Energy is the basic building block for socio-economic development. Though fossil fuels will continue to play a major role in most countries, their availability is limited and may not be sufficient in the long run to sustain the demand. Energy security and sustainable development are high in the global agenda due to the impact of volatile energy prices, high demand for energy security, concerns over environmental sustainability and the global climate change (UNESCAP, Bangkok, 2008). The world energy scenario depicts a picture of concern. The adverse effects on environment caused by the production and consumption of energy have resulted in severe environmental impacts across the globe. The supply of energy is expected to remain adequate in coming years but, imbalance of energy consumption is prevalent around the world. Energy consumption is high in most developed countries. On the other hand, the developing countries need to consume more energy to ensure their economic growth. According to estimates, energy consumption in developing countries is only one-tenth of that in the developed countries.

The economic development of many countries is hindered due to energy scarcity. The total supply of energy in the world during 2010 was projected at 11,500 Million Tons of Oil Equivalent (MTOE) and that in 2020 is expected to be at 13,700 MTOE. Oil is the most important and highly consumed source of energy. However, price of crude oil is very volatile and supply is driven by price. Economic development is closely related to energy availability and supply. The current energy needs of the world are mostly met by fossil fuels with the associated local and global environmental negative impacts. Projections of Global energy for the year 2050 indicate that world energy demand may increase dramatically, with most of the increase coming from developing countries (REN 21, 2007). It is feared that not only these levels of energy production and use from current energy sources are difficult to achieve but also un-sustainable. Being a developing economy the energy needs of India is fast rising along with China and they combinedly account for a significant share of world energy consumption and associated ill effects on environment.

The future economic development trajectory for India is likely to result in rapid and accelerated growth in energy demand. Due to the predominance of fossil fuels in the generation mix, there are large negative environmental externalities caused by electricity generation.
Today, India is mostly relying on the thermal energy but other forms of energy like Solar, Wind etc., are fast on rise. In this context, it is imperative to develop and promote alternative energy sources that can lead to sustainability of energy-environment system. Therefore, energy use-efficiency needs to be increased to moderate the growth of energy while contribution from clean energy sources needs to be increased to reduce adverse environmental impacts of energy usage. Renewable Energy (RE) is accepted as a key source for the future, not only for India, but also for the world. There is a significant opportunity for Renewable Energy Technologies (RETs) in India. RE provides a promising solution not only in meeting the ever increasing demand of energy but also in mitigating the adverse environmental effects. It is considered as an important measure to meet the challenges of ever increasing energy use and related environmental concerns. It is essential to tackle the energy crisis through judicious utilization of abundant RE resources, such as wind, biomass, solar, etc., as these sources are going to become the long-term solution for future energy needs. It offers a promising alternative to traditional energy sources in developing countries. Being a developing country India is poised to achieve an economic growth rate of around 7% on the moderate term average, despite the global slowdown (Ishan, and Pallav Purohit 2009). This requires sustained energy supply including RE resources.

Amongst the various renewable energy sources like wind, solar, geothermal, tidal etc., the first one is a promising source not only at the global level but also at the domestic level. It is one of the fastest developing RETs across the globe including India and is an alternative clean energy source compared to fossil fuel, which pollute the lower layer of the atmosphere. Wind energy not only offers a power source that completely avoids the emission of carbon dioxide (WWEA 2012, and Manwell et al 2007), the main GHG, but also produces none of the other pollutants associated with either fossil fuel or nuclear generation. Thus, the increasing investment in wind energy systems is justified from an environmental point of view too. India now stands at the fifth position in wind power development at the global level. India also has an ambitious plan of increasing wind energy share in the 12th five year plan (MNRE website). Though the policy of the central government for RETs is common for all, individual states have different policy measures.

