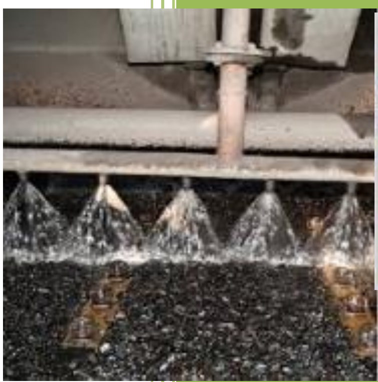
2020

Economic and Environmental Impact of Coal Washing in India



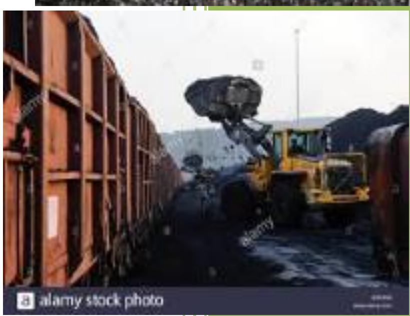


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Table of Contents

List of Tables

List of figures

Chapter 1: About the study

1.1 Introduction

Electricity plays an extremely important role for sustaining economic growth, social development and welfare of a nation. Coal based electricity is a dominant source of electricity generation in India and is expected to remain the primary source of electricity in the short to medium term.

Use of coal at the same time raises environmental concerns. The impacts of increased coal utilisation will have increased environmental impacts from emissions of air pollutants during coal mining, coal transportation and coal combustion, contamination of the surface and ground water, forest loss due to mining, etc.

In order to address the environmental challenges, Ministry of Environment Forest and Climate Change under the "Environment (Protection) Amendment Rules, 2015" specified revised limits in respect of four pollutants as well as specific water consumption for power stations. The existing stations as well as new stations including upcoming stations were required to comply with the new standards within 2 years of issue of notification i.e. by 7 December 2017. Table 1 presents the summary of the old and new emission norms.

Table 1: Old and new environmental norms for thermal power stations

	Category	**PM (mg/Nm3)**	**SOX (mg/Nm3)**	**NOx (mg/Nm3)**
Old Norms	TPPs greater than 210 MW	350	None	None
	TPPs with less than 210 MW	150		
New Norms	TPSs (Units) Installed Before 31.12.03	100	600 (For < 500 MW Unit)	600
	TPPs between 31.12.03 to 31.12.16	50	200(For => 500 MW Unit)	300
	From 01.01.17	30	100	100

Source: MoEFCC (2015)[1]

Notification with regard to water consumption include:

1. All plants with once through cooling (OTC) shall install cooling tower and achieve specific water consumption (SWC) up to maximum of 3.5 m^3/MWh within a period of 2 years from the date of publication of the notification.

2. All CT-based plants reduce SWC up to maximum of 3.5 m^3/MWh within a period of 2years from the date of publication of the notification.

[1] http://www. indiaenvironmentportal.org.in/files/file/Moef%20 notification%20-%20gazette.pdf

3. New plants to be installed after 1 January 2017 shall have to meet SWC up to maximum of 2.5m³/MWh and achieve zero waste water discharge.

The new notification implies huge investment on retrofitting and adding new pollution control technologies particularly to address the new PM and SOx emission norms. The status with regard to the implementation is still unclear. Till 2019, Electrostatic Precipitators (ESPs) in plants with aggregate capacity of 66 GW had either been upgraded or were planned to be upgraded, out of which 3.3 GW was in National Capital Region (NCR) while remaining 62.7 GW was across rest of India. ESP installation in nearly 2.4 GW of TPPs in Delhi NCR had been awarded. For the rest of India, ESP implementation plan was available for 61 GW of TPPs as presented in figure 1[2].

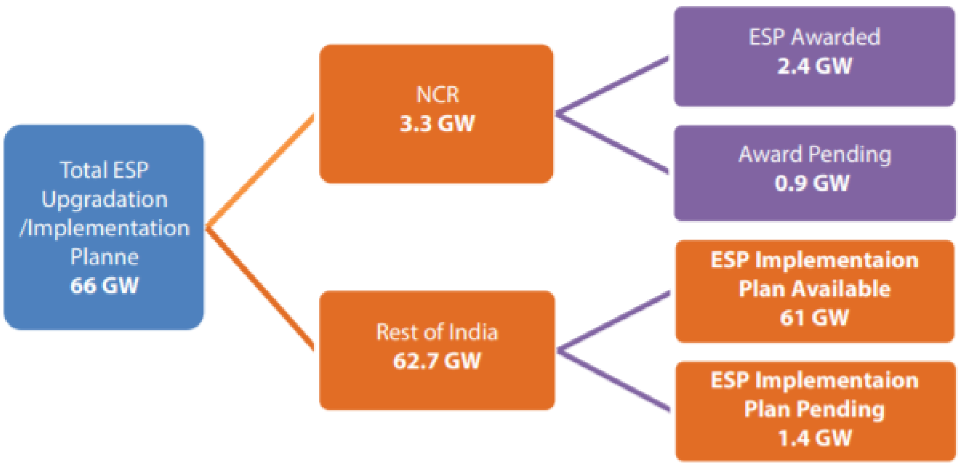


Figure 1: Status of ESP implementation in the country

An alternative cost effective route often professed is promotion of use of washed coal. It has come up in various pilot research analysis (Prasad, 2019) undertaken in the past that increased use of washed coal helps in reducing costs, improves environmental loads and also increases efficiency of pollution control devices.

MoEF&CC has issued a few notifications to mandate use of the washed coal although the guidelines have been revised periodically as provided in Box 1. However, MoEF&CC in its recent notification dated 21st May, 2020 has amended its earlier notification regarding use of coal with ash content less than 34%. The new notification allows use of unwashed coal by thermal power plants, without stipulations of ash content or distance.

[2] https://www.teriin.org/sites/default/files/2020-02/emissions-control-thermal-power.pdf

Box 1: MoEF&CC few notifications to mandate use of the washed coal

- In 2001, MOEF&CC issued the first set of regulations that mandated use of 34% ash content washed coal if transported more than 1,000 km or if burned in environmentally sensitive areas.
    - *Power plants using Fluidized Bed Combustion (CFBC, PFBC & AFBC) and Integrated Gasification Combined Cycle combustion technologies were exempted to use beneficiated coal irrespective of their locations.*

- In November 2014 directive for supplying coal of not more than 34% ash content for TPPs located beyond 750 km from the pithead with effect from January 1, 2015 and those located beyond 500 km from the pithead with effect from June 5, 2016.
    - *Further, the notification mandated that all new (as well as expansion) opencast projects of 2.5 million tonnes per annum (mtpa) and above capacity, which are not linked to pithead power stations, should be designed with integrated washeries.*

The domestic production of coal in India is dominated by non-coking coal and the reserves of coking coal are limited. The total coal consumption in India was 968 MT in 2018-19, out of which domestically produced 69 MT (7.1%) was coking coal, 715MT (74%) non-coking coal and 183 MT (19%)imported coal, which is coking coal (Ministry of Coal, Annual report, 2019-20[3]).

Indian coal is characterized having high ash content and low heat value in nature compared to coals of US or Australian origin. More than 90 percent of coal mined in India is produced from opencast mines contributing to inert contamination. Run of mine (ROM) coal extracted from opencast mines in India typically has ash contents in the range of 35 percent to as high as 50%, low and reducing calorific value (2500-4500 kcal/kg). Presence of high ash content is reported to lead to faster wear and tear of power plant components, difficulty in pulverisation, poor emissivity and flame temperature, low radiative transfer, generation of excessive amounts of fly-ash containing large amounts of un-burnt carbon, etc. Further, transportation of high-ash coal across long distances leads to increased cost because large quantities of non-combustible inert materials are also transported. It also leads to increased freight service demand causing excess pressure on the rail transportation. Transportation of inert materials also lead to additional consumption of energy due to rail and road transportation contributing to emission of carbon-dioxide (CO2) and other green-house gases (GHG) from the mode of transport (rail and road) (Prasad, 2019).

Review of studies brings out that coal washing lead to higher quality fuel with better heat value (could increase thermal efficiencies by as much as 4%-5% on existing pulverized coal-fired boilers with an accompanying reduction of CO2 emissions), reduces fuel quantity

[3]https://coal.nic.in/sites/upload_files/coal/files/coalupload/AnnualReport2019-20/Chapter6-en.pdf

requirements (handled and transported) and cost of transportation for the same energy value, enhances utilization of installed generation capacity, reduces capital expenditure in the power plant, , reduces ash volume in both pre-combustion and post combustion stages, and also reduces land requirement for ash disposal (particular in newer plants) (Criag D. Zamuda and Mark A. Sharpe 2007).

The benefits summarized in the in the EIA Guidance Manual – Coal Washeries published by MoEF&CC in 2010 are presented below.

