

Chapter 1

Introduction and Literature Review

1.1 Motivation for Renewable Energy

The rising energy demands and to mitigate the carbon emissions, globally, the government of different countries are promoting exhaustively the use of the alternate source of energy also known as Renewable Energy (RE). RE sources like Biomass, Hydropower, Solar, Wind, Nuclear, and Geothermal are clean, reliable, affordable and sustainable. The sustainable clean electricity requires higher initial investments, latest technology and research innovation.

Efficient and reliable energy supply is critical for economic growth. Keeping the momentum of sustainable growth, availability of clean power supply is a must. India being a responsible country took the challenges to contribute voluntarily to reduce the carbon emissions using RE sources.

IEA report states that the gap between present global emissions level (62 Giga-tonnes [Gt]) and the needed emission level (14 Gt) is enormously high. This projected gap is to be filled by a comprehensive RE technologies portfolio and could help to reduce the needed emission level at 450ppm (CO₂) by the year 2050 [1][2]. This transition towards RE would offer sustainable benefits of energy savings, better quality life, energy security and human jobs. The transition path has proposed a programmed shift in the energy mix from fossil fuels to renewable energy resources (Nuclear power, Compressed Natural Gas, Biomass, Geothermal Power, Radiant Energy, Hydropower, Wind power, Solar Power, Wave Power and Tidal Power). Worldwide, the RE sources like Solar energy through Photovoltaic (PV), Concentrated Solar Power (CSP), utilization of Bio-mass are being explored and also being utilized for electricity generation.

The exhaustive studies based on CO₂ ppm concentrations as in Figure 1.1 of the concern of global warming are being carried out and emerges that world needs comprehensive actions, along with right policies to maintain the limits of warming in the range of 2°C.

Hence, the motivation of multidisciplinary study (Solar Energy, Electrical Energy generation, and Biomass utilization) has been the driving force for this thesis in the area of environmental sustainability.

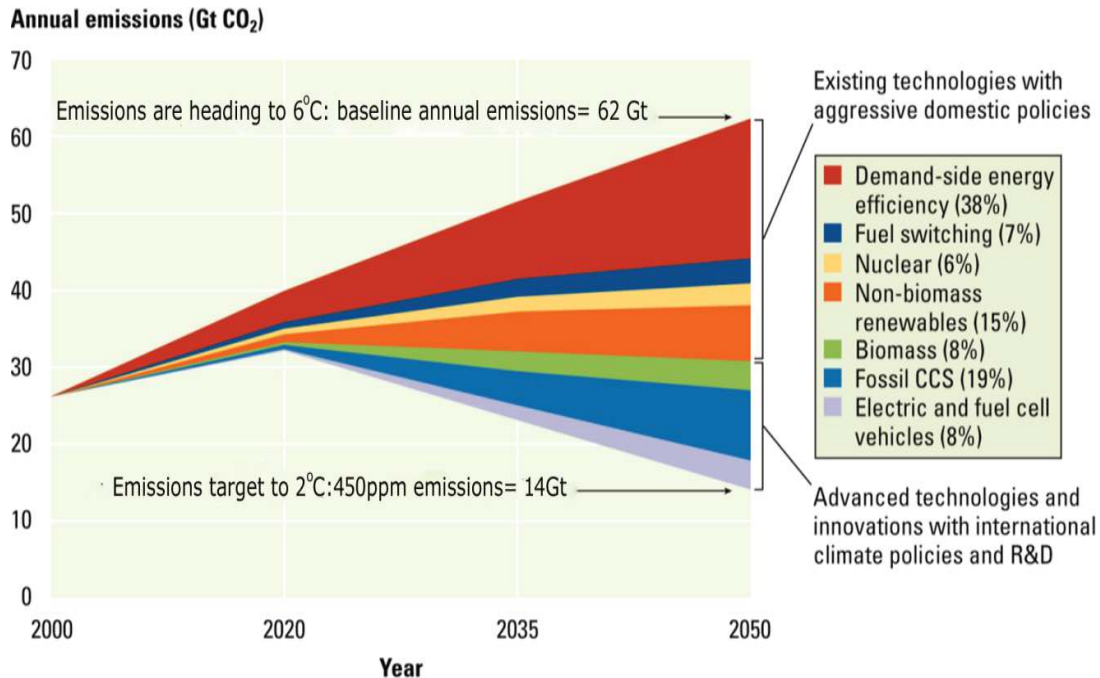


Figure. 1.1. 2° C trajectory curve for CO₂ ppm scenario [3]

1.2 Indian Perspective: Renewable Energy, Plans and Scope

India has been acknowledged as the first country in the world which has an independent government institution for the renewable resources utilization, the Ministry of New and Renewable Energy (MNRE) at national capital New Delhi. India Energy Security Scenarios (IESS-2047) conducted by Niti Ayog has projected the higher possible solutions to reach the target of 410 GW of wind power and 500 GW of solar electricity by the year 2047 [4]. The capacity of biomass and hydropower has been also acknowledged as future energy anchors for Indian electricity sector. Today, in India, RE based electricity is in the share of ~12%, the total installed power plant capacity and aims to achieve the target of approximate 175 GW by the year 2022 as shown in Figure 1.2. Out of which 100 GW is expected through solar energy and this energy basket comprises of decentralized rooftop project, utility-scale plants and ultra-mega solar parks [4].

The decreasing cost of solar panels indicates as positive sign for the installation and associated research. The estimated cost of solar PV panels has been reduced almost 100 times from Rs 4606/ W during the year 1977 to Rs 47/ W in the year 2013 [4]. It has been also reported that, by the year 2021-22, India's electricity demand would rise to double of the requirement in 2011.

