Energy is an indispensable input in every sector of an economy; however it is crucial for the industrial sector, which accounts for almost half of the total energy used around the globe. This is true even in the case of Indian industrial sector, which has a large number of small scale industry units apart from medium and large-scale industries. Micro, Small, and Medium Enterprise (MSME) is a major sub-sector of Indian economy in view of its size in terms of number of units, number of employment, value of output and value of exports, absolutely as well as relatively. According to estimates, in terms of value, this sector accounts for about 45% of the manufacturing output and 40% of the total exports of India. The MSME sector employs about 42 million persons in over 13 million units throughout the country. There are more than 6000 products, ranging from traditional to high-tech items, which are being manufactured by the Indian MSMEs. Thus, MSME has a diversified and prominent presence in Indian economy. Considering the size of MSMEs, its demand for energy is likely to be substantial and will increase in the future, looking at its prospects for growth and the current policy emphasis on small industry modernization. Energy being an essential input to economic growth, its efficient use in any sector of the economy, specifically in industrial sector, will have multiple benefits in India, which is a ‘net energy importer’.

Another significant feature of MSMEs in India is that they have clustered naturally and spontaneously in different regions of the country. It has been found out that there are over 400 small industry clusters and approximately 2000 rural and artisan-based clusters in India. Many of these small industry clusters are found to be energy intensive. Though individual units may not consume large amount of energy, collectively, their energy needs in such clusters cannot be ignored. Improving energy efficiency is necessary for survival and growth of these clusters, because, higher energy efficiency not only improves their competitiveness through cost reduction but also minimizes the adverse environmental implications associated with the energy consumption. Energy efficiency improvement in MSME clusters will have multiple benefits like:

- Demand for energy supply will grow at a lesser rate.
- Saved energy can be made available for other economic activities.
- Reduction in per unit cost and thereby making the concerned sector more competitive.
- Reduction in negative environmental impacts

Although some energy and environmental related studies of MSMEs are reported in literature from certain regions and sub-sectors of India, there is still scope for further study in this large and diversified country. In India, the energy consumption by the MSME sector as a whole is likely to be substantial in view of their large and growing population. However, small industry sectors have not succeeded in attracting researchers and policy makers in the past to the desired extent to study this vital issue. Energy represents an important and expensive factor of production in many MSMEs, particularly in energy-intensive sectors such as mineral processing (ceramics, tiles, pottery, brick, glass etc.), metallurgical and metal industries (foundries, forging, alloys, heat treatment, steel re-rolling, etc.) and agro and food processing (bakeries, dairies, rice mills, etc.). There is a need for increased energy efficiency and better environmental performance of such energy intensive MSMEs. From the available literature pertaining to brick industries in southern India, covering states of Karnataka, United Andhra Pradesh, and Tamil Nadu, it appears that this issue has not attracted the desired attention from researchers and policy makers in the past.

Further, a detailed review of available literature on energy related studies in the context of Indian small scale industries has revealed the following:

1. Though it is appropriate to analyze energy consumption within its social context, most of the energy studies in the past have ignored the influence of some of the factors influencing energy and environmental aspects in MSMEs.
2. There is hardly any comparative study of different geographical small-scale brick production clusters substantially dealing with energy and environmental performance.
3. Most of the studies are either single cluster based or single industry focused and there is hardly any study of clusters comprising different regions of the country or involving drivers and sub sectors of the country.
4. There are very few cluster based studies substantially dealing with barriers and drivers to energy efficient improvement.
The identified research gaps and subsequent discussion with the experts helped in formulating the objectives, scope and methodology of the present study. Overall objective of the study is to ascertain the importance of energy as an input in the energy intensive three south Indian brick industry clusters, and to demonstrate the linkage of energy use with environmental performance. Further; it aims at analyzing the energy consumption by probing causes, consequences and constraints for energy efficiency improvements in the energy intensive brick industry. The specific objectives of the current research are as follows:

1. To study the energy consumption pattern and associated environmental pollution.
2. To find out the current level of energy efficiency and estimate the potential for energy conservation.
3. To categorize and analyze the factors influencing energy efficiency.
4. To identify and probe the barriers and drivers to energy efficiency improvement.
5. To analyze the differences amongst the three clusters in terms of energy and environmental performance.

The study covers three energy-intensive small scale brick industry clusters in three south Indian states viz., i) Brick cluster of Malur, Kolar district, in the state of Karnataka, ii) Brick cluster of Tiruvallur district in the state of Tamil Nadu, and iii) Brick cluster of Krishna district in the state of United Andhra Pradesh. These clusters were identified by preliminary exploratory field visits, discussion with experts, media reports, and consultation with the officials of brick associations and Directorate of Industries & Commerce (DI&C). Within each of the selected clusters a “random sampling design” is followed in picking brick units, to enable wider generalization of results obtained in the clusters. The study involves a total of 150 brick units (50 units in each of the three brick clusters)

Majority of the surveyed units have come up in the 1980s or after and are started by first generation entrepreneurs. The Malur cluster, with the exception of Krishna and Tiruvallur cluster, work throughout the year. Though all the units in the cluster are engaged in producing bricks, these units function independently and formal linkage with other units and associations is barely found. In terms of size, majority units are small sized as they employed up to 50 workers. Units in the three clusters primarily rely on agents for marketing their products or
sell directly to the customers.