A review of literature shows that though Wind Energy Technology (WET) sector share in total energy generation across the countries of the world is small, it is one of the largest energy producing
sectors of almost every significantly industrialized economy. The global wind power market recovered somewhat in 2011, the market grew by about 6% compared to 2010, and the 40.5 GW of new wind power brought on line with investments of more than about $ 68 billion. The US market made a respectable recovery, Canada had a record year, and Europe remained on track to meet its 2020 targets, but with essentially a flat market. Offshore installations in Europe decreased slightly but strong growth figures were posted in Romania, Poland and Turkey; and a strong year in Germany reflects a renewed and even stronger commitment to Renewables in the wake of the nuclear phase-out decision. The new global total at the end of 2011 is just short of 238 GW, representing cumulative market growth of more than 20%, which is certainly a respectable figure for any industry in this economic climate, even though it is lower than the average over the last 10 years, which is about 28%.

The main drivers of growth in the global market, as they have been for the past several years, are the Asian powerhouses of China and India. While the era of double and triple digit growth in China’s wind market may be over for the time being, it still represented about 43% of the global market, and India posted yet another year of record installations; the two countries together accounted for just over 50% of the global market in 2011. India is likely to march up the cumulative wind energy table, surpassing Spain to move into fourth place by the end of 2013. The Indian market passed the 2 GW milestone for the first time in 2010, and the 3 GW milestone in 2011. Continued increase in demand and policy priority for Renewables has turned India into one of the most dynamic markets in the world (GWEC, 2011). However, Indian WET sector has not succeeded up to the expected level of investors, wind farm developers, policy makers, researchers due to the introduction of new tax code, uncertainty about the future of the tax benefits, etc. This has driven much of India’s growth to date, a cause for concern in future. Moreover, it is noticed that most of the initiatives to implement and sustain WET have adopted mainly technocratic approach and lacked a holistic approach to comprehensively address the associated problems.

On the whole, the review of available literature concerning the diffusion of RETs with focus on the implementation of WET reveals the following.

- Most of the studies are either single cluster based or single wind turbine manufacturer focused and there is hardly any study of clusters comprising different regions of the country with different rating wind turbines.
The existing cluster-specific studies adopt only the roles and effects of government policy and institutional settings and enabling environment for technology transfer. This is to learn lessons regarding how developing countries can build favourable environments for replicable technology transfers involving climate change mitigation technologies and catch-up industries.

Though it is not sufficient to analyze renewable energy production within technical context, most of the renewable energy studies have ignored the influence of socio-economic context, policy regulatory and political aspects of WETs.

There is hardly any cluster based study substantially dealing with the barriers to implement WETs.

There is hardly any cluster based study dealing with the development of an index which estimates the performance of the cluster and facilitates comparison of various wind farms.

The afore-said research gaps and subsequent discussion with the experts including researchers and academicians, the officials from Karnataka Renewable Energy Development Limited (KREDL), Government of Karnataka, wind farm developers (private NGOs), private investors in wind industries and the officials from Wind Turbine Generator (WTG) manufacturing industries helped in formulating the objectives, scope and methodology of the present study. Overall objective of this research is to assess the relevance, the diffusion and the implications of renewable energy to sustainable development with a special focus on wind energy.

The specific objectives of the research are as follows;

1. Detailed policy analysis with respect to the diffusion of renewable energy in India with a special focus on wind energy.
2. Case study of three wind energy clusters in Karnataka with respect to techno-economic, socio-economic and environmental aspects.
3. To identify and prioritize the barriers for the implementation of WETs.
4. To synthesize the lessons learnt from the case studies and develop a comprehensive Cluster Performance Index (CPI) and compare the three wind mill clusters using CPI.
5. Policy and strategy recommendations for sustainable wind power dissemination in India in general, and Karnataka particular.
The study covered three major wind mill clusters viz., Chitradurga, Gadag and Davangere located in Karnataka (a Southern Indian state). The study involved a total of 93 different stake holders working in the field of wind energy.

