Zero-carbon footprint, mechanical intervention for potentially reducing forest fires and generating livelihood options in Western Himalaya

Kapil Kumar Joshi
Indian Forest Service Officer, Post-Doctoral Fellow, Department of Management Studies,
IIT Roorkee, Uttarakhand, 247667, India.
kapilkjoshi@rediffmail.com

Vinay Sharma
Professor, Department of Management Studies,
IIT Roorkee, 247667,Uttarakhand, India.
vinay.sharma@ms.iitr.ac.in

Abstract

This paper provides an appropriate technological intervention with a zero-carbon footprint operating model while converting a dangerous forest bio-residue into a usable commodity. In our study, the dangerous forest bio-residue consists of the dry and fallen pine needles of the trees that grow in the Western Himalayan region. The appropriate technological intervention is the evolution of a manually operated biomass briquetting machine, and the usable commodity is the bio-briquettes, which could be used as an alternative to fossil fuels. Dry and fallen pine needles induce devastating forest fires in the Himalayan region, which facilitates the release of huge amounts of carbon into the atmosphere without obtaining any productive use from it. The purpose of this research is to present an easy-to-operate manual intervention to densify the loose and dry bio-residue into a useful and salable fuel option while promoting community involvement. The studies propelling the evolution of the briquetting machine are based on reflexivity, where communities themselves have been demanding such types of basic and indigenous interventions to create reasonable livelihood options for themselves and to address the socio-climatic issues caused by forest fires in the Himalayan region.

Keywords: Forest bio-residue, Briquetting, Climate Change, Himalayas, Livelihood, Zero-carbon footprint

I. INTRODUCTION

The Indian Himalayan region comprises of about 12% of India's total landmass and approximately 30 % of India's total faunal diversity [30]. This area has a great influence on the ecology of the entire northIndian region as it hosts around 280 species of mammals, 940 bird species, 316 fish species, 200 species of reptiles, and around 80 amphibian species [12].The region has numerous lakes, ponds, rivers, glaciers, forests, and high-altitude grasslands that support different ecologies and additional flora-fauna species.

Unfortunately, climate change models implemented to estimate the climate of the Himalayan region predict ever-increasing temperatures and erratic precipitation [22], where in the tree and shrub lines moving up the mountains, glaciers will be melting at a faster rate, alpine meadows will decrease, quality forests will shrink, and flowering pattern of wild species will also change [12,26,21].

Although indigenous people in the Himalayan region clearly understand climate change and are well aware of global warming, melting glaciers, unpredictable rain patterns [4], loss of habitat, degradation, and deforestation, many of them strongly attribute these changes to spiritual causes and suggest prayers and ceremonial practices as solutions [27]. Since time immemorial, the traditional Himalayan livelihood had been carbon negative as communities used their natural resources, such as timber, grasses, medicinal plants, fire wood, flowers, fruits, tubers, and water, for sustained living. They never overexploited, destroyed, or polluted their natural resources and believed in sustainable consumerism. However, they knew well to arrest or mitigate climate change by implementing strong traditional ecological knowledge (TEK) in their day-to-day affairs. This knowledge would be shared from one generation to the other thereby creating a sustainable community-environment cycle.

Climate change has been strongly attributed to deforestation. Ironically, during the past decades, climate change in the Himalayas has not accelerated because of deforestation. This is evident from the aerial satellite data of the region pertaining to forest biomass; the data show that the opposite phenomenon of reforestation is being actively carried out in the region [5]. States of Himachal Pradesh and Uttarakhand (Himalayan states of North India) indicate degradation (rather than deforestation) to be the key problem. A majority of the forest area exhibits crown cover below the ecologically sustainable threshold of 40%; heavily lopped trees and stunted tree-growth with limited foliage is a common scenario in this region. Additionally, repeated forest fires in the Himalayan region are gradually becoming a major cause of degradation of forest areas.