At the outset, the study of energy consumption pattern revealed that biomass, coal, electricity and diesel are the main energy carriers used in the brick clusters under reference. The biomass mainly in the form of eucalyptus leaves and small amount of firewood provided the thermal energy needs of brick firing in the Malur brick kilns. Coal dominated the energy needs in the Tiruvallur cluster. Whereas, coal and rice husk dominated the energy needs in the Krishna Cluster. From an end-use perspective, it is observed that in all the three clusters the thermal needs dictated the energy consumption.

As far as environmental pollution connected with energy use is concerned, the study estimates air pollution in terms of Green House Gases (GHGs) and other pollutants as per the guidelines of Intergovernmental Panel on Climate Change (IPCC). The emissions of Carbon Dioxide (CO₂), Methane (CH₄), Sulphur Dioxide (SO₂), Nitrous Oxide (N₂O), Carbon Monoxide (CO), Nitrogen Oxides (NOₓ), and Total Suspended Particulate matters (TSP) are estimated. Based on annual emission of CO₂, the main GHG, it is found that the Malur cluster causes highest air pollution (about 46032.82 tonnes) followed by Tiruvallur (about 36100.82 tonnes) and Krishna cluster (about 7252.92 tonnes) respectively. Thus, global pollution caused by individual brick clusters may not be substantial, but their effect on local pollution merits attention. However, in view of the existence of a large number of such brick clusters in many other developing countries, the total effect of all such clusters on global pollution also is likely to be significant.

The second objective of the study is to assess the prevailing energy efficiency levels and subsequently to arrive at the energy conservation potential in the clusters. In each cluster, generally adopted micro and macro level energy efficiency indicators (Specific Energy Consumption (SEC) and Energy Intensity (EI) respectively) are estimated. The average energy efficiency in terms of SEC (MJ/brick) in each of the clusters of Malur, Tiruvallur and Krishna is found to be 11.41, 2.41 and 4.57 respectively. However, the efficiency expressed in terms of EI (MJ/Value added Rs.) for these clusters are at 3.31, 0.56 and 1.06 respectively. When efficiency is expressed in pure economic units in terms of Economic Energy
Consumption (EEC) (Energy Rs./Value added Rs.), the values for the cluster are found to be 0.39, 0.22 and 0.21 respectively. The foregoing values bring out that lower SEC need not mean lower EI or lower EEC.

Further, a wide variation in energy efficiency values was observed among brick units. Comparing the mean SEC values with the best among the sampled SSIs, an energy saving potential of about 35.4%, 30.7% and 34.13% was estimated in the Malur, Tiruvallur and Krishna clusters respectively. Even higher energy conservation potential can be achieved in the clusters if one considered the option of technology-shift in addition to other measures. In brick industry, replacement of presently employed Intermittent Downdraught Kilns (IDK), and Brick Clamps with Vertical Shaft Brick Kilns (VSBK) is expected to save around 45-71% of energy use.

With the intention of ascertaining the importance of energy input in the value of output, the Cobb-Douglas production function was estimated in each of the three energy-intensive industries. The high values of adjusted $R^2$ (0.924, 0.864 and 0.986 in the Malur, Tiruvallur and Krishna brick clusters respectively) of the estimated functions indicate their ability to explain most of the variations in the value of output with considered factors of production. Further, the significant beta coefficients of energy (0.673, 0.266 and 0.200 in the Malur, Tiruvallur and Krishna brick clusters respectively) in each of the industries establish that energy is indeed an important input affecting the value of output.