As far as policy and regulatory frame work for the implementation of RETs is concerned, study referred the secondary data pertaining to RETs with special focus on WETs. As far as cluster specific data with regard to techno-economic aspects are concerned, study collected the actual field data by visiting all the three wind farms through a set of questionnaires and analyzed the empirical data to obtain economic indices and compared them amongst the clusters. As far as environmental pollution connected with energy production is concerned, the study estimated the amount of air pollution avoided in terms of Green House Gases (GHGs) and other pollutants by comparing with an equivalent coal thermal power plants as per the guidelines of Intergovernmental Panel on Climate Change (IPCC, 2007). The emissions of Carbon Dioxide (CO₂), Oxides of Sulphur (SOₓ) and Oxides of Nitrogen (NOₓ) were estimated. Based on annual emission reduction of CO₂, the main GHG, it was found that Gadag wind farm avoided highest air pollution (970998 tCO₂/MW/Yr.) followed by Chitradurga wind farm (889626 tCO₂/MW/Yr.) and Davangere wind farm (824450tCO₂/MW/Yr.) respectively. In comparison, the annual emission reduction of CO₂ in all the three clusters put together is about 35% of emission from a typical coal thermal power plant of about 27 MW capacity.

In the first objective of the study, an attempt was made to analyze and review the policies of RETs in general and wind energy in particular for the selected few states of India. Policy analysis work related to the study was carried out with the aid of secondary data (through books, research articles, R&D persons working in wind industry, Government articles/website, etc.), as well as through the resource persons working in the RE sector and wind industries. This study revealed that, there are several financial and fiscal incentives provided to the wind power producers in the union and state government level; however, unstable policies of the state governments and poor institutional framework increase the risk associated in the wind energy sector. Therefore, for the large-scale penetration of wind energy in India, it is critically important to assess realistic potential estimates, identify niche areas to exploit the wind energy resource and introduce a stable and uniform national policy to make wind power projects financially attractive. In addition, Capacity Utilization Factor (CUF) for wind power has been an area of concern as it is around 22% in India against the
International average of 25% - 35% (WWEA annual report 2011). Thus, wind energy policy must also address this issue appropriately. The five States Tamil Nadu, Maharashtra, Gujarat, Karnataka and Rajasthan account for more than 96% of the total potential at present and hence need to further fine tune their policies to promote CUF. Different states have established regulatory commissions which formulate and implement policies for, among others, renewable power promotion such as preferential tariffs, wheeling and banking charges, third party sales, etc. In view of Tamil Nadu’s success in wind power generation, the policy features of that state need to be emulated by other states as well. Further, if India has to match the growth rate in the global wind energy sector, outstanding regulatory and policy issues need to be addressed and improved on a regular basis.

With regard to the second objective of the study, it aimed at an economic and environmental analysis of selected wind farms in the state of Karnataka. The result of analysis using empirical data has clearly demonstrated the viability of Wind Energy Conversion Systems (WECS) and also significant environmental benefits. Study also provided the comprehensive economic and environmental analysis, especially making use of empirical data in the Indian context for the selected three wind farms of Karnataka state in southern India.

Present study facilitated choosing suitable Wind Turbine Generators (WTGs) in the selected wind farm using, the empirical data obtained through field study using (a structured, researcher administered questionnaire). It estimates values of various economic indices like, Net Present Worth (NPW), Annual Equivalent Worth (AEW), Internal Rate of Return (IRR), Pay Back Period (PBP), etc., for ascertaining suitability of investment in wind energy. It also estimated the positive environmental effects by avoided Green House Gas (GHG) emissions, especially reduction in anthropogenic CO₂ emissions, which otherwise would have resulted due to coal thermal power generation.

WET holds a promising future in the Indian context. However, the implementation of WET faces several barriers acting in the field. Prioritization of these barriers is the first step in overcoming them. But, any prioritization of these barriers has to necessarily involve the multiple criteria relevant to the implementation of WET. The identification of relevant barriers and their appropriate prioritization in the implementation of WET is a prerequisite to effectively tackle them. The current study proposed a multi-criteria frame work for ranking the barriers for implementation of WETs. The various Barriers,
Barrier dimensions and Factors were finalized based on an empirical study conducted at the three wind farms. Further, the barriers were prioritized using (a structured, researcher administered questionnaire) based on the perceptions and experiences of different stake holders of WET implementation such as Wind turbine manufacturers, Government agencies, Researchers and Policy makers, etc. Multi-Criteria Decision-Making (MCDM) network for ranking the barriers for WETs using AHP was proposed. The Policy Regulatory and Political Barrier (PRPB) and Institutional And Organizational Barrier (IAOB) have emerged as the top two impediments to the implementation of WETs.

