Techno-Economic Feasibility and Environmental Impact Mitigation Assessment of On Grid-Solar PV Solution for Nano Entrepreneurs in The City of Bangalore

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Abstract

One of the most significant issues of the 21\textsuperscript{st} century, is global warming, which is primarily caused due to the emission of Green House Gases (GHG). While most climate actions are targeted to cut back on GHG emissions from large industries and transportation sector, small scale solutions to achieve the same have been overlooked, especially in developing countries such as India. The paper analyses the economic and environmental impacts of one such solution, which proposes the use of electric iron powered by grid connected roof-top Solar PV system, across 40,000 plus manual clothes pressing service stores currently using charcoal-based iron in the city of Bangalore. An incentive of subsidized power, resulting in free supply of 200 kWh/month and low-interest capital loan at 5\% is proposed as an implementation catalyst, for faster adoption of the technology. The proposed solution and incentives help in the entrepreneurs gaining a monthly profit of ₹27,819 which is equal to the LPG based option, a 48\% increase from current profits of ₹18,686 using a charcoal-based iron. Subsequently, the proposed solution helps in annual reduction of GWP by 344,407 and 32,722 Tonnes of CO$_2$eq, when compared against charcoal and LPG options. It also leads to a maximum savings of ₹280.9 million and ₹8.433 million in external costs, against charcoal and LPG based irons respectively, across the city of Bangalore. The work further analyses the emissions and cost of
operation for various levels of incentives and energy mix, to provide a comprehensive study of the solution.

**Keywords:** External costs; Global Warming; Environmental Economics; Emissions; Climate Change

1. **Introduction:**

Global warming is touted as the biggest environmental challenge and existential crisis faced by the human-race today (LH Huang, MM Li, 2015) [1], and is primarily caused due to the emission of Green House Gases (GHG’s). Currently, India ranks third in the list of highest GHG emitters, behind USA and China, and one of the most obvious reasons, quite intuitively, is its reliance on fossil fuels to power the country’s growing energy needs. While, the growth of renewable energy has been extremely well paced in India, challenges in implementation of a low carbon grid such as reliability and intermittency have kept the scales in favour of thermal energy. As a result, thermal energy sources still account for 62.22% of India’s total power generation, of which more than 85% is being sourced through coal-based power plants [2]. Furthermore, coal utilization has been identified as one of the key contributors to Indian emission landscape (MoC, 2017) [3], with a considerable share of emissions, coming from lower quality fuels such as charcoals. In addition to the above, the Paris Agreement has also put obligatory pressure on India to reduce its carbon emissions per unit of GDP by 33-35% by 2030, compared to 2005 levels (PIB, 2015) [4].

Therefore, to fast-track the progress of achieving climate goals, the government has implemented various policies to reduce carbon footprint and improve energy efficiency (BEE) [5] in major emission generating sectors such as iron and steel, cement, thermal power plants and other energy-intensive manufacturing industries (MoC, 2017) [3]. It has also been analysed and reported that these interventions have largely been confined to large enterprises, as there could be significant reduction in emissions, with narrowed focus and directed efforts (Bo Meng, et.al., 2018) [6]. However, it is pertinent to note, that according to the ministry of statistics and program implementation, the informal sector consumes around 13% of the total coal consumption annually, i.e., 81 million tons [7]. Furthermore, because of the rampant increase in domestic fossil fuel usage and reluctance to transition to cleaner energy sources, India’s informal sector emitted more than 110 million tons of CO2e, in 2015-16 [7]. Therefore, it becomes essential to focus and implement reforms in the informal sector, for India to overcome climate change concerns.
One such informal industry/sector in India, is the field of manual clothes pressing. The clothes presser’s industry in India is largely dominated by archaic business practices and continues to use the coal heated irons (D Arora, U Jain) [8]. Our work analyses the potential to reduce emissions from the above, with the city of Bangalore, Karnataka as a model case study. Furthermore, it is proved in the work, that the coal usage for heating iron can be reduced through technological interventions and that these interventions could create an environmentally beneficial and financially rewarding solution for the nano-entrepreneurs, i.e., the clothes pressers in Bangalore, as well as reduce the government spending to offset the external impacts. In this work, we specifically envisage certain future scenarios, while trying to determine the level of benefits each could offer. A backwards estimated incentive is proposed as transition catalyst, which could be used as a neutral point to control the rate of transition, while investigating the socio-economic implications in terms of external cost.