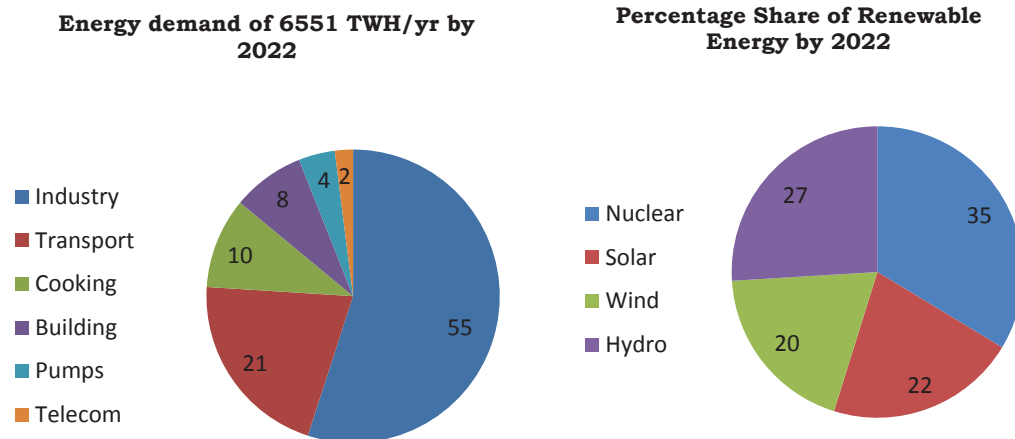


Figure. 1.2. Projected RE contribution for India's Energy in 2022 [4]

The macro economic outlook states that by the year 2022, to achieve approximate 175 GW of Renewable power, huge reduction in coal consumption is foreseen. This reduction in coal has been considered as growth path for RE sector. Indian Government targets need much of the research, investments, and acceptance of society with the consideration of the uncertainty of RE generation.

1.3 Research Proposal Flow chart

Oil and Natural Gas Corporation (ONGC), the flagship National Oil Energy Company of India (www.ongcindia.com) under Ministry of Petroleum and Natural Gas, Government of India, has over-arching future objective of the sustainability with the high-level and strategic views on India's energy security.

Carbon is at the center of the business and understands well the implications of pursuing a low carbon high growth strategy. This is being reflected in all future endeavors within operations to become energy and resource efficient as well as in the pursuit of alternative sources of power through research. The author employed at ONGC has undertaken innovative multi-disciplinary research studies on PV technology, CSP and Biomass to cater the electricity needs, specific applications and finally to protect the environment from carbon emissions.

Based on RE sources motivation and specific oil sector perspective, a research proposal flow chart for this research thesis has been prepared as mentioned in the Figure 1.3.

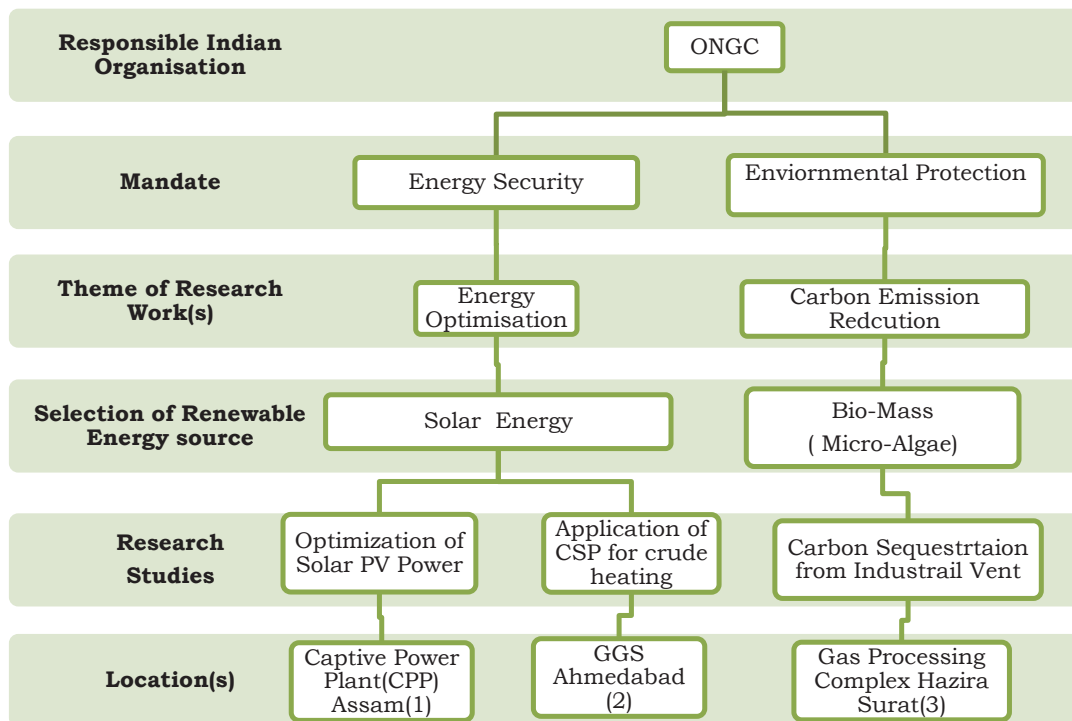


Figure. 1.3. Emergence of three multidisiplinary research themes in ONGC

1.4 Major Two Renewable Energy Resources in Indian Oil and Gas sector

Three major aspects of research studies are, Optimization of Solar power at Natural Gas fed Captive Power Plant using PV technology, utilizing CSP for Oil and Gas applications and innovative solution through algal-biomass for the industrial vent carbon capture. These researches have been successfully conducted / studied for real industrial sites. The details on these studies have been briefed in Figure. 1.4

1.4.1 Photo-Voltaic based Solar Electricity and its optimization

Due to volatile nature of sun light, RE based electricity are being hard to control. This makes renewable energy unreliable, so it is hard to balance consumption and generation in case of unpredictable generation.

