CNG, CBG, HCNG to play a major rule in the next 10 years.

6. 74% 2w, 4% 3w and 13% 4W. With modest calculations, 80% are petrol but diesel is 3 times more consumed. So, unless cars, buses and trucks shift, the benefits from emissions are marginal. IsnâĂŹt it?

   #11 Emissions to be compared on 2 parts: 1. Co2(more co2) and 2. PM2.5 (more diesel) and this is the most deadly reason causing deaths. Therefore diesel engines are the biggest issue. CNG is a mature tech. (Maruti is investing huge amounts). SO CNG will be an intermediary tech. The pollution content is way lesser nearly 100 times lesser than a diesel car. Tata, Mahindra, EIcher, Leyland are all betting big on CNG and LNG. Running costs of EV is cheaper than EVs. Therefore people are asking govt to push cng too. Also, people want to wait to watch how firm the govt is. AMount invested for BS6 has to be recovered. Large investments made. How the fuck should these be recovered?

7. *Help me visualise the costs involved. TS current electrical cons is 60 TWh. 1% is 600GWh. How do we plan for storage at such a grid level? How is it planned? Help me understand the economics involved.*

   #9 When planning, software - COMET software. Hours to weeks. Where the storage adds value by seeing profiles. Separate energy throughput and size of project. Deep cycle, shallow cycle, etc.
   Its not like x% of a region's energy consumption. Its misleading. Won't give optimised results.
   Any projects you helped?
   Implementation for grid scale projects are lagging. Lots of announcements. Pondicherry .5MW deployed to show frequency regulation. Lots of them stuck at paperwork.

8. *The infrastructure related to electric vehicles comes under which agency? Why is it not promoted under TSREDCO?*

   #2 As per the State Draft policy of EV, state Govt will provide incentives and subsidies for manufacturers of EV Vehicles and ancillary industries. Govt of India (Ministry of Power Min of Transport and Highways) will provide incentives and subsidies for manufacturers of EV Vehicles and ancillary industries in respective states along with state govts (Please refer to FAME II) policy of MOP). TSREDCO is appointed as the State nodal agency for charging infrastructure under FAME-II guidelines. The infrastructure will come under the respective transport department as far as EV is concerned and the charging infrastructure will come under TSREDCO.

9. *What are the various pilot projects or experimental projects currently being undertaken in Telangana on Storage technologies (Lithium ion, Lead acid, Hydrogen, other technologies) and any other Renewable energy tech? I could not find this information on tsredco website.*

#2 Currently there is no policy related to Storage technologies (Lithium ion, Lead acid, Hydrogen, other technologies) and any other Renewable energy. The same will be issued at a later date. Once this policy will come then we will take up some pilot projects.

10. *How much does it cost per kwh in India today for Li ion?*

    #9 250$/kwh. Cost depends on 1kw or 5kw or etc By what % do you foresee the costs of storage fall down in the next 10 years?

    #10 in terms of technology costs, its the same globally. Duties and taxes only makes sense.

11. *Which one requires directed policies for incentives? Home based storage or grid level storage?*

    #9 more subsidies are required for retail customers. But industrial subs is better.
    Do you think the sales have to be incentivised by subsidies to end customers or subsidies to manufacturers?
    #9 subsidies to mfg is easier and that's the way govt. is head.

    #10 Something to cost come down, it has to scale up. Similar to solar. SO cost wont come down. Uptake of EV will help cost of batteries come down. So scale will incentivise. Ask more people to have solar first place. Then net metering. But storage is already growing at 6% pa. Subsidy can help only large scale. Then solar+storage.

12. *For EVs, how did FAME subsidies help? What more are the expectations from business players?*

    #9 FAME had challenges- benefits were taken by mild hybrid cars. Didnt go to intended beneficieries. Fame 2 is better. Doing it with aggregator is better. More utilisation vehicles so better economics. Where is govt targetting 10000cr for ev infra?
    Depends on where the EV demand is growing and then it will be decided.

    #10 Definitely an enabler. But many funds were unutilised and govt had to do last minute tenders. It was an enabler for fleet level companies. Which segment benefitted the most? Fleet operators.
    Expectations: TO have continuity in the policy. Govt is now more conscious to provide more subsidy to a normal customer. Subsidies to target whom better? End consumers. Govt Want to increase import duty to encourage domestic mfg.
    Solar procurement: unit prices were reduced. Hence its difficult. So this has better chances.