2. Context of the Case Study:

The work envisages a list of possible policy options and interventions within the cloth pressing community and their practices, in India. The work assumes the city of Bangalore to be a suitable study case, owing to its high share of working professionals intuitively conveying the need for laundry and cloth-pressing services at large. The work derives the current baseline scenario based on the survey conducted as part of the grassroot-level intervention by Udhyam [9], a Non-Governmental Organization. The manual cloth-pressing service has been in existence for more than 100 years now, while the number of customers, competition and complexity has increased multi-fold in time, the technological and working infrastructure has stayed stagnant.

Currently, the practice uses charcoal-based iron which involves a considerable amount of pre-operational preparation and post-operational maintenance. Therefore, the practice is majorly diurnal in nature, with minor exceptions extending beyond daylight timings. Furthermore, the use of charcoal-based irons is detrimental to the entrepreneurs/workers health, due to its emissions, occupational hazards, etc.,

The charcoal-based irons are estimated to consume about 30 minutes per heating cycle, and an average total time loss of 2.5 hours per day, taking into account the multiple heating cycles, post-work maintenance, safe disposal of ash and unburnt coal. This issue combined with the diurnal nature of the occupation, greatly limits the potential to extend the service time and limits the number of clothes pressed per day to 150. Two upcoming solutions for the issue, are the introduction of Liquefied Petroleum Gas (LPG) based iron and electric iron, which have significantly reduced maintenance, with heating cycle time of about 2 minutes. This opens the potential to expand the service time and capacity, enabling them to press 50 additional clothes per day on average. Due to the ever-growing number of white-collar jobs in the city of Bangalore, the demand is assumed to be large enough to compensate for the additional capacity in service.
Therefore, to cover a significant share of future possibilities, recommended policy changes and intervention, scenarios 1 to 5 are assumed, as follows:

Scenario 1: Business as Usual

The analysis assumes the case to be a baseline scenario and estimates the current level of emissions and analyses the working characteristics of charcoal-based iron. Based on the grassroots level surveys, a fuel usage of 5 kg/day is assumed for the standard workload, with a nominal revenue of ₹6/unit and initial investment of ₹3000. The number of working days in a month are averaged out and assumed to be 25, owing to the lower margin rates of operations.

Scenario 2: Replacement by LPG based iron, through non-governmental intervention

The scenario assumes the replacement of charcoal-based irons with LPG based irons, the same has been found to increase the quality of living significantly, based on the findings of a pilot project by Udhyam. The increased efficiency in operations also helps in significant cost cutting, with an observed fuel usage for 5 kg/1000 clothes, or ₹2000/month in net fuel expenditure. The net investment for LPG based irons is about ₹8500, based on publicly available data and correlations with grassroots surveys.

Scenario 3: Replacement by electric irons, with no incentives and 100% grid power.

The scenario proposes the change to electric irons, with grid connected power systems. It is assumed that the electric iron operational characteristics are similar to that of LPG irons, owing to the same heating capacity and weight specifications. It is assumed that service time of the practice, is an average of 7.5 hours/day. Combining the time of service, along with a higher end capacity of 2 kW electric-iron, the net electricity usage is calculated to be 375 units/month at ₹5.9/kWh. The scenario in particular is dependent on the availability and reliability of power utilities, especially the transmission constraints across lower voltage transmission systems in Bangalore. It is assumed that an initial investment cost of ₹10,000 is required to set-up the infrastructure for electric irons. It is also assumed that the grid power is sourced entirely from thermal resources at a conversion efficiency of 30%, as still majority of the supply in the state of Karnataka, where Bangalore is located, is sourced from coal-based power generation.