Nowadays, when the share of the RE in the total electricity generation is relatively small, demand site management of electricity market can be made by traditional power industry facilities. RE electricity propagation and demand site consumption management needs new tools for development with augmentation. One of the aims of this work is to create such a system for balancing of grid energy consumption and utilizing solar energy generation for effectiveness.

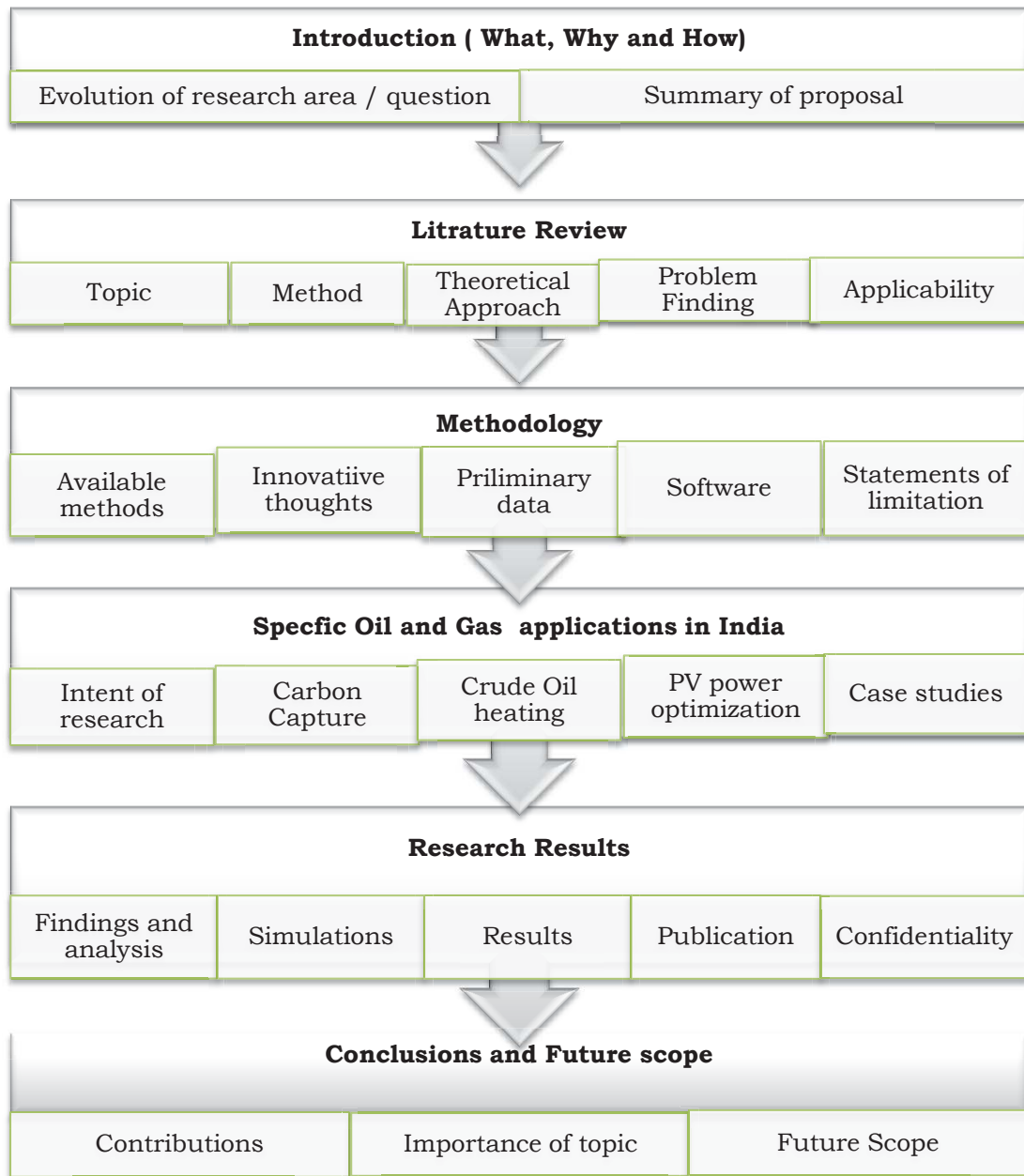


Figure. 1.4. Research Proposal Flow chart

1.4.2 Concentrated Solar Power based system and applications

This unique and ‘State of Art’ research has been focused on the utilization of solar radiation for the heating of extracted crude oil industrial applications. This unique idea increases the cost effectiveness of system besides lowering the carbon footprint. Here the concept of CSP has been applied and proposed a prototype and sustainable solution. The CSP prototype substitutes the existing NG heating method and also targeted to improve the safe working conditions.

1.4.3 Algal-Biomass system: Carbon Sequestration

The Biomass based energy systems have been prioritized and Microalgae based systems have been reported for the Carbon Capture (CC) technology for industrial application. Due to maximum yields of biomasses from the Microalgae, the concept has been adopted and utilized for the ONGC's one of the gas processing complex, where a huge amount of Carbon emissions are being venting out. Algae play a major role in Oil and Gas sector for energy security and carbon emissions.

1.5 Solar Energy and their Classifications

It is estimated that in one minute, the sun provides enough energy supply to World's needs for one year and also in one day. It provides more energy than the World's population could consume in 27 years. Since India has abundant RE source especially sunlight, it can cater to all the energy needs of the country. Solar energy can be utilized in many ways; traditionally the captured heat can be used as solar thermal energy, with applications in space heating. This work has been focused on Solar Photo-Voltaic (PV) systems. The PV based solar system classifications has been shown in the Figure 1.5.