- *Increased generation efficiency, mainly due to the reduction in energy loss as inert material passes through the combustion process*
- *Increased plant availability*
- *Reduced investment costs*
- *Reduced operation and maintenance (O&M) costs due to less wear and reduced costs for fuel and ash handling*
- *Energy conservation in the transportation sector and lower transportation costs*
- *Less impurities and improved coal quality*
- *Reduced load on the air pollution control system; and*
- *Reduction in the amount of solid waste that has to be disposed off*

In the presence of these possible benefits, thermal power stations (TPSs) have the following options that allow a power station to follow new environment norms:

1. By coal washing alone, if possible.
2. By coal washing and smaller retrofit/new pollution control equipment.
3. Only by bigger retrofit / new pollution control equipment.

1.2 Relevance of value chain assessment of use of unwashed vs. washed coal for power generation

The use of washed coal in India is still limited despite the benefits stated and supportive and mandatory policy interventions being in place for over two decades. This limited rate of establishment of coal washeries is often related to many economic, environmental and financial issues but one of the major issues is the perception that coal washing increases the cost of electricity generation which adversely impacts the plants using washed coal in merit order scheduling.

Based on discussion with key stakeholders and experts, trade in coal is based on coal preparation after mining that include washing post which the prices are fixed. Currently India's leading coal mining company Coal India Limited (CIL) offers both Run of Mine (RoM) coal as well as prepared/washed coal. It was reported that despite India's switching over to fully variable Gross Calorific Value (GCV) based grading of thermal coals from the earlier Useful Heat Value (UHV) system, the enhancement of the heat value/reduction of ash in coals after washing (of below G10 grade i.e. G11 to G17) is not off-setting the cost of washing and the economics is not favourable to coal companies. Because of this many power plants do not prefer using washed coal.

It is extremely important to acknowledge here that there are significant variations with regard to plant capacity, vintages, coal quality usage, and location of power stations from mining and washing sites, etc. Such complexities in the Indian power sector call for development of an integrated value chain framework and plant specific data analysis using that framework which will help in improved understanding of the impacts of use of washed coal over unwashed coal. Such an assessment will help in developing an implementation strategy of possible use of washed coal for all TPSs in India that is economically feasible and environmentally viable.

1.3 Terms of reference/Objectives

In line with the above discussion, the study aims to:

- Assess technological impact of coal washing
- Assess economic impact of coal washing on power generation
- Assess environmental impact of use of washed coal; (including environmental and economic impact of coal transportation in respect of raw coal and washed coal from coal mine to power plant)
- Explore the rationale for fixing threshold limit of maintaining 34% ash content in coal for transportation beyond 500 km limit

Chapter 2: Framework for integrated assessment

2.1 The overall assessment framework

Economic activities, particularly when it is linked to use of natural resources, not only have benefits but also costs linked to environment. Such costs may arise during the extraction phase as well as during the use phase of natural resources. In case of coal based power generation, there are potential benefits and adverse environmental impacts along the use of the unwashed coal vis-à-vis washed coal based value chain of electricity generation. With reference to objective and scope, the study has been divided into (i) economic and (ii) environmental impact assessment along the aforementioned coal based value chains.

2.2 Economic impact assessment framework

The impact of costs and benefits of coal washing for power generation is based on the value chain impact analysis. The associated costs and benefits are estimated for the shift from raw coal usage to washed coal usage at the power plant end. Economic impact is traced and measured by coal supply chains from mining, washing, transportation, and especially in the process of power generation.

In order to have a good understanding and analysis of the costs and benefits across the value chain, the relationship needs to capture the current/existing practices among each activity along the value chain, which is developed using secondary as well as primary data from the key stakeholders. Further, the economic analysis is based on technical evaluation and an integrated framework consisting of specific elements of the system is developed and demonstrated for the use of washed coal to the amount and proportion of costs in each value addition activity.

Economic evaluation of beneficiated coal is based on the results from improved coal quality and reduced ash content and detailed analysis is provided in Chapter 4. This chapter deals with economic impacts of coal washing up to 34 percent and 32 percent and presents the cost of coal beneficiation and its implications on transportation, cost build-up of landed coal to power plant, impact on variable cost of electricity generation for different capacity sizes, impact on fixed cost of power plants which were in pipeline as per National Electricity Plan (NEP). Economic assessment of the coal washing includes examining technical and economic parameters as under.

2.2.1 Coal Washing

The coal washing process depends on a number of factors, mainly the washability characteristics of input coal, ash content and moisture requirement of output coal, capital and operational costs, etc. The cost components associated with economics of coal washing are :

- **Capital cost**- cost towards design & engineering, civil works, plant and machinery, etc.
- **Operational cost** - salary & wages, consumables like water, energy, lubricants, magnetite, maintenance consumables, and washery overhauling charge, administrative expenses and miscellaneous charges, etc.
- **Rebate on washery rejects.**

2.2.2 Transportation

The benefit due to washed coal transportation depends on the distance of the power station from the loading point of mines/washery. The coal beneficiation process results in GCV improvement of coal which in turn leads to reduction of coal requirement to generate same quantum of electricity as well as savings in coal transportation cost.

2.2.3 Plant Operations

When the low ash coal is used for power generation, it impacts the technical operating parameters which results in decrease in operating costs and are reflected in the variable cost component of tariff. The incremental benefits from use of washed coal leading to better unit heat rate, improved aux. power consumption on the variable cost have been analysed on three variants of unit size of power plant i.e. 660MW (super-critical), 500MW and 300 MW (sub-critical). The three important aspects in this context are as under.

Fixed costs: The impact on fixed cost due to reduction in capital requirement for a power plant operating on washed coal can only be seen for the new power plants proposed. Improvement in capital cost of power plant, designed for usage of washed coal, is considered for overall impacts in fixed cost. Also, there will be additional benefits by use of washed coal such as reduction in land requirement for ash disposal for power plant using 34% ash coal instead of 41%[4].

Variable costs: Improved quality coal will lead to reduced coal consumption, improved heat rate, reduced auxiliary power consumption (APC), higher availability and life of equipment etc., to support unit generation.

Pollution Control Equipment (PCE) requirement: In order to comply with the new emission limits, Electrostatic Precipitator (ESP) retrofitting, new installation of Flue Gas Desulfurization (FGD) units and De-NOx systems are required. The impact of washed coal on emissions estimated using secondary literature.

[4]https://www.orfonline.org/wp-content/uploads/2017/07/ORF_Report_CoalBeneficiation_FinalForUpload.pdf

2.3 Environmental benefits assessment from use of washed coal

The environmental benefits in this study have been assessed from the reduced CO_2 emissions from the use of washed coal over the current mix of coal usage to produce the same level of electricity generated in 2018. Current practices majorly include consumption of raw coal and small share of blended and beneficiated coal. Out of the total 1,303 TWh of electricity generated in 2018, 985 TWh was from coal based power plants. The total coal consumption to produce 985 TWh of electricity was considered under the three scenarios to assess CO_2 emission. Improvement in specific coal consumption due to washing of coal has been considered to estimate coal consumption and CO_2 emissions across scenarios. The three different scenarios are described as:

- **BAU scenario (S1)**: The actual coal consumption of 2018 is used to estimate the overall CO_2 emissions from coal based thermal power generation. The ash content data of coal is available at the power plant use end which represents mixture of raw coal, blended coal and washed coal.
- **Washed Coal Scenario (34%)(S2)**: In this scenario, all the TPSs currently using higher than 34% washed coal (including blended coal) shift to coal containing 34% ash irrespective of plant capacity and the distance; while other power stations using coal having less than 34% ash content continue with that mix. The improvement in ash content also leads to improvement in specific coal consumption.
- **Washed Coal Scenario (30%) (S3)**: All the TPSs switch to coal having 30% ash; while other power stations using coal having less than 30% ash content continue with the mix, and the specific coal consumption is improved w.r.t ash content reduction.

The installed capacity and the electricity generation remains the same, however the specific coal consumption to produce them varies under the three scenarios which finally leads to a difference in the total coal consumption and thus CO_2 emissions at the country level.

The overall methodology used to assess the CO_2 emissions under the three scenarios is given in Figure 2.