    #11 Biggest beneficiaries are small players - since they are able to capitalise on it and sell. Okinawa - released a vehicle that ran electric, ramped up production to 50,000 vehicles/yr. Lohia Auto, Hero electric as well. Because, nobody knew them prior to FAME subsidy. Afterwards, they grew, atleast 5x because of FAME. This is for 2 and 3W. This is helping bus mfgs also like tata, ashok leyland, BYD. Subsidy on bus: 50L

13. *Resi rooftop pv + ev charging point. .* #9 releasing a doc that helps Discoms. Rooftop pv+storage how they can work, costs, economics, tech,; how storage can help them?
    Still need to work on capacity building. Most of them are working like how they did before. No incentive to change the modi operandi. Regulators need to play a more pro active role to support initiatives.
    Working with new dynamic biz models, where you deploy new tech, etc.

    #10 There is an economic incentive. But packed urban congregations is difficult. Especially apartments.
    What role can DISCOMS play in improving infra for this? Ans: If they can getting sufficient funds for RE integration by making tariff rationalisation, then they can take the inistiative forward.

14. *Can we expect variable electricity tariffs to promote workplace EV charging or peak time EV charging? (Or V2G via DSM)*

    #10 Currently the idea is to have spl EV tariff. Variable tariffs will eventually follow. And more infra too is needed. Smart meters too. But utilities find it difficult. Since expensive. Integrating will take time.

    #11 No time of day pricing. And the variation is not very significant.

15. *Do you think all the fuel station outlets can be converted into EV charging points over a period of time? What are the operational, financial challenges and policy constraints?*

    #8 Space constraints for every retail outlet. So all is not possible.

16. *Status of Research in Hydrogen projects; overview; when can commercialization be seen? What are the major operational and policy challenges?*

    #8 Safety is not yet proven. Stability is an issue. Working along with TATA. HCNG is also used. Ministry of Environment has not yet given approvals for commercialization.

17. *Community storage Options: In rural areas, how can the growing demand be met with storage instead of adding more coal based peak capacities? How can micro grids help?*

    #9 can be done is grid connected way to optimise requirement. Grid connected microgrids +storage.

18. *What is your opinion on Li over-dependence? Wrt material scarcity and also wrt comparing it to other storage technologies available, what can u comment?*

    #9 at grid scale, PSP is much preferred. Li ion is still small. Li also took a long time. Didn't become popular overnight. Li per battery is very small % of overall. Concerns are overblown.
    What are the other commercially available options for storage in India apart from Lithium?
    Ans: PSP and Pb acid batteries at avl at MWh levels. No anciliary. Research project by BHEL.

19. *What more are needed from the Electric mobility segment in India in the coming decade? What is expected?*

    #10 More efficient and high energy batteries. Fast charging infra.

    #11 next 5 and 10 years personally. Evs will rule. Its a question of when. The more you delay the greater there is a change for disruption of older companies and takeover of new companies. Cars - atleast 5-6 years. RDE - Real Driving Emissions It puts a cap on CO_2 emitted/km. 2023 is an ideal timeline.

C.3 Other Major Stakeholders

The list of stakeholders who could not be interviewed is given below alphabetically.

1. ARAI: Automotive Research Association of India is the leading automotive R&D organization of the country set up by the Automotive Industry with the GoI. It is an autonomous body under the Ministry of Heavy Industries and Public Enterprises. It is a Scientific and Industrial Research Organisation and is one of the prime Testing and Certification Agency under the Central Motor Vehicle Rules.
2. BEE: The Bureau of Energy Efficiency is an agency under the Ministry of Power under the provisions of the Energy Conservation Act. The agency's function is to develop programs which will increase the conservation and efficient use of energy.

3. CEA: The Central Electricity Authority is a statutory organisation that advises the government on policy matters and formulates plans for the development of electricity systems.
4. CERC: Central Electricity Regulatory Commission, a key regulator of power sector in India, is a statutory body functioning with quasi-judicial status.
5. IREDA: The Indian Renewable Energy Development Agency (IREDA) is a Non-Banking Financial Institution under the administrative control of this Ministry for providing term loans for renewable energy and energy efficiency projects.
6. NISE: National Institute of Solar Energy is an autonomous institution under the Ministry of New and Renewable (MNRE), is the apex National R&D institution in the field Solar Energy. It assists the Ministry in implementing the National Solar Mission and to coordinate research, technology and other related works.
7. NITI Aayog: National Institution for Transforming of India Commission is a policy think tank of the Government of India, established with the aim to achieve Sustainable Development Goals and to enhance cooperative federalism by fostering the involvement of State Governments of India in the economic policy-making process using a bottom-up approach.
8. TSRTC: Telangana State Road Transport Corporation is a state-owned corporation that runs public transportation services in TS. It has more than 10,000 buses in its fleet.