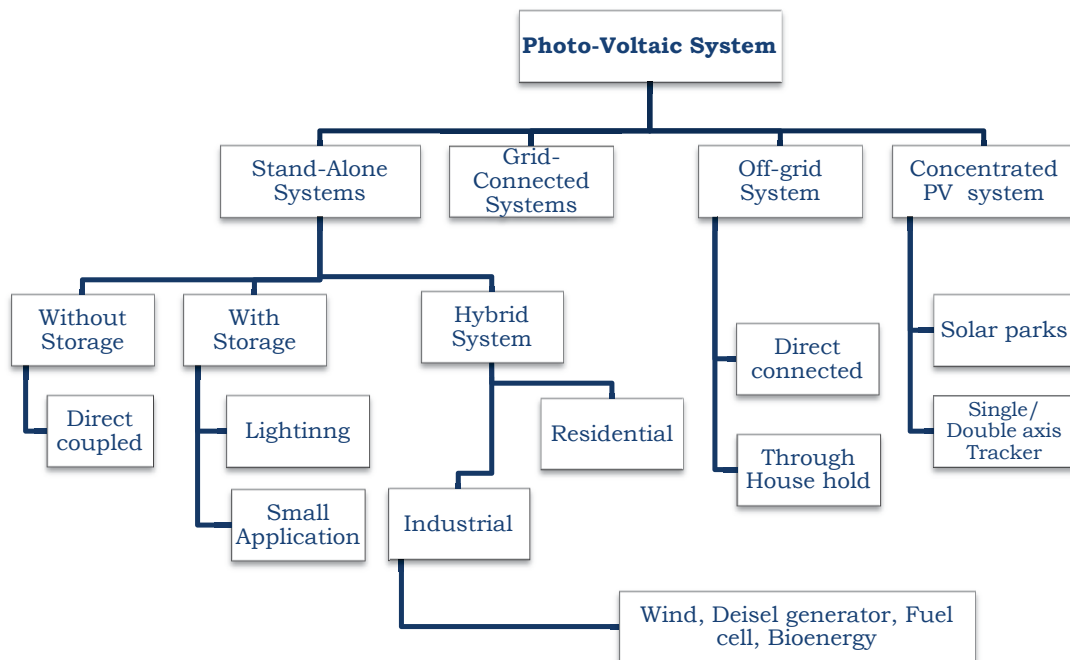


Figure. 1.5. Classifications of Solar Photovoltaic System [5]

Further, various study models have projected that India would be dependent of other RE source like Bio-mass to supply around 30% of total energy requirement by the year 2050 [6]. However, it has been very surprising that the evolution of biomass based energy projects are not yet potentially developed due to failure of supply chain of major raw materials like, agricultural waste and forestry. The clean energy revolution in middle / low-income developing countries would be leapfrog to the next generation of technologies.

On the other side, the global quantum of heat loss during electrical power generation has been estimated in the range of 10 percent and major reason has been identified as inefficient conversion technologies [7]. In the present scenario, this power conversion has switched to power electronics or combination of intelligent technologies. Emerging new material platforms like Gallium Nitrate (GaN) has been further supporting to power electronics and switching topologies for efficient improvements [8]. Power electronics systems have given key devices for integrated PV building for sustainable society.

1.6 Advantages / Disadvantages of PV based Solar Energy

Any PV cell is made up of semiconductor material which has the property of converting sunlight into direct current electricity. The cost effective and green power PV power technology has advantages and disadvantages as in Table 1.1.

Table 1.1. Solar Energy advantages and disadvantages [9]

Advantages	Disadvantages
<ul style="list-style-type: none"> • Free energy source with Environmental Benefits • Decrease of harmful green-house gases emissions • Reliability & low maintenance • Increasing efficiency and decreasing price with regulatory and financial incentives • Economic and scalable design • Tax credits & Low interest loans 	<ul style="list-style-type: none"> • The low PV conversion efficiency of solar cell • The still relative high commercial costs, though reducing sharply • Has limited generation capacity compared to other RE sources like wind power • The regional differences of solar radiation and seasonal variations

RE has been treated as a foremost importance for CO₂ reduction and the growth rate of clean energy is expected to continue. Although, this has drawn attention to power industries, because rapid increase in installed capacity connected to grid power may cause problems and the quality of the power.

1.7 Literature Review

The overall aim of the literature review has been oriented to analyze the *existing imperatives of climate change, mitigation and adaptation methodologies, and environmental assessment methods*. The literature considered in this review has been scientific articles, reports, thesis, books or other published material available globally. The topic on carbon emissions, mitigation methods, RE technologies, policies, and major challenges associated has been studied.

The review has been initiated with the views on global energy sources basket and their importance. The percentage of today's major and minor energy contributors are shown in Figure 1.6 [10]. Historically, the alternate solutions to oil had been perceived as a priority, because of rising prices of crude oil and remain high at a level of \$140 for many years. However, the oil prices declined suddenly and down near to \$100 a barrel and further much lower of \$45-55 a barrel. These phenomena in crude price gave birth of commercial electricity from RE sources specially the solar energy resources. Hence the concept of *Oil Economy* is faded away and new era called as *Solar Economy* is emerging [11]. To start with literature review, it is also critically analyzed that within these fluctuating oil prices, the large oil reserve based countries are promoting the use of RE electricity and able to export more of their oil and gas.

Several countries apprehended the catastrophic scenario by carbon emissions, and the metaphor of *Sustainability and Sustainable development*. Brundtland Commission Report [12] had explained their chronological emergence sequence in 1987, as shown in Figure 1.7. A consequence to this, use of the term "Sustainability" or triple bottom approach of People (Society), Profit (Business) and Planet (Environment), spread much faster into major fields like sociology, ecology, technology, environment, human rights, and economics.