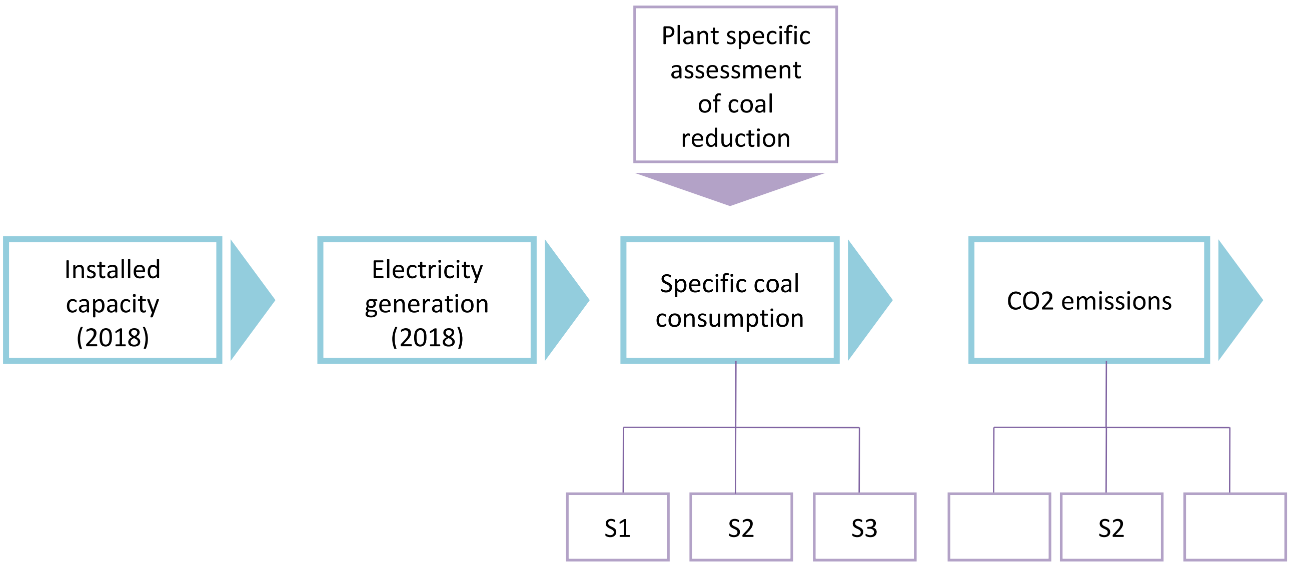


Figure 2: Overall methodology to assess CO2 emissions under each scenario

Once the CO_2 emissions are estimated under each scenario for 2018, the cost of climate change due to emission of $CO_2$was estimated as part of the study using the social cost of carbon based on estimates presented in (Nordhaus, 2017). Social cost of carbon (SCC)represents the economic cost caused due to an additional tonne of CO_2 emissions or its equivalent in the atmosphere. Though various models are used to estimate the monetary value associated with the cost of CO_2 emissions, using multiple assumptions, this study uses the estimates from Nordhaus (2017), which uses the DICE (Dynamic Integrated model of Climate and the Economy) framework. Therefore, due to the reduced CO_2 emissions under each scenario, a gap could be estimated leading to an incremental environmental benefit.

Chapter 3: Coal Washing Technology (Practice and Policies)

The global coal washing technologies as well as the technologies used in India are presented in this chapter on the basis of secondary research and stakeholder consultation. Coal preparation process includes a range of methods such as (a) crushing; (b) screening into different size fractions; (c) washing (physical, chemical and mechanical); (d) dewatering; (e) thermal drying (f) blending (g) waste disposal, designed for a specific particle size range such as coarse (>10mm), medium (>1mm), fine (1-0.15mm) and ultra-fine <0.15mm). Coal beneficiation starts with preparation process by crushing and screening of ROM coal, which removes some of the in-organic material. Coal is then advanced for washing process which predominantly involves using water and mechanical techniques to remove the impurities (mainly minerals, ash and sulphur -to some extent) from raw coal. As a result, the process improves the heat content of coal on weight basis.

The choice of technology and process design for the beneficiation depends on a number of factors such as (IEA Clean coal centre, 2017):

1. Washability characteristics of the raw coal feedstock
2. Percentage fines content of the ROM coal, which is dependent on the extraction technique, and results in carbon losses
3. Assessment of coal quality over a longer period
4. Market, regulatory and taxation environment
5. Capital and operating costs for the selected coal preparation plant (CPP) design;
6. Projected value of the separated coal products
7. Cost of waste treatment and disposal.

These factors may vary from country to country and hence, the technology and process design needs to be carefully considered before adoption. The section below will focus on the present status of washing technology used in India & abroad and the supporting policies.

3.1 Coal Washing Technologies

The physical separation process is the most common method for washing coal particles due to its efficiency and optimal yield attainable at a wide density cut-point range[5]. Within this, dense media separation technologies are mostly deployed world-wide in wet beneficiation methods. Gravity separation using air as media are commonly used in dry separation methods. The dry-beneficiation methods are cost effective compared to dense media separation methods. However, globally, these were considered to be much inferior to wet

[5] https://www.iea-coal.org/report/coal-beneficiation-ccc-278/

processing methods but are better than simple de-shaling of coal. In wet separation, particle separation efficiency (Ep)[6] is normally in the range 0.01–0.05, while for dry methods the reported range of 0.07–0.25[7]. Also, extensive gas and dust handling needs to be done for operating in dry conditions. Over the years, due to growing concerns on water availability and climate change, there is an emerging trend to adopt dry separation technologies in certain regions supported by further & innovation and development. The particle separation efficiency difference between wet and dry methods has also reduced substantially and so the adoption.

3.1.1 Wet Beneficiation technologies

Under the wet beneficiation process, jigs and dense media bath technologies are commonly in practice for washing coarse coal (exceeding 10mm) and medium coal (1-10mm).

i) Jigs (Pulsating water as media (Batac/ Baum)
ii) Dense –media separation
   a. Dense/Heavy Media Vessel or Baths,
   b. Dense/Heavy Media cyclone
   c. Combination of above)

Jigs

Jigs are commonly used for washing coarse coal. Its operation depends on stratification in a bed of coal based on specific gravity when the carrying water is pulsed. The shale tends to sink and cleaner coal rises due to specific gravity difference to water. There are two types of Jig commonly practiced; which are Baum and BATAC Jig. Even though, Baum jig can clean a wide range of coal particle sizes, it is most effective at washing 10-35mm (CIL, 2020). However, BATAC jig is suitable to wash medium coal (less than 10mm) as well. Hard dense minerals like feldspar, etc. are also used for enhancing the stratification and prevent rejigging, which is suitable for medium coal washing.

Dense media separation

Dense/Heavy Medium vessels also operate by specific gravity difference; however rather than using water as the separating medium, a suspension of magnetite and water called pulp is used. The dense-media washing process typically rejects about 20–40% of the ROM coal feed[8]. Different types of vessels are used for dense-medium separators such as baths, cyclones and cylindrical centrifugal separators. For coarse coal washing, various kinds of baths are used, but substantial quantity of dense- medium, and therefore magnetite is required for its operation. Hence the control and recovery of magnetite is at-most important

[6]The effectiveness of a coal separation method may be assessed by examining the particle efficiency (Ep) value; this provides a measure of the particle density difference at 25% and 75% coal partition. Lower Ep values indicate a more efficient separation and low ash content.
[7] https://www.iea-coal.org/report/coal-beneficiation-ccc-278/
[8] https://www.iea-coal.org/report/coal-beneficiation-ccc-278/

from operations perspective. For smaller sizes, cyclones are used where the settling time is short and throughput is relatively high. The centrifugal effect created by vortex when pulp is passed through inlet pipe of cyclone, separates the light carbon particles and high density shale at wide range of density-cut points (1.3-1.9) and at high separation efficiency (0.02-0.03). It can also process high near gravity material coal (NGMI -10 or more) at lowest Ep. Cylindrical centrifugal separators are used for coarse and intermediate coal.

While dense media both provides better separation efficiency while washing coarse coal but in case of fine and ultra-fine particles, dense media techniques are not suitable due to requirement of long settling times and low coal recovery rate. Also for the ultra-fine coal particles, dense media separation couldn't be carried out based on density cut as difference range is very small. Thus, for the separation of fine & ultra-fine particles, technologies such as spirals, water only cyclones and flotation techniques (suitable for ultra-fine particles also) are commonly practiced across the world.

Concentration table

In a concentrated air table separator, tables are tilted, ribbed and they move back and forth in a horizontal direction. The feed and dense media is fed to the separator. The lighter coal particles settle to the bottom of the table, while the heavier particles (rejects) are collected in the ribs and are carried to the end of the table. Even though, the capacity is quite small; the fine coal (upto density cut 1.5) can be clean cost effectively by this unit.

Hydro cyclones

Hydro-cyclones are water-based cyclones where the heavier particles accumulate near the walls and are removed via the base cone. Lighter (cleaner) particles stay nearer the center and are removed at the top via the vortex finder. Thus, the cyclone diameter has a significant influence on the separation efficiency.

Flotation

The floatation technique is another method for cleaning fines and ultra-fine coal particles. There are two types of floatation methods; Column and Froth flotation. Froth flotation cells, the widely used technique within, utilize the hydrophobic property of coal particles to separate and the method is suitable for washing ultrafine particles as well. The coal-water mixture is conditioned with chemical reagents so that air bubbles will adhere only to the coal and float it to the top, while the high dense particles sink. Air is bubbled up through the slurry in the cell and clean coal is collected in the froth that forms at the top. This type of cleaning is very complex and expensive and is principally for metallurgical coals.

Spirals

Spiral separation is internationally practiced method for fine coal washing in which coal-water slurry is fed into a spiral conduit. As it flows downward, stratification occurs for the heavier particles which will concentrate in a band along the spiral. An equipped adjustable splitter separates the stream into two product streams – a clean coal and the rejects.

3.1.2 Dry beneficiation technologies

Dry separation techniques are based on exploiting different aspects of coal particle properties such as coal density, particle shape, friction, electrostatics, and magnetism. Major dry beneficiation technologies deployed across countries are:

1. Air dense media fluidized bed separation (ADMFB)
2. Fluidized bed separation
3. Compound dry separation – Air Jigs, concentration air tables, FGX separator, TFX-8 AIR jigs, Pneumatic sorter etc.