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Among many other reasons, the chir pine(Pinus Roxburghii) forests in the region contribute substantially to the forest fires. Forest fires in Indian Himalayan states, such as Uttarakhand, have emerged as the biggest enemy of the unique megabio-diversity of this region. Over half a million hectares of forest land is covered with chir pine trees (Pinus Roxburghii), and they shed millions of tons of leaves annually during the summer season (March to June). Either intentionally or accidently , thedry and fallen pine needles catch fire, causing colossal damage to not just the unique biodiversity of the region but also the whole environment [28]. It is estimated that 4–5 million tons of dry and highly- inflammable chir pine leaves fall over the forest floor in the Indian Himalayan state of Uttarakhand alone [24, 29].

As pine needles are highly combustible because of their turpentine content, they spread fires with lightning speed. Although the incendiary nature of these pine needles is a major cause of forest fires in hot summers that can lead to destruction of life and ecosystems, they can still have precious use as an alternative fossil fuel; the fallen dry pine-needles could be conveniently converted into bio-briquettes. It is also worth mentioning that transporting these pine needles in loose form, from point of origin to the factory site, is highly cost-intensive because of its very high volume, which largely restricts the load capacity of the vehicle. As an example, a carrier vehicle designed to transport a load of nine tons can hardly transport two to three tons of loose pine needles, which drastically increases the transportation cost. Simultaneously, because of the absence of an appropriate briquetting technology, local communities find it impossible to create a value-added product from the fallen pine needles. As a result, this important resource is not only causing devastating forest fires and irreversible loss to the environment but is also getting wasted (owing to the fact that it can be a reliable fuel source if treated properly). Thus, producing briquettes from the needles will not only minimize the forest fires but also provide an alternative source of fuel. Additionally, this can be a great way to offer employment and reliable livelihoods to the local communities.

II. OBJECTIVES OF THE STUDY

In this study, we visualize the strengthening of the capacity and development of human capital in the Himalayan region by addressing the socio-economic scenario of the region with the support of technological interventions; using forest bio-residue as a source of renewable energy through bio-briquetting of dry and fallen pine needles, is a promising way to achieve this. This study aims to innovate and provide related knowledge interventions using indigenous green technologies to subsequently, curb migration, mitigate climate change, and capacity building which in turn will create good livelihood opportunities for the local communities residing in the nearby pine forests.

We aim to develop a manually operated briquetting machine for areas that are historically known for rich traditional knowledge practices to serve the larger goal of natural resource conservation. The objectives of the study are to address climate change issues along with providing sustainable livelihood options to the local communities.

III. LITERATURE REVIEW

The world is diligently searching for an alternative source of energy for domestic and industrial usage to ensure sustainable development [13]; corresponding to this need, researchers are working on unlocking renewable energy sources [14]. In the recent years, bio fuel has become a globally accepted form of energy owing to its easy availability [15]. Bio-briquetting, which is reported to be more effective than the other forms of renewable energy such as bio-diesel and bio fuel, requires more research and appropriate technology to use it efficiently and effectively [20].

Solid fuel can be produced through a briquetting technique involving the binding of pulverized carbonaceous matter with or without a binder [16]. This may be a manual or mechanical process involving screw, piston, or hydraulic presses [10]. To produce a bio-briquette, solid waste such as agro-residue, dry organic material, or forest bio-residue can be used [9]. The organic waste is compressed with or without a binder (a specific ratio is adhered to if a binder is used). The proper briquetting technique provides a good quality solid fuel with a low ash content, lower burning rate, better ignition time, and low moisture content [6]. Saw dust [1], groundnut shell [2], grass [11], rice husk, jute dust, de-oiled bran, and corncob are widely used as bio-briquetting materials. The use of forest bio-residue as a briquetting material has not gained much popularity because of factors such as high transportation cost of raw material, non-accessible areas, tough and remote forest terrain, lack of appropriate technology, and various non-cohesive government regulations that supervise forest production. Forests globally have the potential to produce considerable amounts of biomass in the form of forest residue, such as branches, tops, bark, litter, and stumps. Forest residues have the potential to produce 30–150 exa-joules of energy per year [3, 23, 8].

It is further noticed that during a periodic cycle of approximately 240 years, cumulative radioactive forcing is significantly reduced when forest residues are used for energy instead of fossil fuels, although it takes 10 to 25 years to obtain positive results after the fuels are replaced with the forest residue [25,19]. The forestry sector in India has a bio-residue generation capacity of 27.1 metric tons per annum [7]. With such a vast forest bio-residue resource, India can easily address the issue of renewable energy using a low-cost energy generation solution.