The sustainability cognizance has addressed the need of present world without compromising the needs of future generations. This approach led to future studies, critical examinations of depleting natural resources and associated climate change concerns.

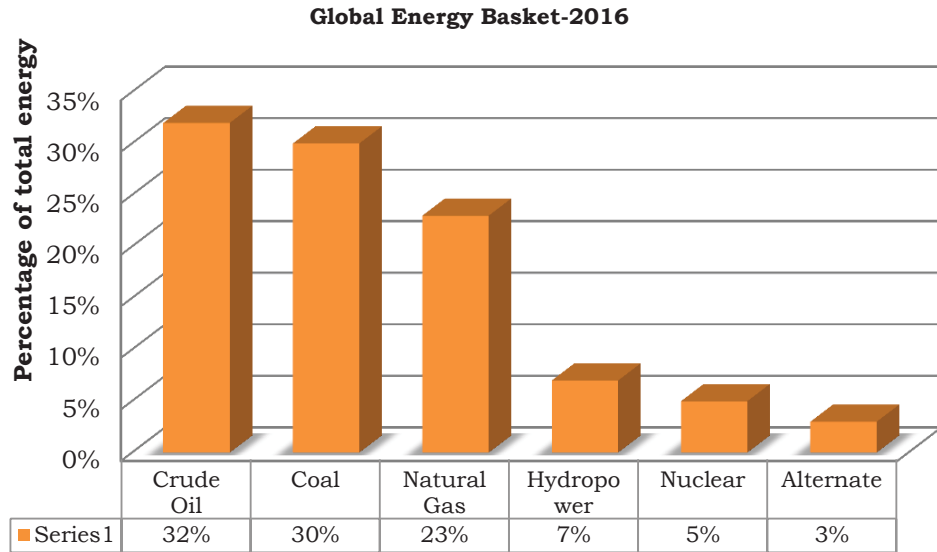


Figure. 1.6. Global Energy Contributors resources-2016[10]

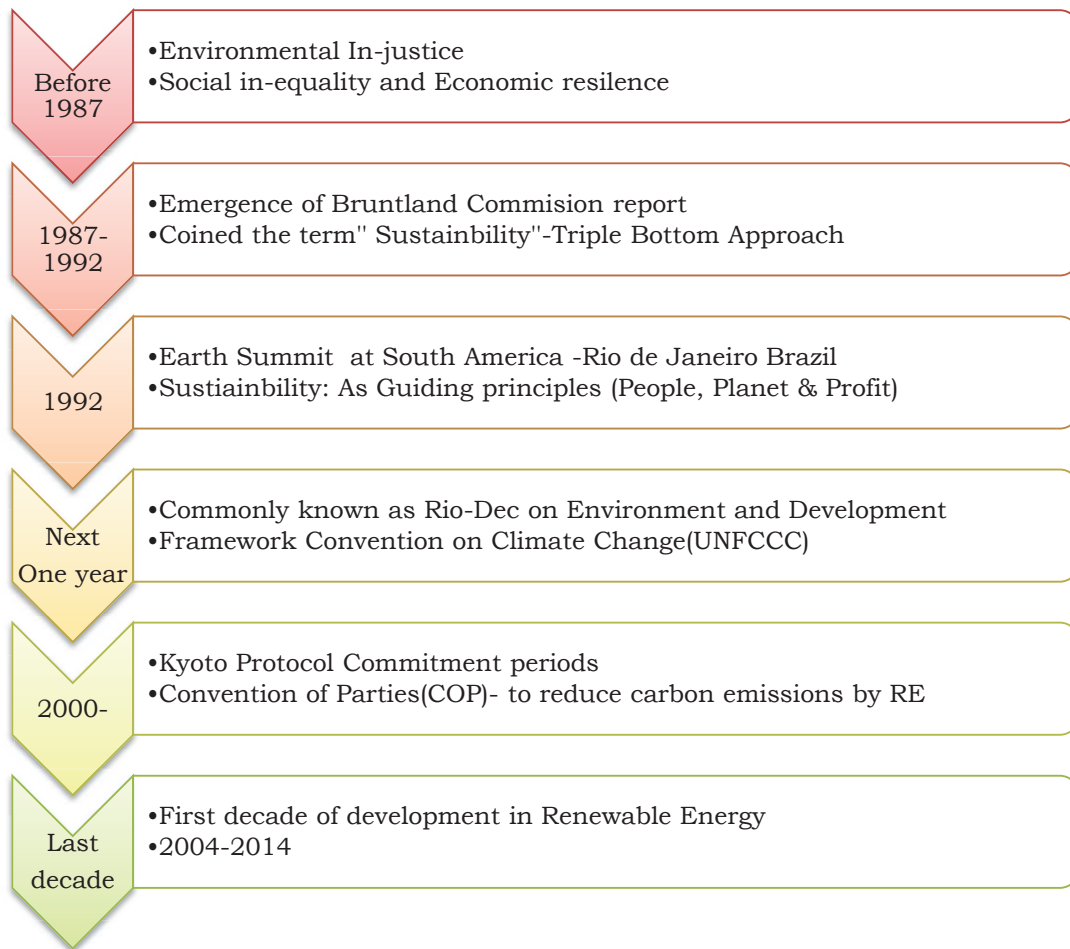


Figure. 1.7. Cognizance & Chronological of Sustainability [13]

This literature review has been reported first to establish the basic understanding of the current RE resources status, ongoing trends, and challenges. This basic foundation for all future research areas includes the comprehensive compilation of factors that completes the research objective into true reality. Different key words and research supply chain process on RE technologies have been classified and summarized in Figure 1.8.