These dry beneficiation technologies are used for beneficiation of coarse and medium coal particle sizes. Out of these, compound dry separators are the dominant ones which mainly use the particle friction, shape and density of coal particles.

Air dense media fluidized bed separation

This dry coal preparation technique uses a pseudo fluid system of the mix of dense medium (fine magnetite powder) and screened coal (6-50mm) as separating medium, to process a certain density cut and thus separate light and heavy particles according to density from stable and uniform air-solid suspension in fluidized bed. The low-density material floats up to the top and the high-density material sinks down to the bottom based on Archimedis principle. The Indian scholars have tested this method with high ash coal and the separation results show that the ash content is reduced from 40% to around 32%–35.5% and separate clean coal product with a 60 %–72 % yield and high separation efficiency (Ep value is 0.12)[9].

Air Jig

The Air jig operates using similar mechanism to that of a wet jig but here, the water is replaced by compressed air. In the separating process the screened coal is fed into the separator from a hopper and exposed to a combination of vibration and air pulses through a perforated table. Light particles are lifted upward at a higher elevation than the dense particles, loosened and stratified due to its relative density before it is separately collected using scrapper.

FGX dry beneficiation

An FGX dry beneficiation is a density-based method which operates by integrating two separation mechanisms i.e. air fluidized bed and a conventional air table separator. It is more efficient and has better dust control. There are more than 2000 FGX separators

[9] https://link.springer.com/article/10.1007/s40789-014-0014-5

installed in China and other coal producing countries[10]. This is because; it separates at typical relative density of 1.8 to 2 and shows relatively high particle efficiency Ep values of 0.2 to 0.3. However, the technology is restricted to process of coarse coal 6-80mm size range mainly due to the operational difficulty when the particle size changes with high proportion fines.

Other Key developments

The TFX-8 AIR jig is capable to process extended range of coal particles with an Ep value of 0.2, which is comparable to FGX unit. The experience of the technology with high ash Indian coal shows that it can achieve ash reduction from 42% to 27% at 59% yield, middling having ash content 55% at 22%yield and rejects having ash content 73% at 19%[11] yield. Several developments are also there in with dry fine coal treatment technologies such as tribo-electrostatic and magnetic separators but not commercialized yet due to its cost[12].

Also, fine coal beneficiation with the application of a Pulsing ADMFB, pulsing air flow with periodical velocity is introduced to air dense medium fluidized bed (ADMFB) to separate fine coal by changing the velocity and pulsation frequency of air flow.

Recently, X-ray optical sorter is getting greater attention as it could separates the heavy particles and light particles based on the color change occurred due to different radiation absorption potential. This is under trial in different parts of world (CIL).

3.1.3 Global Washing technology

Globally, there is lack of uniformity in the coal characteristics especially the quality of input coal and the washability characteristics due to the formation of coal. Hence, for the determination of technology and process design of coal beneficiation, these are factored. A summary of the key washing technologies deployed world-wide are shown in the table 2 below:

Table 2: Country-wise coal washing technologies in practice

Countries	Coarse washing	Medium washing	Fine washing
Australia	Mainly by DMC (diameter 1000 mm or more), Drums or baths in some plants, Jigs at few plants.		Spiral + Jameson or micro cell technology Froth flotation
China	Mainly jigs (60%), Dense medium separator (Drewboy, vertical lifting wheel separator)	2-product dense medium cyclones (diameter 660–1300 mm) 3-product dense medium cyclones (diameter 1000–1400 mm)	Mainly flotation Column flotation (for very fine coal)
USA	Dense medium vessel	Dense medium cyclones	Water-only cyclone Spirals

[10] http://www.fgxseptechllc.com/dry-coal-processing/separators/
[11] https://www.iea-coal.org/report/coal-beneficiation-ccc-278/
[12] https://link.springer.com/article/10.1007/s40789-014-0014-5

Countries	Coarse washing	Medium washing	Fine washing
		(diameter<1000 mm)	Combination of both froth flotation (very fine coal after desliming: 35–40 μm)
Russia	Heavy media baths & cyclones, Jigging, Flotation, High-angle separators (water-only cyclones), Spiral separators, Pneumatics (for thermal brown coals)		
Canada	Dense medium vessel	Dense medium cyclones (diameter <1000 mm)	Water only cyclone, Spirals, Combination of both Froth flotation (very fine coal)
South Africa	Mainly large diameter pump fed dense media cyclones, Dense medium separator (Wemco Drum, Drewboy), Jigs at few plants	Smaller diameter cyclones	Limited use of froth flotation Mainly spirals
India	ROM jigs (moving screen jig), Coarse coal jigs, Dense medium separator, Barrel washer	Small coal jig, Dense medium cyclones (diameter 600–1000 mm)	Flotation, Spirals, Water only cyclones

Source: (IEA Clean coal centre, 2017)

3.2 Global benchmarks and coal washing

Number of coal producing countries have been involved in coal-washing practices to meet the benchmarks standards for exporting thermal coal and to obtain desired quality (GCV) and characteristics (Ash %). Table 3 below compares the thermal coal quality standards of some countries.

Table 3: Country-wise ash content and energy Content of thermal coal[13]

Coal benchmarks	Energy content (kcal)	Ash Content (%)
Australian thermal export coal benchmark	6000	12-14%
Australian thermal export coal secondary benchmark	5500	20%
Indonesian thermal export coal	4500-5000	2-10%
South African thermal export coal	6000	15%
Russian thermal export coal	6500	10-25%
China domestic thermal coal	4000-5500	20-40%
Indian domestic thermal coal	4400	25-45%

It can be inferred that Australian coal has high energy content and thus require lesser quantity to produce similar unit of electricity, which is the reason Australia stands second in exporting thermal coal after Indonesia, which provide better environmental outcome as a result of lesser ash content in coal. Since, countries seeking to limit the externalities from coal fired power plants, aggressively banned imports of high ash and sulphur containing coal which necessitates the washing of coal for the export dependent countries. Interestingly,

[13]https://ieefa.org/wp-content/uploads/2015/10/IEEFA-Australian-coal-briefing-note.pdf

South African thermal coal reserves contain high ash content, but still majority of coal is processed to obtain the export grade coal at much lower yield and the intermediate product so-called middlings are utilized for domestic thermal power generation. While the countries like China and USA having 1380 MT/y and 636 MT/y of coal washing capacity (2015), has not much to do with the exports but the pricing, environmental targets and efficiency which drives the coal washing chain.

The scale of coal washing deployment in some countries is steered by the energy and environmental policy regulations for the operations of thermal coal, while some countries engaged in coal washing practices to maintain the competitive share in international export markets.

An overview of the global coal washing practices has been presented above. However, for proper assessment with regard to benchmarking and related policies for promoting use of washed coal needs interaction and consultation with International/national experts.

3.3 Coal washing in India

Indian coal has general properties of Gondwana coal, having high ash content (35-55%), high moisture content (4-20%), low Sulphur content (0.2-0.7%) and low calorific value (between 2500- 5000Kcal/kg), which is much less than the normal range of 5000 to 8000 kcal/kg observed in other countries. Also, more than 75% of the Indian coal has ash content more than 30%, even as high as 50%. It also has poor washability characteristics (i.e. low Near Gravity Material Index (NGMI) and Govindarajan Washability Index (GWI)) and high level of rejection >30% due to distribution of ash also challenge the washing economics[14][15] (IEA Clean coal centre, 2017) (DOI, 2018). The Indian washery owners/developers underlined that with each percentage decrease in ash content in washed coal, there is considerable decrease in yield of clean coal.

Currently, technologies such as barrel washer, coarse coal jig for de-shaling; Jigs (Baum/BATAC/ROM/AIR), Dense media bath, cyclone for coarse and medium coal treatments, water only cyclones, classifying cyclones, spiral concentrator, froth floatation cells, Hydraulic hindered bed or Teeter bed separators, vibrating tables for fine coal treatment are adopted and preferred by Indian coal washeries (Global mining, ACB, CIL 2020) but due to costlier and complicated technology, fine coal treatment is not carried out at scale in India. Heavy media cyclone is the most favorable process as it is able to wash high NGMI coal at high separation efficiency (low Ep).

[14] https://www.iea-coal.org/report/coal-beneficiation-ccc-278/
[15] https://doi.org/10.1016/B978-0-12-812632-5.00009-4

Ultrafine technologies are not adopted in India yet due to the requirement of complex technology and unviable economics due to washability characteristics.