Because of the large quantity of inflammable material lying on the forest floor, pine forests of the Himalayas are highly prone to forest fires [17]. Only a small fraction of dry and fallen pine needles is used by the local communities for manure, packaging, mulching, and roof shedding, while the rest is burnt accidently or otherwise. There has been hardly any known and implementable commercial activity related to such vast forest residues that are easily available to local communities. In the past, some initiatives were taken by the Uttarakhand state government to convert pine needles into briquettes under macro-level entrepreneurship programs [18]. However, the efforts did not yield because of executive, economic, operational, or policy issues. The transportation of dry and fallen pine needles from the hillside to the factory site is a great concern for entrepreneurs because the collection of pine needles from the forest floor and its transportation to the factory is highly uneconomical.

Though the communities were involved in this but being a contractual or hired laborer, no entrepreneurship skills could be developed among the locals. When the bio-briquetting industries faced forced closures because of the unacceptable cost-benefit ratio, these communities lost their livelihoods and the forest fires continued to destroy the ecology of the region.

Corresponding to this, in another attempt at micro-level entrepreneurship, electrically-operated machines were introduced for coal-making in the year 2010 by the Forest Department in some of the hilly areas of Uttarakhand. This method of coal-making involved carbonization of the pine needles to later mix it with additives, such as molasses or cow dung, before feeding the mixture into the machine for making coal pallets of different sizes. This attempt also turned out to be unsuccessful because the villagers faced serious problems in the maintenance of the electrically-operated machine, they could not achieve perfection in the carbonization process, and it was very difficult for them to arrange cow dung or molasses for mixing as a binder.

This journey began when all the deterrents in the macro scale entrepreneurship as well as in the micro scale entrepreneurship were deeply analyzed, and a manually operated bio-briquetting machine was designed and developed. This machine was conceived and later manufactured, keeping in mind the basics of social entrepreneurship.

IV. METHODOLOGY

The perspective that emerged in this study is that thinkers, authors, researchers, academicians, and policy makers never viewed the subject of forest bio-residue management to create livelihoods for forest inhabitants and to mitigate climate change along with augmenting the associated policies.

Two different options were considered in order to design a manually operated bio-briquetting machine:

Option 1: Application of heat to soften the surface lignin of pine needles and simultaneously compacting it to make briquettes

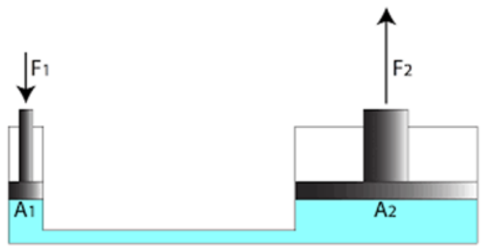
Option 2: Application of pure hydraulic pressure of about 1500 to 2000 psi to compact the pine needles without the use of any additives.

Option 1 had many operational problems, as it was not easy to handle a heated machine. More than that using fire near a highly inflammable material, such as dry pine needles, was not really safe to operate.

Detailed experiments were conducted to validate option 2. Pascal's principle was applied for this purpose. Corresponding to this principle, the force delivered by the fluid at the delivery end is determined by multiplying the pressure and cross-sectional area. The pressure being the same in all directions, the smaller piston feels a small force whereas the larger piston feels a larger force. Therefore, a smaller force input can generate a large force output at the delivery end of a hydraulic system.

A line diagram is shown in figure 1 to illustrate the principle of hydraulics.

Figure 1 Diagram depicting principle of hydraulics



This hydraulic system mainly consists of:

- Moving piston connected to the output shaft in an enclosed cylinder
- Storage tank
- Filter
- Pressure regulator, control valves, and leak-proof closed-loop piping
- High density incompressible oil.

Force calculations for a hydraulic system

A hypothetical calculation is shown below in order to calculate the scope of force multiplication through a hydraulic unit.