Heidari Negin and M. Pearce Joshua [14] presented a comprehensive review of carbon emission liability with respect to RE sources for the legal regulations for anthropogenic damages for climate change. The studies on RE technologies have high potential for reducing these liabilities. This potential are based on their emission costs and GHG's liability is quantified in the range of \$570 trillion. This quantification suggests that human kind shall bear this liability towards carbon mitigation by the deployment of RE technologies.

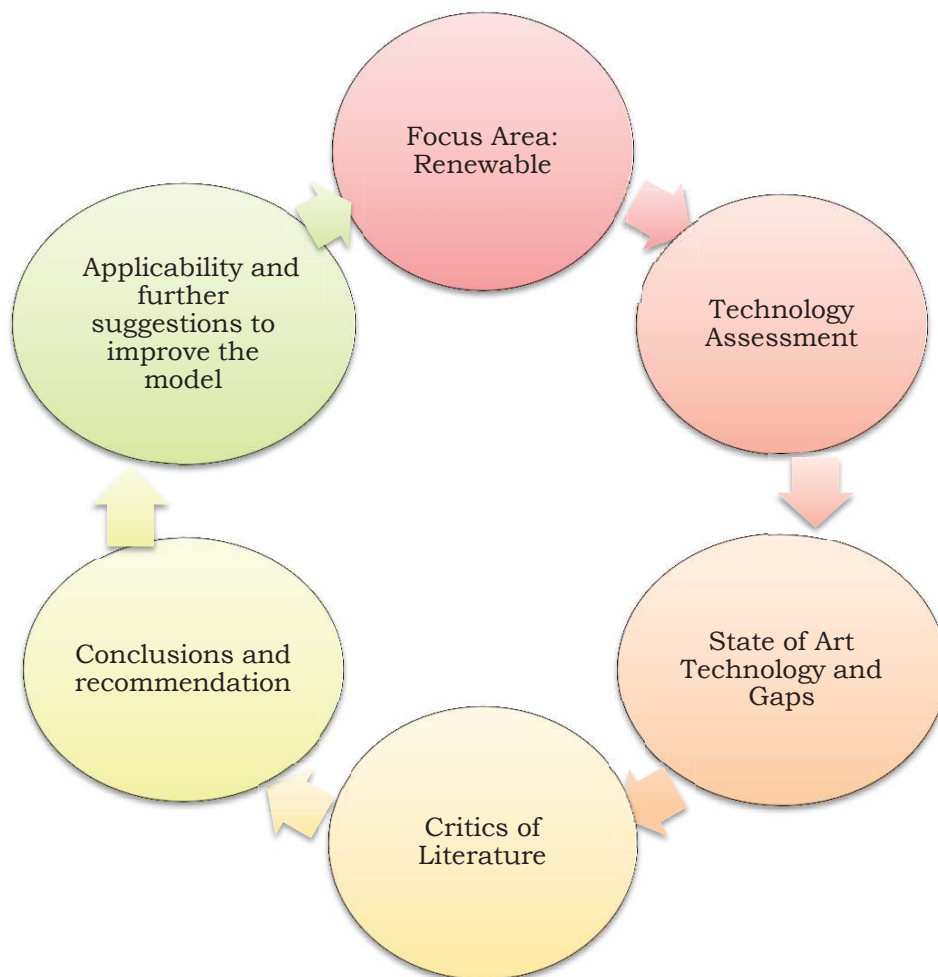


Figure. 1.8. Investment in New renewable power capacity

Antonio et al. [15] studied the RE based investments in the developing and developed countries is based on promotion of government policies, regulations and fiscal incentives. It was emerged that not all RE based policies promotes RE investments and are also not that effective when implemented on real grounds.

One of major research area targeted by researchers is the flue gases/ vent gases from oil and gas plants/ power plants. These exhaust gases has been studied on emerging micro-algal biotechnologies, not just for anthropogenic effects, but also for advancements towards innovative energy applications. Israel Electric Company and Seambiotic Ltd have created algal pilot reactors and inject flue gas into open ponds with algal cultures. The aspect of carbon capture from Indian Oil industry has also studied and reported in this work.

S. Manju et al. [16] critically examined the status, prospects, applications and barriers of solar PV systems for the sustainable and rapidly growing Indian economy. On the other side, Indian government have frames various policies and providing fiscal incentives for the promotion of RE exploitation. The upcoming areas of research with their applications have been also elaborated.

A comprehensive review was reported by Alexander W. et al. [17] which basically analysed the economic assessment of CSP technologies. Two time-varying meteorological and electricity market based assessment methods have been derived. It has been also observed that both Levelized Cost of Electricity (LCOE) and revenue are basically conflicting metrics for today's electricity market. Comparative research directions have been proposed to increase the fidelity of economic assessments and to mitigate discrepancies.

K. Pandey et al.[18] presented the comprehensive review on solar PV systems on advances and emerging applications. It has been recommended that the efficiency needs further research. The integrated building PV systems are better concepts for lesser area requirement and improved construction cost.

Ali Heydari et al. [19] described the biomass- PV hybrid power plant installed at industrial site Kerman, Iran and reported that bioenergy based generation plants could be complementary due to their reliability.

S. Saravanan et al. [20] have studied the power electronics part of PV system and made a comprehensive review on 'Maximum Power Point Tracking'(MPPT) algorithms and their real time hardware implementation. M.A.Hasan et al. [21] presented the mathematical modeling of PV system and

MATLAB simulation is designed for performance analysis. The analysis is oriented for two aspects, first using equivalent electrical circuit and other PV characteristics for dynamic weather conditions.

Enayat A. Moallemi et al. [22] studied India's on-grid solar power systems in PV sector is growing at much faster pace and contributing to reduce the emissions targets. The transformation of governmental approach also intertwined effectively, but also envisaged various challenges in the path.