Table 4: Applicable technology as per NGMI rating (Mahavir Coal washery, 2015)

NGMI	Type of coal	Process
0-7	Simple coal	Jig
7-10	Moderately difficult	Bath, tables, spirals
10-15	Difficult to wash	HM Cylone
15-20	Very difficult	
20-25	Exceedingly difficult	
>25	Formidable	

3.3.1 Reject utilization: Technology and Practices in India

The washery rejects are discarded in considerable quantities during the process of beneficiation. Typically, it contains combustible matter with heat content below 2200 Kcal/kg with corresponding ash content of more than 60% as ideal separation of organic and in-organic matter doesn't takes place in physical separation(ACB,2020) (ORF, 2017). However, the quantity generated and GCV of washery rejects are based on the input coal washability characteristics, ash content in ROM coal, ash content requirement in output coal, selection of technology, washing process design etc. The rejects thus generated can potentially be used in FBC boilers (BP Singh, 2007) such as the following technology alternatives for captive power generation for ash content upto 65%.

i. Atmospheric FBC,
ii. Bubbling Fluidized Bed Combustor (BFBC)
iii. Circulating Fluidized Bed Combustor (CFBC)
iv. Pressurized Fluidized Bed Combustor (PFBC)

Use of coal rejects in highly efficient FBC plants reduces the CO_2 emission and use of the lime stone or dolomite feed reduces SO_2 emissions significantly. According to Bureau of Energy Efficiency (BEE), advantages of FBC plants are listed below[16]:

- The boiler can firecoals with ash content as high as 62% (also fines < 6mm) and having calorific value as low as 2,500 KCal/kg.Even carbon content of only 1% by weight can sustain the fluidized bed combustion.
- Combustion efficiency of over 95% irrespective of ash content and operate at overall efficiency of 84% (plus or minus 2%). Resulting in fuel savings of 4% at elevated pressure operation which also reduces CO_2 emissions.
- High turbulence of the bed facilitates quick start up and shut down. Inherent high thermal storage characteristics can easily absorb fluctuation in fuel feed rates. Response to changing load is comparable to that of oil-fired boilers.

[16]https://beeindia.gov.in/sites/default/files/2Ch6.pdf

- The absence of moving parts in the combustion zone results in a high degree of reliability and low maintenance costs
- Since the temperature of the furnace is in the range of 750 – 900 °C in FBC boilers, even coal of low ash fusion temperature can be burnt without clinker formation thus making ash removal easier, may automated and reduce associated costs.
- SO_2formation can be significantly reduced by addition of limestone or dolomite for high sulphur coals. Low combustion temperature eliminates NOx formation.
- The CO_2 in the flue gases will be in the order of 14 – 15% at full load. Hence, the FBC boiler can operate at low excess air (only 20 - 25%).

The remaining rejects having low GCV (typically less than 1500 kCal/kg) are presently used for backfilling purpose at mines as it is less prone to self-combustion and other safety issues.

A technical committee constituted in 2018 provided the relevant recommendation to MoC with respect to utilization of Coal washery rejects which is reproduced below:

"A threshold for GCV of washery rejects as 1500 kcal/kg may be considered presently and rejects having GCV 1500 kcal/kg and above may be used in FBC/CFBC based power plants whereas rejects of GCV less than 1500 kcal/kg (i.e. low GCV rejects) may be used as replacement of construction material for highways, railways, dams, embankments, reclamation of land, brick making etc. Globally also, coal washery reject is being used as a replacement of construction material in many countries. Coal washery rejects along with biomass may also be used as briquettes for generation of cooking gas."

Based on inputs from stakeholders, it can be inferred that FBC based power plants, construction/infrastructure sectors and domestic fuel producers are the potential consumers of the coal washery rejects. Some current reject utilization practices in India are:

- Rejects from existing Piparwarwashery are being sold to consumers through e-auction. Presently, the GCV of the rejects falls under Grade G-14 to G-16.
- Rejects from existing Gidiwashery were handled by Gidi Reject based FBC CPP which was designed to handle coal washery rejects with GCV varying from 1500 to 4000 kcal/kg. The minimum GCV of rejects fed in the past in Gidi CPP was about 1629 kcal/kg. However, the same is not operational since 3.01.15. Presently, Gidiwashery rejects are collected on surface dumps prior to disposal/sale.
- Rejects from existing Global Coal Mining Washery in Talcher are being sold to Indian Metal &Ferrous Alloys (IMFA) to be used in CFBC boiler in their captive power plant. The GCV of rejects is around 1800kcal/kg with 65% of ash which is blended with high quality coal for operating at designed configurations.

3.4 Pricing of thermal coal and regulations– Global vs India

Encouraging the use of better quality coal is considered as one of the easiest ways to reduce the negative externalities associated and to reap operational and economic gains through-out value chain. Therefore, better pricing and stringent regulations on coal and its usage have due importance in mitigating the impact on environment. For this, it is important to draw learning from international experiences for addressing environmental concerns in the Indian context through pricing of non-coking coal and regulations for its usage. In many of the coal producing countries, the pricing of non-coking coal is based on an elaborate manner taking into consideration the sustainability issue which is discussed in the table 5below.

Table 5: Global experience in coal pricing to reduce the negative externalities

Country	Key pricing interventions to accommodate environment aspect
Poland	Coal price is a function of four quality parameters: heat value, ash+ sulphur and moisture (heat/freight loss). Also, three ash content ranges were applied to encourage coal cleaning. There is a 2 percent improvement in price for marginal decrease in ash content. This increase in price was designed to compensate the cost of beneficiation.
Indonesia	Benchmark coal pricing, price imposes penalty for high sulphur (emission), moisture (heat/freight loss) and ash to account for the particulate emissions and for disposal cum storage of ash.
United Kingdom	Ash penalty on utilities for disposal (landfill tax) in addition to actual ash disposal cost.
United states	Determined in the free market, based among others on environmental issues and on the quality of coal: calorific value, sulphur and ash content. Thermal power plant is heavily penalized, for emission of every additional tonne of CO2 beyond the prescribed limit under pacific coast action plan
China	Besides production cost and labour cost, price component consists of resource cost, environment cost, sustainable development cost and safety cost. Sustainable cost component is levied based on type of coal and tonnages consumed. Utilized for solving regional ecological/environmental problems.

Source: (Rachit Tiwari, 2015)

In India, the pricing of non-coking coal is based on its heating value (GCV), discounting the ash and moisture. Prices are notified for various GCV bands/grades, uniformly spaced at an interval of 300kCal/kg ranging from 2200 kCal/Kg to 7000kCal/kg. The price increases according to the heat content of the coal and vice versa which encourages consumption of low priced coal in general.

For an Indian coal, having approximately same ash content, GCV is found to be varying up to 900 Kcal/Kg which creates an incentive to disregard the negative externalities in handling and use of coal caused through-out value chain. The cost of beneficiation is also fixed by individual washeries, irrespective of the heat content of washed coal. This leads to utilities paying cost which is not commensurate with the heat value of washed coal. The prevailing generation scheduling based on merit order dispatch (based on variable cost) also discourages the use of washed coal. On the other side, the emissions are per se regulated by government through coal ash content and emission norms for coal based power plants. However, as of now there are no-penalties for non-compliance of emission norms. The government has mandated the coal based power plants beyond 500 km from sources to use raw coal or blended coal or beneficiated coal with ash content not exceeding 34% on quarterly average basis[17] (MoEFCC, 2015). Hence, there is a need to look at a proper pricing structure of washed coal, penalty for non-compliance of emission norms, and uniform reject utilization policy.

[17]http://www.indiaenvironmentportal.org.in/files/file/supply%20and%20use%20of%20coal%20with%20ash%20content%20MOEF.pdf

Chapter 4: Economic Impact Assessment of use of washed coal for Power Generation

4.1 Introduction

Coal beneficiation is one of the ways to improve heat value of coal used in power plant. As discussed in preceding chapters, coal washing removes dust/overburden and rock sediments from the coal which leads to improvement in the heating value of coal resulting in environmental as well as economic benefits at various stages of value chain. The economic impacts have been analyzed historically. At Satpura Thermal Power Station, in one 210 MW unit, trial of beneficiated non-coking coal from Nandan washery, WCL was carried out for one month under a science & technology project by the expert team represented by CMPDI, WCL, CEA, MPEB and NPC where benefits have been observed in all the areas of environment, economics, quality power generation, etc. A study conducted by CMPDI in 1998 for a group of coal based thermal power plants located at a distance beyond 1000 km from the source coal pit-head also suggested similar improvements. The detailed findings are given in Annexure 2. The Ronghe Committee report (1998) on economic benefits of using beneficiated non-coking coal in thermal power stations appraised the techno economic benefits for two power plants namely Kayamkulam & Yamunanagar.

Coal washing results in improved GCV, lesser ash content. It also shows improvement in heat rate and specific coal consumption at generating station end. This chapter analyses economic impacts of coal washing up to 34 percent and 32 percent and highlights the cost of coal beneficiation and its implications on transportation, cost build-up of landed coal, impact on variable cost of electricity generation for three representative unit capacity sizes, impact on fixed cost of power plants which are in pipeline as per under National Electricity Plan (NEP), 2018. Other economic impacts like less ash disposal area requirement and enhanced service life with improved efficiency of plant and machineries have not been considered in the present study due to limitation in collection of primary data[18].