- Force applied by a human hand:
  $(F_1) = 60$ N
- Area of the input side cylinder (0.25 m diameter):
  $A_1 = \pi r^2 = \pi(.25/2)^2$
  $= .05$ sq m
- Area of the output side cylinder (0.5 m diameter):
  $A_2 = \pi r^2 = \pi(.5/2)^2$
  $= .196$ sq m
- Force transmitted to the output cylinder:
  $F_2 = F_1 \frac{A2}{A1} = 240$ N

The above calculation shows that through a simple hydraulic piston cylinder design, the force on the delivery end is four times the input force. Similarly, if the force is applied by hand and foot simultaneously on the input side, a force almost equal to 500 to 1000 N could be easily developed on the output side for the same piston–cylinder dimensions.

- Force applied by a human hand and leg simultaneously:
  $F_1 = 160$ N
- Area of the input side cylinder (0.25 m diameter):
  $A_1 = \pi r^2 = \pi(.25/2)^2$
  $= .05$ sq m
- Area of the output side cylinder (0.5 m diameter):
  $A_2 = \pi r^2 = \pi(.5/2)^2$
  $= .196$ sq m
- Force transmitted to the output cylinder:
  $F_2 = F_1 \frac{A2}{A1} = 627$ N

The force on the delivery side will further multiply if the input side cylinder diameter is reduced. Variation in the input force and cylinder diameter will give a number of permutations and combinations to manufacture the perfect briquette.

The above principle of hydraulics was applied to the development of a manually operated bio-briquetting machine for compacting dry chir pine needles into bio-briquettes.

V. EXPERIMENT AND RESULTS

Attempts were made to design and fabricate a machine for making bio-briquettes from dry chir pine needles of the Himalayan region. This work was carried out at one of the pioneer institutes of India named the Indian Institute of Technology, Roorkee, Uttarakhand. Although it was quite a tough composition to densify loose and dry pine needles through a manually operated hydraulic machine, under the concept of grass root -level execution strategy and social entrepreneurship, it was mandatory to develop a machine keeping in mind the following points:

- The whole concept of chir pine bio-briquetting is strictly based on grass root-level implication strategy where villagers will work as entrepreneurs and not as collectors of dry and fallen pine needles.
- The machine must have low cost, low maintenance and easy operation so that villagers could not only afford it but also operate it sustainably.
- It should be manually driven as the Himalayan rural areas face heavy electricity cuts and lack consistent electric supply; an electrical machine would be of very little use to the villagers.
- It should be easily transported to the remote hilly terrain.
- Carbonization of pine needles should not be needed in making the briquettes as villages may not attain expertise in this.
- There should be no need of additives like cow dung and molasses.

- Transportation of pine needles in loose form should be ruled out.
- Multiple types of raw material may be used in this machine.

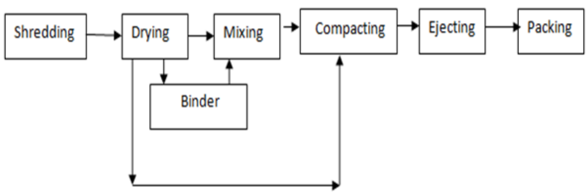
After a series of trials based on various piston–cylinder assemblies and hydraulic unit combinations, a pressure of 2000–2500 psi could be successfully generated at the delivery side of the machine through pure manual means. A series of initial problems like hose pipe burst, bench bend, die dislocation, piston misalignment, oil leakage, and nut and bolt fractures cropped up and were rectified. This finally resulted in the development of a manually-operated bio-briquetting machine, which could successfully convert dry and crushed pine needles into small briquettes of 30 to 40 g (weight) individually.

5.1 Flow Chart: briquetting process

The evolved briquetting machine had the basis of a simple but an appropriate technology in which the process flow chart consists of the following main steps:

- Crush the dry pine needles into small sizes of 1–2 centimeters
- Allow open air drying for a day or two
- Place the shredded needles in the die (cavity for imparting a desired shape)
- Manual application of pressure and compacting the loose mass in the die
- Ejecting the briquette from the die
- Packaging.