Scenario 4: Replacement by electric irons, with local Solar PV + On-grid (Incentivized)

The scenario proposed aims to better the above scenario by introducing a hybrid power source of local Roof-Top Solar PV and On-grid electricity. Based on the data sourced for Bangalore from Solar Atlas Data [10], it is assumed that a total of 1500 kWh would be generated per year, from the PV system installed on roof-top (1kWp) of the cloth pressing venture. The solar PV system, therefore, results in an average low carbon power of 125 units/month, while rest of the supply is assumed to be from the grid. This significantly reduces the transmission constraints or grid congestion, while improving reliability of operations. It is also assumed that the system neglects the need for a large battery storage mechanism, as the demand and supply are both diurnal in nature. An initial investment of
₹1,00,000 is assumed to be required for the installation of Solar PV and necessary infrastructure. In terms of incentive a free power scheme for micro and nano business of 200 kWh/month, is proposed as followed in the neighbouring state of Tamil Nadu. Additionally, the initial investment is offered at half of the market interest rate at 5%, for a period of 5 years, to encourage the transition.

Scenario 5: Replacement by electric irons, with local Solar PV + On-grid Solar (Incentivized)

The scenario is proposed to be a minor modification to the above scenario 4, with the On-grid electricity to be sourced entirely from renewables, primarily solar. The scenario is modelled based on the assumption that the supply density from renewables significantly overlaps the diurnal nature of demand. Therefore, the operational characteristics, investments and incentives mentioned in scenario 4 is assumed valid and constant. Such a mechanism, would also remove excessive baseload capacity installation, aiding in better generation of clean energy. Furthermore, the lack of baseload contracts of renewable energy supplier, removes an inherent reliability risk from supply, which could result in cheaper retail contracts for end-users, while reducing additional cost of supplier. This system would enable a prosumer economy, that boosts the installation of solar, while maintaining the integrity and reliability of the transmission grid and securing energy security.

3. Methodology & Calculations:

The initial investment across all the scenarios are assumed to be standard amortization loans, with a payback period of 5 years. While scenarios 1 to 3 are charged an average market interest rate of 10% per annum for small business, scenarios 4 and 5 are incentivized for solar PV transition at an interest rate of 5% per annum. As mentioned above, an average revenue of ₹6/cloth unit is assumed, and the final monthly profits are estimated accounting for the loan repayment and fuel costs.

The monthly amortization loan repayment is given by the below equation:

\[ A = P \cdot \frac{i (1 + i)^n}{(1 + i)^n - 1} \]

A major component of emissions from conventional fossil fuel-based applications are generated from the combustion of fuels. The Life Cycle Analysis (LCA) of such applications excluding fuel combustion is insignificant, hence neglected in this study. Whereas, for renewable energy sources such as solar, the LCA analysis is the only recognizable and significant emission parameter, therefore it is assumed to be 0.02 kg/kWh for conditions similar to Bangalore, as specified by Kato and Murata [11].
Since the thermal power plant resources, such as coal, are imported from Orissa, the coal composition of the same is used in this work as mentioned by [2]. While 80% of ash is disposed as fly ash, an Electrostatic Precipitator (ESP) with an efficiency of 99.9% [12] is assumed to calculate the level of Particulate Matter (PM) emissions, for thermal power. Since LPG is a liquified fuel it is assumed to be free of solid impurities, hence free of particulate matter emissions. The composition of different fuels used in this study, are given in the table below:

<table>
<thead>
<tr>
<th>Fuel Composition (in %)</th>
<th>Charcoal</th>
<th>LPG</th>
<th>Coal (Orissa)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carbon</td>
<td>51.95</td>
<td>82.5515</td>
<td>33.5</td>
</tr>
<tr>
<td>Hydrogen</td>
<td>2.38</td>
<td>17.4485</td>
<td>NA</td>
</tr>
<tr>
<td>Oxygen</td>
<td>17.4</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Nitrogen</td>
<td>0.61</td>
<td>-</td>
<td>1.5</td>
</tr>
<tr>
<td>Sulphur</td>
<td>0.51</td>
<td>0.015</td>
<td>0.6</td>
</tr>
<tr>
<td>Moisture</td>
<td>7.89</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Ash Content</td>
<td>19.27</td>
<td>-</td>
<td>29.5</td>
</tr>
<tr>
<td>Volatile Matter</td>
<td>NA</td>
<td>NA</td>
<td>29</td>
</tr>
<tr>
<td>GCV in (kJ/kg)</td>
<td>NA</td>
<td>NA</td>
<td>19.89</td>
</tr>
</tbody>
</table>

Table 1: Composition of Fuels

The emissions are calculated from the above values as specified in [12] and related external costs of the emissions are estimated. The external cost is assumed to be value of damages, or the cost needed to compensate such damages to the environment, health, and well-being of the public. The emission-wise external cost adjusted for the population density factor (PDF) of the state and inflation rate, based on external cost prices of 2018, are given below as specified by [12].

<table>
<thead>
<tr>
<th>External Costs /kg</th>
<th>Indian PPP Price</th>
<th>Inflation Adjusted Value</th>
<th>Final External Cost (PDF Adjusted Value)</th>
</tr>
</thead>
<tbody>
<tr>
<td>CO₂</td>
<td>0.096</td>
<td>0.108</td>
<td>0.248</td>
</tr>
<tr>
<td>NOx</td>
<td>30.22</td>
<td>34.02</td>
<td>78.19</td>
</tr>
<tr>
<td>SO₂</td>
<td>32.81</td>
<td>36.93</td>
<td>84.89</td>
</tr>
<tr>
<td>PM</td>
<td>131.95</td>
<td>148.54</td>
<td>341.40</td>
</tr>
</tbody>
</table>

Table 2: External Costs/kg based on Emissions. (Adjusted)
4. Results and Discussions:

One of the most important factors, that naturally induce transition towards cleaner energy sources and practices is the economic viability of change. Since, the scenario 2 to 4, are more profitable than the current baseline scenario, it naturally encourages the entrepreneurs to adopt LPG or electric irons. But unfortunately, the proposed scenarios are capital intensive in addition to being part of an unorganized sector, which further increases the complexity in raising capital. Therefore, as a catalyst to change, collateral free loans need to be arranged, by the government. The figure given below, represents the revenue, costs, and net profitably of each scenario monthly, with 25 working days.

Fig 1: Monthly Financial Projections for Scenarios

While it is clearly visible that scenarios 2, 4 and 5 give about 49% increased profits over a month when compared against scenario 1, scenario 3 marginally edges out with 51% increased profit. Furthermore, scenarios 2 and 3 are not capital intensive to the government lender, but scenario 4 and 5, creates significant distress on the government financials owing to the additional risk of collateral free loans and reduced interest rates. The interest rates were calculated through backward estimation and 5% interest rates with a 5-year payback period was assumed to be the net-neutral case when compared with a pilot tested solution of LPG option, i.e, scenario 2. Therefore, any extension in payback period or reduction in interest rate will further increase the revenue of scenarios 4 and 5, making it the most profitable options. Alternatively, the incentive of no-cost electricity amounting to 200 kWh per month could be increased to better the economic favourability of these scenarios.

In terms of environmental impact, the net emissions, along with the corresponding external cost is given below in the figure. To present a uniform viewpoint, the net monthly values for
the emission and external cost is represented, despite the variation in number of clothes ironed or revenue generated, as the industry is demand driven. It is to be noted that the net GHG potential of the emissions is estimated using CO₂eq, which assumes the impact of NOₓ’s on climate change to be 298 times of CO₂. Since, the greenhouse effect is not a localized phenomenon and affects a considerably large share of surrounding area, the net population density of the state, i.e, Karnataka is assumed instead of Bangalore, to prevent over-estimation of external costs.