While taking the learning from previous studies and empirical analysis, interaction was done with key stakeholders such as CIL, CMPDI, NTPC, BHEL, and MOEFCC and sector experts. Latest available data has been used to conduct analysis considering that the Indian thermal power generation and coal sectors have witnessed changes which have a bearing on power generation and emissions. The factors involving economics of power generation such as quality and cost of raw coal, cost build-up of coal supplied, railway freight, tax structure,

[18] https://www.researchgate.net/publication/279848475_Economic_Assessment_of_Utilization_of_Beneficiated_Indian_Power_Coal_for_Thermal_Power_Generation

have, over the years been periodically revised/increased. Deployment of higher sized and more efficient generating units, cost of complying to prevailing environment pollution control norms have also impacted economics of power generation

Improvement in GCV and ash content in the washed coal vis-a-vis RoM coal are extremely important factors in the context of use of beneficiated coal for power generation. GCV being a function fixed carbon, volatile matter, inherent moisture and ash, estimation of ash% in any grade of coal is a challenge, more so because of the GCV spread of 300 kCal/kg in each grade. In absence of primary data of proximate analysis, we have relied upon secondary data for drawing relationship between Ash% and GCV of coal.

To analyze economic impact of washed coal for various ash% improvements, distance from mine/washery to power plant, and type of generating unit, a framework for integrated assessment across the value chain has been developed. The framework has been developed to study the results for three variants of unit size of power plants i.e. 660MW (super-critical), 500MW and 300 MW (sub-critical). Based on this framework, the cost build-up of landed ROM coal and washed coal, and their impact on variable cost of power generation have been presented in this chapter.

4.2 Grade wise coal GCV, its ROM cost and ash content

The quality of coal plays an important role in the regard to environmental impact of a thermal power plant. Due to drift origin of Indian coal, inorganic impurities are intimately mixed in the coal, resulting in difficult coal characteristics. In India, coal quality varies in a wide GCV range of 7000-3000 kCal/kg. Indian coal has been classified by CIL in various Grades starting from G1 to G17 as per the GCV range of coal. In Indian power sector, mostly G11, G12, and G13 grades of coal (GCV range of 3400-4300 kCal/kg) are used for power generation. CIL issues the Grade wise pithead Run of Mine (ROM) coal price applicable for various coal fields. In our modeling framework, we have considered pithead ROM coal price from CIL notification on dated 8 Jan’2018[19].

4.2.1 Relation between ash content and GCV of coal

GCV of coal depends on the percentage / composition of four components, fixed carbon (FC), volatile matter, inherent moisture and ash. Proximate analysis of coal gives the value of this composition of coal in terms of these components. In the absence of proximate analysis for various grades and GCV of coal, Ash% vs GCV correlation developed by using CMPDI data and the correlation presented in the NIT, Rourkela study[20]has been used in the study (figure 3).

[19]https://www.coalindia.in/DesktopModules/DocumentList/documents/Price_Notification_dated_08.01.2018_effective_from_0000_Hrs_of_09.01.2018_09012018.pdf
[20] http://ethesis.nitrkl.ac.in/6858/1/PREDICTION_Seervi_2015.pdf

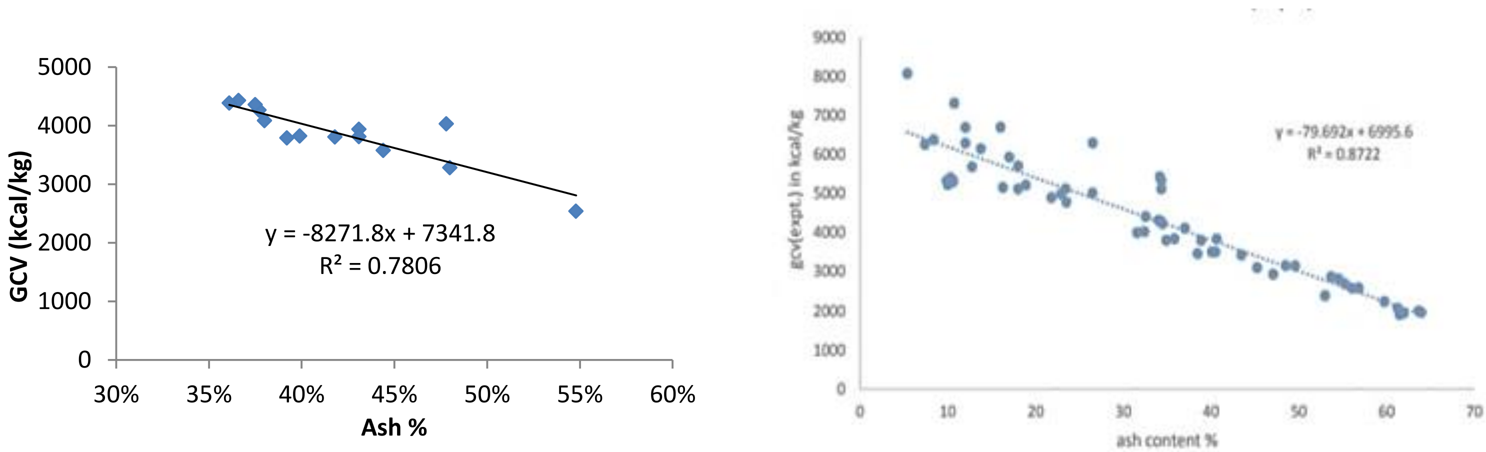


Figure 3: Relation between Ash% and GCV of coal developed using CMPDI data - TERI analysis (left), Relation used by NIT Rourkela study (right)

Of the two, relationship reported in NIT Rourkela study has been considered for analysis view of higher number of sample points, greater variability in ash% versus GCV as well as better fit (R^2= 0.872).

4.2.2 Cost of coal washing

In India, non- coking coal washeries are designed and set up to beneficiate high ash content coal (38%-55%) to ash not exceeding 34% in order to comply with the norms for coal usage in power plants located beyond 500 km from the pit-head. The process design and equipment selection for the coal beneficiation plant depends on a number of factors, mainly the washability characteristics of input coal, ash content requirement and moisture of output coal, capital and operational costs, projected value of output coal, etc.

Generally, the cost of washing consists of capital costs and operational costs, and total cost of washing depends on the project model. This also includes the additional capital and operational costs incurred for water treatment process and costs for pollution control. In India, washeries have been set up under different models such as Build, Operate, and Maintain (BOM), Build, Own, Operate (BOO), turnkey basis. Historically, washeries were set up by CIL majorly under Build, Operate, and Maintain (BOM) concept where the selected bidders needed to install the washery, and operate and maintain the same for initial period of 10 years with a provision for further extension of 5 years[21]. Under this model

- Finance for projects developed through BOM model was required to be provided by CIL or its subsidiaries.
- The power plants needs to sign contract with CIL or its subsidiaries, if they require to beneficiate the input coal from CIL owned washeries.

[21] https://books.google.co.in/books?id=M-hODQAAQBAJ&pg=PA165&lpg=PA165&dq=boo+model+washery+india&source=bl&ots=fo3CJE2wSz&sig=ACfU3U3dtp7LbbpiCjOcsXPTCKL3j8A09Q&hl=en&sa=X&ved=2ahUKEwinnuOymJrpAhXDxTgGHa-GDBMQ6AEwBHoECAoQAQ#v=onepage&q=boo%20model%20washery%20india&f=false

- Since ownership of washery and coal production are with same entity, the cost of washed coal from their washeries is used to be notified instead of charging cost of beneficiation and cost of input ROM coal separately.

Since 2003, considering the funding constraints of CIL, GOI has been encouraging adopting BOOM and turn-key model to speed up development of CIL's nine planned non-coking coal washeries. Many private players such as ACB (India) Ltd, Global washeries etc. have already set up their washeries on Built, Own, Operate and Maintain (BOOM) model which attracts financing from private sector.

Under such model the practice was that,

- The power plants need to sign separate contracts with coal producing company for procuring ROM coal and with washery to beneficiate the coal procured.
- Since ownership of washery is with different entity, the cost of washing is charged separately unlike in the BOM model.

The detailed break-down of cost of washing (capital and operational costs) of a typical washery are discussed here in after.

4.2.1.1 Capital costs

The capital cost of washery typically includes costs of land and plant &machinery. In India, jigs and dense media separation process are commonly followed. On the basis of stakeholder consultations with private and public sector coal washeries and pre-feasibility reports of various washeries, the capital cost of washeries is noted to be typically in the range of Rs 18 - 35 Cr/ MTPA for commonly used De–shaling/Jigs based plants to dense media separation-based plants. The cost of financing also has an impact on the capital costs. However, typically it amounts to around 25 – 50 Rs/Tonne of throughput coal. The table below provides the components in capital costs and its respective share for a typical dense media separation based plant.

Table 6: Cost components in capital costs and its respective share in percentage

S n:	Cost components	Percentage Cost (%)
1	Design and engineering	1-2
2	Building and structural (incl. Furniture, fittings and electrical)	40-45
3	Plant and machinery (including pollution control equipment in washery)	54-58

Source: Authors estimate[22]

[22] Compiled data from washery stakeholders, prefeasibility reports prepared by CMPDI and private companies for setting up washeries.

4.2.1.2 Operating costs

The operating cost of the washing includes salary & wages, consumables (Incl. magnetite, flocculants, lubricants, electricity, maintenance (incl. spares), washery overhauling charge, administrative expenses and miscellaneous charges. Altogether, it ranges between Rs 80-120/Tonne of raw coal for beneficiating coal having ash content of 42% to 34%. Composition of operating costs for a typical dense media separation equipped washery is shown in figure 4. For de-shaling or Jig based plants, the operational cost reduces by Rs 20-30/Tonne of raw coal as the magnetite is not required and so the magnetite recovery process. However, as discussed in chapter 3, de-shaling or Jig based plants have certain limitations to efficiently beneficiate coal with high ash, low washability characteristics.