Figure 2 Flow chart of briquetting process

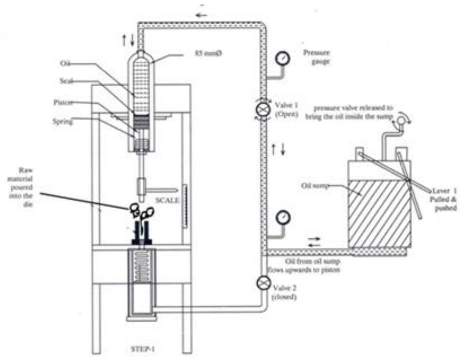


5.2 Manually operated briquetting machine

Figure 3 shows an actual photograph of the briquetting machine, and figure 4 shows the design of the briquetting machine with its various components.

Figure 3 Actual photograph of briquetting machine

Figure 4 Design of briquetting machine



This briquetting machine has the following main components:

- Oil pump and hydraulic unit with lever 1 and lever 2
- 85 mm diameter output cylinder–piston assembly
- Mild steel die for making briquettes
- Valves, pressure gauges
- Ejection mechanism
- Compression scale.

5.3 Machine operations

Briquetting machine follows the following procedure to make a bio-briquette from chir pine needles:

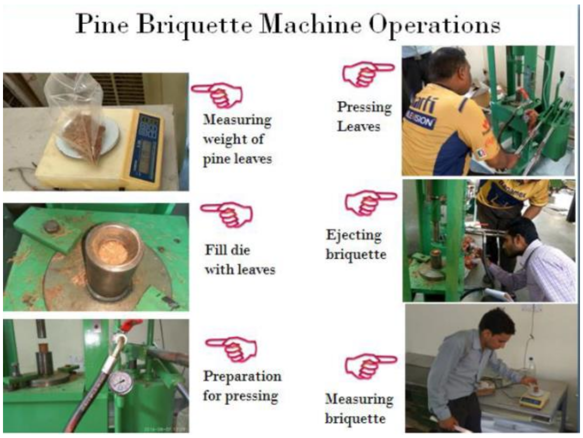
a. Step 1:
   - Crush the dry raw material
   - Pour the raw material into the die
   - Close valve no 2 (lower side valve)

b. Step 2:
   - Close pressure valve to bring the oil inside the cylinder from oil pump
   - Manually pump a desired pressure
   - Observe desired compression level on the scale
   - Open valve no 1 (upside valve)
   - Open pressure-release valve and close valve no 1

c. Step 3:
   - Close pressure-release valve
   - Open value no 2

d. Step 4:
   - Use lever no 2, operate the hydraulic pump until the briquette is ejected from the die

Figure 6 Briquetting on manually operated machine



5.4 Briquette density calculation

A laboratory test was conducted for a variety of raw material mixtures and different input pressure applications. The findings of the test are given in Table 1.

Table 1 Pine briquette density analysis

Sr.No	Weight Before pressing (gm)	Weight after pressing (gm)	Compression pressure (PSI)	Ejection pressure (PSI)	Height of the brick (mm)	Time to make one briquette (min)	Compression ratio	Material type
1	14.73	14.41	500	300	31	2	2.1	Powder
2	15.04	14.79	1000	400	23	2	2.9	
3	15.01	14.37	1500	500	20	2	3.3	
1	7.38	7.25	500	300	18	2	3.7	Leaf
2	7.02	6.37	1000	400	11	2	6.0	
3	7.01	6.78	1500	500	10	2	6.7	
1	6.12	5.93	500	300	15	2	4.4	Mixed
2	6.07	5.98	1000	300	11	2	6.0	
3	6.18	5.97	1500	400	9	2	7.4	

Laboratory tests of various briquettes manufactured by this machine show the following results:

- Briquetting is possible with a pressure as low as 500 psi if the raw material is in almost powdered form (leaf size is 1–3 mm)
- As the size of the raw material increases, more pressure is needed to form a briquette
- For the same amount (weight) of raw material the height of the briquette varies from 31 mm to 9 mm i.e. varied density bricks may be manufactured from the same machine
- Average time taken to complete one cycle of briquetting is about 2 minutes
- There is no appreciable loss of weight while compacting the raw material and making a briquette
- Briquetting machine may satisfactorily work for a compression range between 2.1 to 7.4
- For ejecting a briquette, a pressure of 300–400 psi is sufficient.

5.5 Briquette

An actual photograph of pine needle briquettes made by this machine is shown in figure 5.