Third objective of this study is to analyze the internal and external factors influencing energy efficiency in the brick clusters. Based on the limited literature available on linking energy use with non-technology factors, a hypothetical model of factors influencing energy efficiency in the study clusters was developed. The high values of adjusted $R^2$ (0.71, 0.69 and 0.64 in the Malur, Tiruvallur and Krishna brick clusters respectively) along with statistically significant ‘F’ value. Additionally, both the coefficients have negative signs indicating that with the increase in factor scores the SEC is going to reduce, in other words, the energy efficiency is going to increase. Considering this, it is concluded that the considered set of two factors does possess a linear relationship with energy efficiency (SEC) in the brick clusters.
The fourth objective of the study is to identify and prioritize the barriers and drivers to energy efficiency improvement with an intention of scuttling the former and boosting the latter. A factor analytic approach was adopted for identifying crucial barriers for energy efficiency improvement. Thirty two statements representing various dimensions of the barriers were recognized before performing the factor analysis. The factor analyses on the thirty two statements representing the barriers were then reduced to eleven factors in all the three clusters with explanation of variances of 76%, 73.45% and 73.3% in the Malur, Tiruvallur and Krishna brick clusters respectively. The results showed that “management finds production more important than energy efficiency”, and “Lack of awareness of the terms like energy efficiency etc.,” were the top two barriers in Malur cluster. Similarly the “present technology is easy and they are familiar with it and not confident of new technologies” and “management is concerned about investment cost of energy efficient technologies” were ranked as the top two barriers in Tiruvallur cluster. Whereas “size of the unit is too small, the production volume is too low and hence incentive for better technology and energy efficiency improvement is low” is the top barrier and “management finds production more important than energy efficiency”, and “Lack of awareness of the terms like energy efficiency etc.,” were ranked as the next top barriers to be addressed for energy efficiency improvements in the Krishna cluster.

The nine potential drivers of energy efficiency enhancement considered in the study included ‘EE (Energy Efficiency) as a tool to reduce energy consumption’, ‘EE as a tool to reduce per unit cost’, ‘EE as a tool to reduction in wastage’, ‘EE as a tool to meet shortage of energy supply and rising energy price’, ‘EE as a tool to minimize environmental degradation’, ‘EE as a tool to improve compliance with governmental regulations’, ‘EE as a tool to occupational, health and safety improvement’, ‘EE as a marketing label and status symbol in improved product quality’, and ‘EE as a tool to achieve competitiveness and sustainability of the unit’. Utilizing the entrepreneurial experience and value judgment, these drivers were prioritized. Further, to obtain the relative strength of each driver, weighted average score was computed using normalized weights. Again, the ranking of drivers revealed that the ‘EE as a tool to reduce per unit cost’ is top choice in all the three brick clusters and ‘EE as a tool to achieve
competitiveness and sustainability of the unit’ ranked second in the Malur and Tiruvallur cluster. However, ‘EE as a tool to meet shortage of energy supply and rising energy price’ ranked second in the Krishna cluster. At the same time ‘EE as a tool to occupational, health and safety improvement’, ‘EE as a marketing label and status symbol in improved product quality’, ‘EE as a tool to minimize environmental degradation’, were ranked towards the end by the brick clusters. The almost identical ranking of both barriers and drivers is significant considering the cluster dissimilarities in terms of socio-economic conditions, geographical location, entrepreneurial background, energy carriers used and so on. This suggests that irrespective of dissimilarities the entrepreneurs in the brick clusters encounter identical hurdles and are motivated by similar set of benefits associated with energy efficiency improvement.

The final objective is to compare the three south Indian brick industry clusters. The results of comparison showed that there was significant scope for improvements in energy efficiency and thereby reducing the negative environmental impacts, by adopting better technology, labour skill development, better work practices, layout, housekeeping, etc..

Based on the empirical study, few policy initiatives to enhance energy efficiency in brick clusters are made. They include: i) recognize brick kilns as a formal industry, ii) create a “Brick Technology Center” for understanding the current situation in terms of technologies being followed, resource consumption and to raise awareness about the benefits of energy efficient technologies, iii) support research and development aiming, iv) Introduce a “National Programme on Brick Sector Efficiency Improvement” thereby training several stakeholders with regard to the benefits of adopting energy efficient technologies.

Finally, the major contributions of this thesis are as follows:

- The study covered three highly energy-intensive brick industry clusters in three South Indian states.
- A scientific sampling procedure was followed and hence the findings of the study are applicable to the entire population in the respective clusters.
• The thesis analyzed current pattern of energy consumption and estimated the associated environmental implications in terms of air pollution.

• The study has responded to the questions “Where do the clusters stand?” in terms of energy efficiency, and “How much of unrealized potential existed in these clusters?” based on the primary data obtained from the field.

• The ‘production functions’ were estimated in each of the industries under reference leading to appreciation of the role played by energy input in the value of output and the total variable cost.

• A comprehensive theoretical model was put forward to analyze the factors influencing energy efficiency in the study clusters.

• A quantitative approach was adopted to analyze barriers and drivers for energy efficiency enhancement.

• A barrier analysis was conducted using factor analysis. The barriers were prioritized based on the value judgment of brick owners who are the main stakeholders of efficiency augmentation.

• The potential drivers for energy efficiency improvement were identified and prioritized utilizing a weighted average scheme, again from an entrepreneurial perspective.

It is believed that this empirical study of energy consumption along with its associated issues in the three energy-intensive brick clusters would be able to assist in triggering the concerned stakeholders to seriously consider energy efficiency improvement for the sustainable and long term growth of this sector. The analysis of causes, consequences, constraints and motivators is likely to assist in fine-tuning the MSME policy in general and energy-intensive brick clusters in particular.