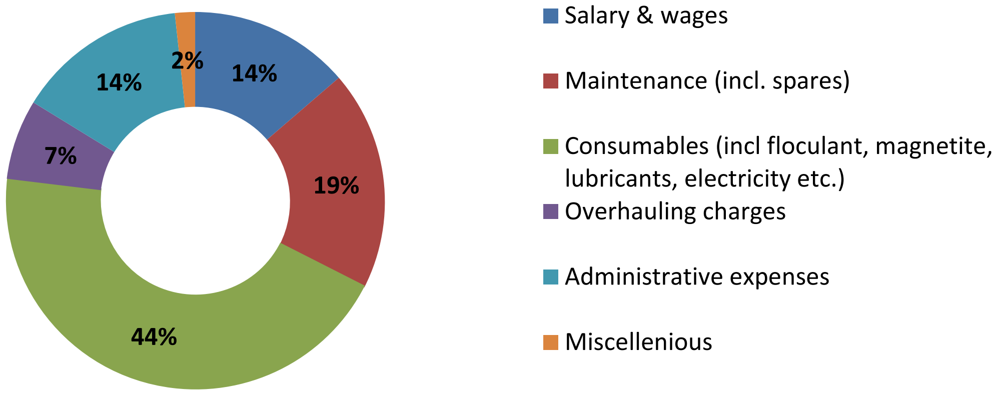


Figure 4: Composition of operating costs for a typical dense media separation equipped washery

Source: (CMPDI) (MAHAVIR COAL WASHERIES PVT. LTD, 2015)

Overall, the most important parameters which affects the technology/process selection and so, the cost of washing are washability characteristics& ash content of ROM coal, target ash content of output coal The total cost of coal washing in the market typically ranges in Rs 90-160/Tonne throughput of raw coal (incl. GST). Out of the total cost of washing, the operational cost is the major component which comes around 70-80%[23] and the fixed cost is comes around 20-30% for majority of the projects. GST on coal washing is currently being charged at 18% slab.[24]

4.2.1.3 Price added to ROM and comparison with data from secondary sources

As discussed in previous sections, washing of coal generally costs around Rs 90-160/Tonne. The landed cost of washed coal at the power plant includes impact of clean coal yield which is a function of input coal characteristics such as ash % and extent of washing. To take clean

[23] Assumption includes loan repayment period@ 12 years, interest on loan @11%, depreciation upto 90%, debt: equity@ 70:30 and 100% equity (BOM), return on equity @12%, economic life of project 15 years.

[24] For the process of washing ROM coal having ash content of 42% to beneficiate to 34%

coal yield in to account, we have developed a correlation between input ash content and clean coal yield for washing upto 34%, 32%, 28% and 25% ash using data of CMPDI.

4.3Relation between Ash percentage and clean coal yield at different level of washing

Due to high degree of ash content in Indian coal, there is comparatively low yield of washed coal. Using coal data received from CMPDI such as - ash % in input coal, yields observed at various degree of washed coal with 34%, 32%, 28% and 25% ash, correlations have been established (figure 5).

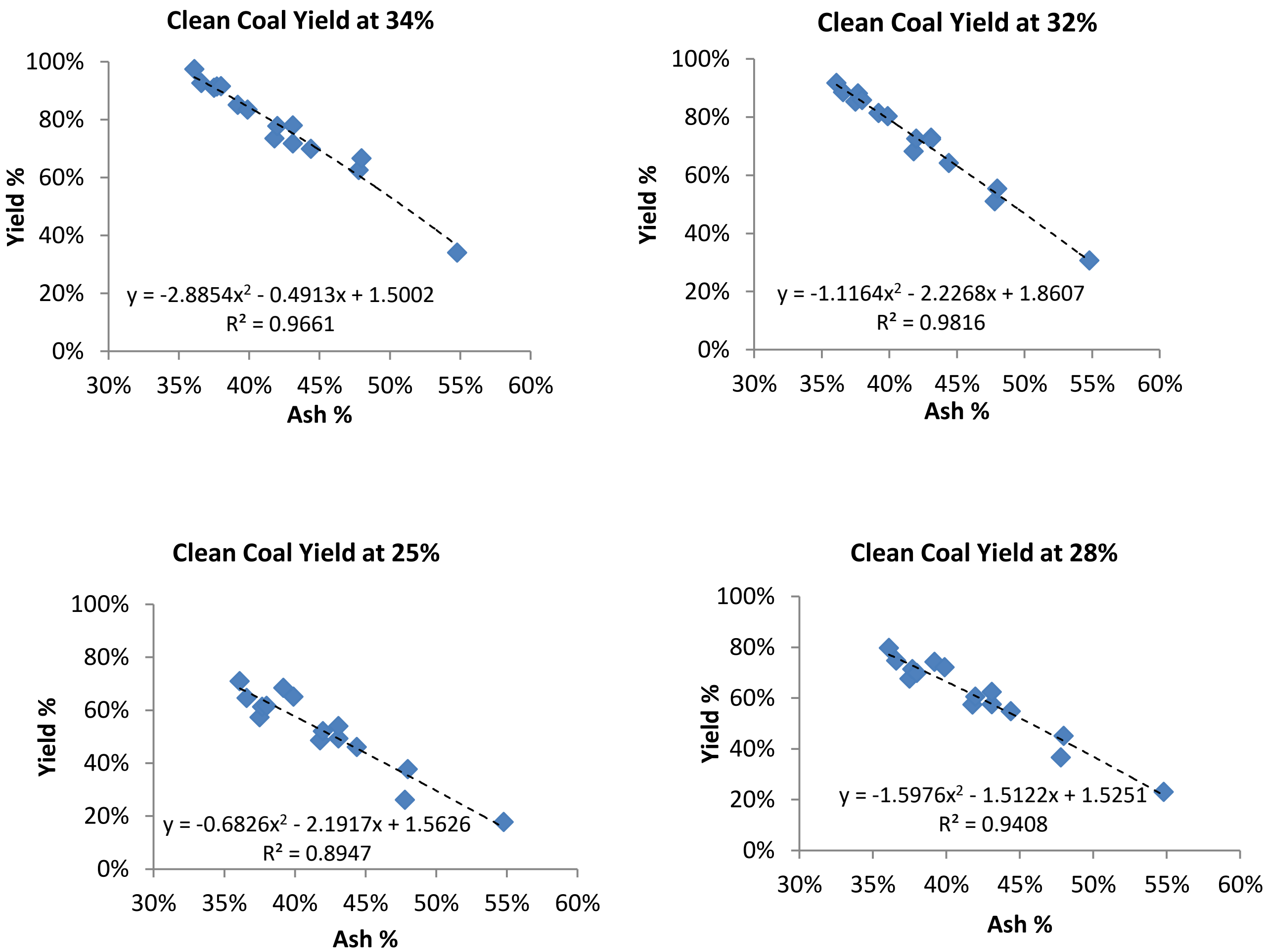


Figure5: Clean coal yield w.r.t ash percentage of input ROM coal - TERI analysis

From figure 5 it can be seen that for 43% ash ROM coal, yield of clean coal varies as 75%, 70%, 58%, and 49% for washing of coal upto 34%, 32%, 28%, and 25% ash in output coal respectively. Using these yield curve, yield % has been calculated for wide range of input ash% and used in integrated value chain framework.

4.4 Rationale for selection of coal grade for baseline analysis

An analysis of the use of grades of coal for thermal power generation in India reveals that it primarily ranges from G 7 to G14. However G 11 is found to have the highest consumption as can be observed from figure 6. The estimated consumption of G11 is more than 160 million tonne followed by G10 (115 million tonne), G13 (95 million tonne) and G12 (60 million tonne). Coal of G-10 & G-11 grade has lesser ash content (30-36%) and bulk of it may not be candidate for the washing with ash content not exceeding 34%. However coal of G12 and inferior grade will require washing that has the benefits of enhancing energy content while having the potential to reduce emissions.