![Monthly Emissions & External Costs (In INR) per entity](chart)

Fig 2: Monthly Emissions and External Cost per entity/entrepreneur

It is clearly observable that the external cost for charcoal-based ironing operations is the highest, followed by scenarios 3 and 4. While the scenario 4 has significantly lower emission due to the introduction of localized solar PV, scenario 5 has least value of emission levels and hence, the least external cost. Therefore, from the point of view of a government, the net savings in external cost is highest for the scenario 5, followed by scenario 2 and 4. It is also of importance to observe that the scenario 2, LPG is one of the cleanest options available in terms of external cost, but the net emissions in terms of CO₂eq is still considerably higher than scenario 5.

The figure given below represents the net difference in emissions as CO₂eq, as a matrix in metric tons (MT) per annum for the city of Bangalore, assuming positive sign to be reduction in emissions.
Fig 3: Annual Reductions in emissions, between various Scenarios in Metric Tonnes of CO₂eq

The figure above clearly displays the magnitude of emission reduction that can be achieved through simple interventions, especially within a major city such as Bangalore. The best-case scenario is observed between switching from current scenario 1 to scenario 5, which can reduce 344,407 metric tons of CO₂eq emissions per year, in the city of Bangalore. While, all scenarios are better than Scenario 1, it is argued that scenario 2 is one of the cleanest cases, especially providing significant benefit over thermal/coal-based energy sources.

Extrapolating the net savings to 40,000 entrepreneurs in the city, the government of Karnataka could save annual external costs up to ₹280.9 million based on the scenario 5 versus scenario 1, while the net expenditure in terms of incentivized power would be ₹240 million, at a cost price of ₹2.5/kWh. The price of power is assumed to be lower than typical long-term contracts, factoring in the reduction of inherent risk premiums, due to the diurnal supply and demand. Therefore, the government would still have sufficient financial leverage to increase the incentives over the recommended scenario 5, thereby catalysing the change towards a cleaner unorganized sector and nano-entrepreneur community in the city of Bangalore. Furthermore, the initiative will increase investments and employment opportunities in the renewable energy sector.
5. Conclusion and Policy Recommendations:

As the world aims to achieve climate change goals and move towards a low carbon future, it is imperative to pursue efforts from all facets of the society. The above work reports and suggests the following policy recommendations:

- Charcoal based ironing is the least productive of all scenarios under consideration, causing significant impacts in the economic and physical wellbeing of the workers, owners, or entrepreneurs.
- Charcoal based ironing is also greatly detrimental to health, owing to its very high rate of particulate matter (PM) emissions, at close proximity to human settlements unlike thermal power plants.
- The best tested solution would be the implementation of LPG based ironing systems, as the economics of the model have been proven to be beneficial, while there is no major technological changes or complexity in operation.
- The most environmentally friendly solution is the case of Scenario 5, with a hybrid of localized PV and On-Grid Renewable energy supply. The scenario, if implemented across all entities could result in emissions reduction of 344,407 metric tons of CO$_2$eq and savings of ₹280.9 million in external cost per year.
- Such incentives and policy changes are required to reduce emissions from the vast unorganized, micro- and nano-business sectors in India, therefore, the above said solution is one of the many changes that could bring in sustainable carbon reduction with net zero investments from the government, in the long run.

References:


[10] Power Output for Floating Solar PV system obtained from the “Global Solar Atlas 2.0, a free, web-based application is developed and operated by the company Solargis s.r.o. on behalf of the World Bank Group, utilizing Solargis data, with funding provided by the Energy Sector Management Assistance Program (ESMAP)” For additional information: https://globalsolaratlas.info