Final stage of the research was meant for synthesizing the lessons learnt from the case studies and developing a comprehensive Cluster Performance Index (CPI). CPI was also used to compare the selected wind farms in the state of Karnataka. Here four important performance indicators were considered viz., Technical Performance Indicators (TePI), Economic Performance Indicators (EcPI), Environmental Performance Indicators (EnPI), and Social Performance Indicators (SoPI) to ascertain the best performing wind farm amongst all the three. Under each performance indicator a total of ten parameters were considered with five subjective and five objective oriented responses. The methodology was implemented by collecting empirical data from three windmill clusters in Chitradurga, Gadag and Davangere. Totally fifteen different stake holders were consulted through a set of structured researcher administered questionnaire to collect the relevant data. Stake holders involved engineers working in the field of wind farms, wind farm developers, Government officials from energy department and a few selected residential people near the wind farms. After the analysis, it was found that Chitradurga wind farm performed better with a CPI of 44.387 than other two wind farms as Gadag wind farm performed with a CPI of 29.672 and Davangere wind farm got a CPI of 19.470.

With regard to the policy implications study recommends following points:

◎ Policy should be made in such a way that the assessment of right regions or geographical locations in different Indian states for large wind turbine installations with technology to cater to lower wind speeds (according to the region wise) will helps the small investor to invest locally.
The requirement for grid codes that promote grid reliability and wind farm controls that work with the grid codes is essential in the selected wind farm clusters. The consumption of wind energy through the grid and the compatible generation of wind power must be matched.

The policy initiatives to enhance the implementation of WETs in the existing wind mill clusters must necessarily recognize the role of non technology and non financial factors. While the prevailing thrust on technology up gradation is undisputable, it is equally important to focus on economic, social, institutional and environmental issues to produce discernible changes on the dual fronts of energy production and environment, at the wind farm level.

Enhancing the quality of human resource in wind farms by imparting specialized and periodic training to workers to improve their skill set and advanced managerial and technical training for the WTG manufacturers to tackle complex issues like technology transfer, improvement in energy production, social and environmental benefits, etc., is essential to produce better results in the long run.

RET policy must also aim at providing substantial support (in terms of economy, subsidy, etc.) to those wind farms with highest CUF.

The major contributions of this research work are as follows;

- The study covered three wind mill clusters in different geographical locations (North, South and Central part of Karnataka state).
- Study has outlined the effect of various policy instruments in supporting the implementation of RETs in general and WETs in particular for the few selected states of India.
- The thesis analyzed current pattern of energy production and estimated the associated environmental implications in terms of avoided pollutant emissions compared to a typical coal thermal power plant.
- The positive association between energy production and economic benefits in the wind farm industries is analyzed by considering various economic indicators.
- Empirical data analysis has proved that it is necessary to take initiatives in wind mill clusters to address several issues like, geographical, policy, political, institutional, economic, environmental, and social factors in addition to technical factors to bring about improved performance of wind farms.
Study found out the best rating WTGs suitable for each wind farms to so that a new investor can select the right type and rating of WTG.

A barrier analysis frame work was proposed under a multi criteria decision making model using AHP.

A quantitative approach was adopted for prioritizing barriers in the implementation of WET through multi criteria approach.

The study prioritized the barriers in the implementation of WET based on the perception and value judgment of the different stake holders of WET.

The study provided a methodology to assess the performance of a wind farm using multiple criteria.

The study facilitated comparison of the three wind farms using the Cluster Performance Index (CPI).

It is believed that, this empirical study of three wind farms involving policy, economic and environmental issues helps in better dissemination of wind energy technology in the years to come. Further, the detailed barrier analysis will help in busting the barriers to facilitate implementing WET. Finally, the cluster performance index will go a long way in measuring the performance of various wind farms and comparing them for fruitful results.