Figure 5 Pine needle briquettes

As mentioned in Section 5.4, the size of the briquette depends largely on the pressure and compression ratio as exerted by the machine. It is further observed that a 15–20 mm diameter briquette is conveniently made from this design; however, if a larger diameter die is attached to the machine, a much bigger briquette could be easily manufactured. On an average, a briquette of 20 g to 40 g weightis most convenient to manufacture with the least wear and tear of the machine. It was further observed that if the die diameter is larger in size, with the same effort, a bigger bio-briquette could be manufactured easily.

5.6 Barriers

As the machine is manually operated and supposed to work on rough and remote hilly terrain, it is associated with various technological limitations:

- There is a chance of corrosion of the storage tank, piping, cylinder, and piston; hence, the material must be selected carefully.
- Impurities of hydraulic fluid may have a damaging effect on the system.
- Proper sealing should be adopted to avoid the leakage of hydraulic fluid because this is a critical issue.
- The hydraulic fluid must be disposed of properly.
- The structural weight and size of the system is less and therefore, daily working hours on the machine have to be optimized in order to avoid unnecessary maintenance work.
- Some bottlenecks such as piston jam, fluid spray, nut and bolt loosening, briquette sticking to the die, cutter blade misalignment, and tilting of the machine frame may occur during operations. All these problems can be easily handled through minor mechanical interventions.
- Government regulations and policies will always have an impact on the process of bio-briquetting as the raw material used in this machine is treated as a forest produce.

5.7 Enablers

The briquetting machine is designed on a very simple fundamental of hydraulics. The cost of manufacturing a single machine is below USD 1000. This machine could easily be adopted under a social entrepreneurship strategy as the communities and the nearby villagers will obtain good livelihood opportunities from this venture. This machine is completely eco-friendly, and the carbon footprint while operating it is almost zero. In totality, if a complete analysis of this manufacturing process is made, it will certainly lead to a negative carbon footprint. Moreover, the biggest enabler in this process is the willingness of the local communities. These communities want to reduce the repeated occurrence of forest fires and also wish to have sustainable livelihood options from nearby forest resources.

VI. ACKNOWLEDGMENTS

Attempt to collect dry and fallen pine needles from the hilly terrain and transporting it to the factory site before making the briquettes under a macro-level entrepreneurship program failed. Similarly, a micro-level entrepreneurship approach of pine needle coal-making by carbonizing the dry organic material and mixing it with additives, such as cow dung or molasses, before shaping it into a coal briquette through a motorized machine, could also not achieve success. With these two failed experiments, the problem of forest fires and the disposal of chir pine needles remained unsolved. The third intervention in the form of a manually operated, easily transportable briquetting machine was designed and fabricated, as mentioned in this paper. With this machine, dry biomass is directly compressed to give it a small brick shape. Upgrading raw biomass waste and providing it as a substitute for wood or coal may be useful cooking, industrial furnaces, domestic heating, and other applications.

It is worth mentioning that in a Himalayan state like Uttarakhand, every year, approximately 500,000 tons of dry pine needles fall on the forest floor, and this large mass is unproductively burnt because of the induced forest fires, releasing over a million tons of carbon into the atmosphere. This is clear waste of a useful resource of energy. The process of converting harmful forest bio-residue into a useful resource for energy under grass root-level execution strategy and social entrepreneurship, has great potential to not only provide sustainable livelihood opportunities to the communities, but also to get qualified under the Reduced Emission through Deforestation and Degradation (REDD +) scheme of the UNFCCC (United Nations Framework Convention on Climate Change) by facilitating carbon credits to the state.

This experiment of bio briquetting through a manually driven machine has immense potential to address issues such as climate change, economic gain to villagers, forest improvement, forest fire control, and many other tangible and intangible benefits. National missions on climate change, such as the Green India Mission, and the mission for sustaining the Himalayan region, strongly support such types of activities that address development with sustainability, promote community-based management of ecosystems, provide incentives to communities for protecting and enhancing forest areas, and enhance carbon sinks and ecosystem services; this helps us to view forests as carbon sinks and formulate socially accepted and scientific fire-management strategies for protecting the Himalayas. The evolution of a manually operated bio-briquetting machine, especially for the Himalayan region, is an extremely useful preposition to fulfill any international or national level commitment towards climate change issues

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