The comprehensive review of D. Fytili et al. [23] has been focused on the gaining interest of bioenergy development globally. The interdisciplinary review approach has been reported in the area of awareness of climate change and its impacts. This perception is as preparatory for decision making in industries.

Jørgensen, Kirsten and Wagner, Christian[24] have highlighted the low carbon developments in the European Union (EU) is a leader in global climate policies. It has been proposed that the multi-level reinforcement between EU and India has not been yet exploited and it needs accelerating relation.

Ahmet Aktas et al. [25] have emphasized on RE Sources (RES) for future green electricity and identified energy storage technologies as major challenge. Smart Energy Management Algorithm (SEMA) is proposed for Hybrid Energy Storage System (HESS) supplied from grid connected PV system. The HESS an effective energy storage system has been verified simulations results and experimental tests for its high power density, fast response, and high efficiency.

F Rasool et al.[26] has presented a specific and simplified PV modeling which improvise the characteristics by adjusting its five parameters and the two diode model is helpful for designers for easy design and simulation.

Ekrem Kandemir et al.[27] have studied the PV power dependence on dynamic weather parameters and the importance of MPP where the PV system operates in maximum efficiency. Popular MPPT techniques and alternative solutions are used to detect true global MPPs point among the other local MPPs.

Rahul Rawat et al. [28]reported a review on solar PV modeling, selection of power electronics elements, design methodology, size optimization for the PV fed water pumping system. The techno-commercial aspects are reported for the optimization of solar power. This paper has completed a State Of Art literature survey, which is very useful for designing of solar PV systems.

Rodolfo Dufo-López et al.[29] presented a detailed optimization methodology for the RE hybrid system. A Monte Carlo based stochastic approach has been developed for incorporating unreliable irradiation and load. The batteries lifespan and operating conditions are projected for the evaluation.

Ahmed Said Al Busidi et al. [30] and S M Zahraee et al. [31] addressed the limitations of single RE system described the ability RE hybrid module. The hybrid systems are projected as consciousness sustainable model for much better for power efficiency, reliability, stability and cost effectiveness.

Farahiyah Abdul Rahman et al. [32] have elaborated the human generated CO₂ emissions, its estimation and projected the concept of carbon sequestration as call of future. However, the physical CO₂ storage would be a challenge, with the cost, capacity and the reservoir. For more feasible solutions it also suggests biofuel production using CO₂ as a feedstock. Biomass being high yield performance could replace the energy deficit scenario in the future.

Maegaard, Preben[33] have reported that the technological advancements in industry needs for cogeneration. Bio-mass is emerged as major source of hybrid solutions for incorporation. Similarly, Combined Heat, Cooling and Power (CHCP) coincides with excess RE energy, power capacity may increase. It is also derived that electric boilers have proved to be a low-cost solution to capture excess energy, by using RE power in combined heat and power systems.

Also it has been estimated that solar PV panels in space are capable of harnessing 10-20 times energy annually in comparison to earth surface based PV system. The Space Solar Power Systems (SSPS) of Japan is working to transmit energy from orbiting solar panels by 2030. Mitsubishi Heavy Industries Ltd, Japan has successfully completed a demonstration test of wireless power transmission (WPT), a basic concept for the SSPS[34]. In this demonstration, 10 kW of solar electricity was transmitted using microwave and power received at the distance of 500 meters away. This technology is similar to a solar battery in orbit, which generates electrical power and transmit to earth using microwave[35].

In the present work *multi-disciplinary* outlook have been evolved from literature survey and which motivates the further research. In addition to these multi-disciplinary studies, two other studies on solar water pumping system and 100% renewable energy based electricity system for India and SAARC countries has been also studied for research publications.

1.8 Motivation for Research and Problem Statement

The *three multi-disciplinary* aspects have been thought in the context of ONGC vis-a-vis global oil and power institutions, and research ideas have been briefed as under:

1. Because of the volatile nature of sun light, it is impossible to control PV plant generation and to balance consumption changes. Whether a control system be designed to balance the solar electricity generation and the consumption of fossil fuel grid electricity could be reduced or regulated?
2. Whether Natural Gas (NG), being used for conventional crude oil heating could be replaced by CSP or hybridized with other RE based system? Whether a prototype system could be modeled?
3. Whether Algal-Biomass based system is able to be utilized in Oil and Gas processing complex for the effective sequestration of CO₂ from industrial vent gas? If, then what would be environmental impact and as business economics?

A SIMULINK model has been developed based on real data at BHEL Hyderabad, India and referred for its utilization for its compatibility for the research study conducted at location 1. The problem statements on above three research studies are briefed in Figure 1.9

1.9 Road Map of the Thesis

The illustration of the work carried out has been spread over six chapters and outlined consecutively as below:

Chapter 1 gives an insight into the introduction and motivation towards role of RE and their classifications. Out of several RE sources, the relevance of Solar Energy and Bio-Energy has been focused and three unique research studies were evolved. It reports the essential literature survey for the overall aspects of environmental sustainability utilizing RE resources. Briefly, it states the thesis contribution and road map to the thesis write-up.

Chapter 2 sketches the preliminaries essential understanding mathematical model of Photovoltaic system and their associations with related power electronics sub-elements. This chapter has been oriented towards optimization of solar PV electricity using a unique ‘Dispatcher’ control system.

Further utilization of Concentrated Solar Power (CSP) and Carbon sequestration concept using microalgae has been comprehensively explained for real industrial locations of ONGC India for effective utilization of solar energy or sunlight.

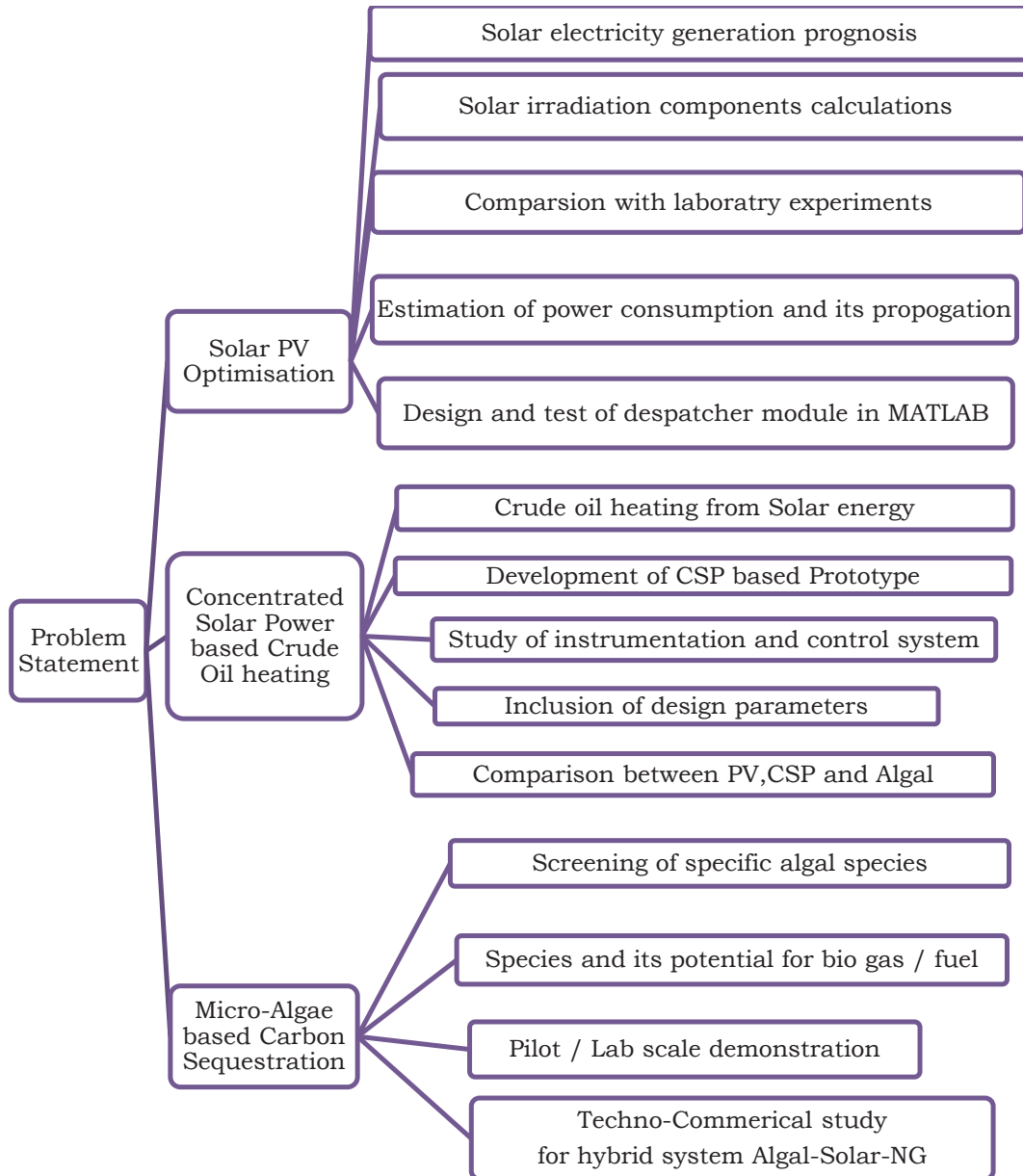


Figure. 1.9. Research statement for carbon mitigation research studies

Chapter 3 reports the design of despatcher control system oriented towards PV energy generation prognosis, estimation of power consumption propagation and intelligent decision by the despatcher. CSP based hybrid model for crude oil heating has been deliberated. Emerging aspect of carbon mitigation through

microalgae from industrial vent gases has been aimed for another integrated research study.

Chapter 4 focuses on a ‘State of Art’ unique hybrid solution for ‘Crude Oil heating’ at Indian Oil and Gas sector in conjunction with PV system, CSP technology and microalgae biomass. Apart of above, the research methodology for a prototype of hybrid system has been explained.

Chapter 5 demonstrates the two hybrid model, first CSP with existing NG system and second Bio-gas, PV, CSP and NG system. Both the models have been studied using established research methodologies. A comparison has been prepared for most efficient, environmental friendly and cost effectiveness. The validation of three research studies, their analysis, MATLAB simulation and concluding results have been elaborated. Finally it has been suggested that Algal-Solar-NG based hybrid heating system is effective for industrial sites.

Last **Chapter 6**, concludes the whole study to highlight the major findings and suggested the scopes for future work. In the last the appendices, list of references, and publications have been reported.

1.10 Thesis Contributions

The primary objective of the thesis is to develop an *Algal-Solar (PV&CSP)-NG* based hybrid model for crude oil heating applications in Oil and Gas sector in India. The hybrid model is expected to support the environmental sustainability and energy security of oil industry. A brief discussion of the limitations also has been discovered during the discourse of the proposed hybrid model.

1.11 Conclusion

The present work concludes with a multi-disciplinary research study based on PV technologies, applications of CSP for industrial applications and utilization of algal Biomass for carbon capture. These studies have been implemented at real different industrial Oil and Gas sites in India. These studies would open new implementable and real solutions across the industry irrespective of Sector, i.e., the concept of Carbon Sequestration could be utilized at power industry with flue gases, CSP technologies could be used for Boiler industry and many other applications and Solar PV optimization techniques are better solutions in industries as well as residential applications for conventional use of electricity.