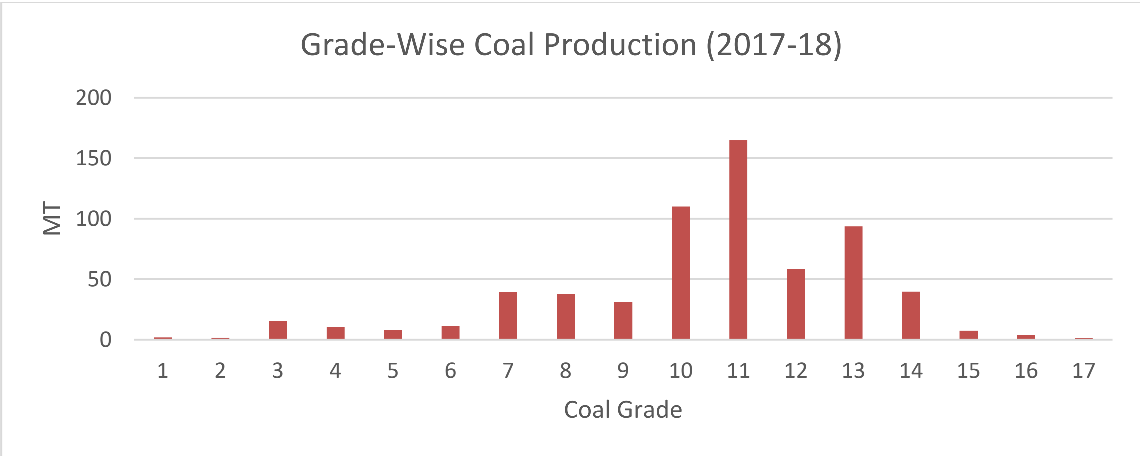


Figure 6: Grade-Wise Coal Production (2017-18)

Source: Coal Directory of India

Most of the coal mined in India is by the various subsidiaries of Coal India Limited. The Largest coal production subsidiaries are MCL & SECL (combined production of around 46%), and the coal produced largely fall under G-13 & G-14 grades which may require washing (figure 6). An analysis of the production figures of MCL reveal that the G14 has the highest production (34.5 million tonne) followed by G12 (34 million tonne) and G13 (32.2 million tonne).

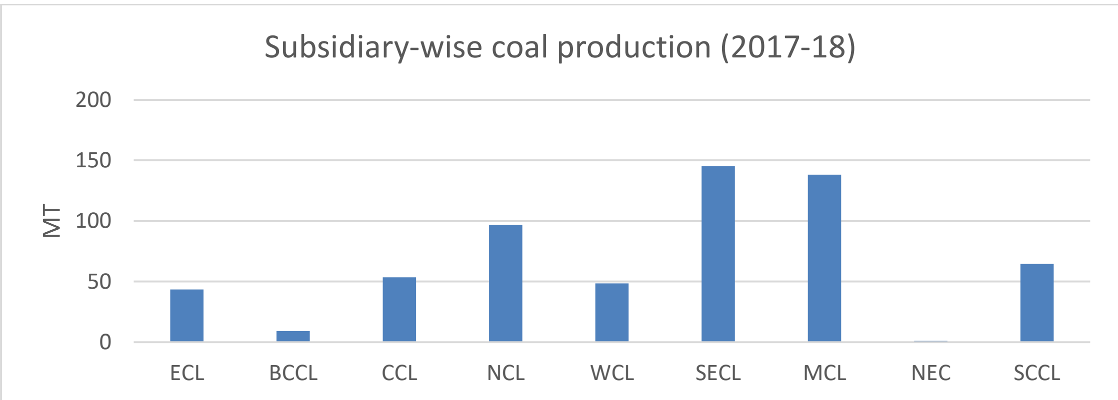


Figure 7: Subsidiary-wise coal production (2017-18)

Source: Coal Directory of India

Most of the private washeries are situated in MCL as well as SECL, which are washing coal having ash ranging between 40-45% or even higher as reported by washeries in MCL indicating the grade of coal washed in India is G-13 coal for beneficiation. Hence from the consumption and washing perspective G13 grade has been considered for analysis under the reference case. Sensitivity analysis with G12 and G11 grade of coal has also been carried out.

4.5 Washing Cost including impact of yield of clean coal

Washing of coal cost usually varies in range of Rs 90-160 /Tonne but it is the yield of washed coal that makes washing of coal expensive. After taking yield correlations, washing costs including impact of clean coal yield for various grades of coal have been estimated. A sample calculation used in model has been presented in table 7 for G13 coal (GCV of 3550 kCal/kg) for which yield of clean coal is 75% for 9% ash improvement.

Table 7: A sample calculation used in model has been presented for G13 coal

S.N	Particulars	UOM	Variables
A	Input coal quantity	Ton	1
B	Input coal ash%	%	43%
C	Washing up to ash %	%	34%
D	Yield (as per curves)	%	75%
E	Input coal cost(including taxes)	Rs/Tonne	1508
F	Washing cost	Rs/Tonne	122
G	Rebate on rejects	Rs/Tonne	0
H	Washed coal quantity (yield)	Tonne	0.75
I	Reject quantity **(A-H)**	Tonne	0.25
J	Total per ton cost for washed coal **((E+F)/H – G*I)**	Rs/Tonne	2174
K	Washing cost (including yield impact) **(J-E)**	Rs/Tonne	666

In above table, no rebate on rejects (GCV: 1347kCal/kg) has been considered because CIL considers the rejects at zero value in their books. Also, it can be seen from above table that due to the yield of coal, the overall washing cost is significantly high, Rs 666/Ton, as compared to basic washing cost of Rs 122/Ton.

4.6 Transportation

In India, installed capacity of thermal power stations that are pit head stands around 34 GW for which the main source of transportation is trucks, MGR or through over land conveyors, remaining capacity around 163 GW (80%) gets coal hauled over much longer distances, mostly through rail network. Due to the fact that Indian coal has high ash % and average ash content touched 42% in 1999-2000[25], many attempts were made to address the issue of hauling ash at such longer distances. There are implications of additional burden on railways to deliver the higher ash quantity and higher freight charges as well as reduced energy content. Average lead distance of coal shipments in India has fallen from 639 km in 2012 to 460 km in 2017,[26] while the tonnage carried has increased from 456 MT to 533 MT during the same duration. Falling average lead distance can be attributed to the fact that the plant load factor (PLF) of generating stations that are distant from coal mines (Arora, 2017) have been falling after FY 2012 due to the one-time coal linkage rationalization.

Indian Railways had revised freight charges multiple times in the past few years and also withdrawn the busy season surcharges and development charges levied on transportation of 'coal and coke'. While estimating economic impact of washed coal transportation over unwashed coal, freight charges on delivery of coal have been considered from rate circular no 19 of 2019 released by Ministry of Railways[27]. Moreover the impact of increase in moisture content by 5% and decrease in density by 10% is considered on payload of the rail transport.

The benefit due to washed coal transportation will increase with increasing distance between the generating station and loading point at washeries as could be seen from Table 8. The freight charges and the benefits have been used to calculate landed cost of coal and the overall impact on variable cost of electricity generation.

Table 8: Annual transportation benefits due to use of washed coal in a 500 MW unit.

Annual benefits (INR crore)	Washed up to 34%			Washed up to 32%		
Distance travelled	G-11	G-12	G-13	G-11	G-12	G-13
250	3	12	21	7	15	25
500	6	22	40	13	29	47
750	9	30	56	19	40	65
1000	11	38	70	23	50	82

Savings from transportation of coal is the major saving and after breakeven distance, counter balances the impact of higher yield and washing of coal. This aspect has been discussed in greater details in later sections of report.

[25] https://www.orfonline.org/wp-content/uploads/2017/07/ORF_Report_CoalBeneficiation_FinalForUpload.pdf
[26] https://www.brookings.edu/wp-content/uploads/2018/07/Railways-and-coal.pdf
[27] http://www.indianrailways.gov.in/railwayboard/uploads/directorate/traffic_comm/downloads/Freight_Rate_2018/RC_19_2018.PDF

4.7 Cost- Build Up (Landed Cost of coal- washed upto 34% and 32% ash content)

The build-up of landed cost of coal consists of various components such as ROM cost, central and state-level taxes, levies, duties, cess, washing cost and freight etc.. Economic impact has been analysed for the grades of coal which are commonly used in power generation. Built-up cost of coal using a sample G-13 Grade (for 500 km – the distance beyond which coal washing was required as per Environmental protection rule dated 2nd January, 2014) is given in Table 9.

Table 9: Coal cost build up for raw and washed coal (in Rs/Ton)

S.N.		UOM	Raw Coal	34%	32%
X	GCV	Kcal	3550	4286	4445
Y	Ash%	%	43%	34%	32%
Z	Yield	%	1.00	0.75	0.70
1	ROM	Rs/Tonne	817	817	817
2	Sizing charges	Rs/Tonne	87	87	87
3	Royalty	Rs/Tonne	114	114	114
4	MMDR - central fund	Rs/Tonne	2	2	2
5	MMDR - central fund	Rs/Tonne	34	34	34
6	GST compensation cess	Rs/Tonne	400	400	400
7	GST on coal	Rs/Tonne	53	53	53
A	**Total cost of ROM coal (1+2+3+4+5+6+7)**	Rs/Tonne	**1508**	**1508**	**1508**
B	**Surface transportation to/from washery to railway slidings**	Rs/Tonne	**60**	**60**	**60**
8	coal washing charges	Rs/Tonne	0	666	866
9	GST on coal washing @ 18%	Rs/Tonne	0	22	24
C	**Coal washing charges (8+9)**	Rs/Tonne	**0**	**688**	**890**
10	Railway Freight charge (500km)	Rs/Tonne	1107	1107	1107
11	GST on transportation (@ 12%)	Rs/Tonne	133	133	133
D	**Transportation charges (10+11))**	Rs/Tonne	**1240**	**1240**	**1240**
E	**Total delivered cost of coal (A+B+C+D)**	Rs/Tonne	**2808**	**3496**	**3698**
F	**Cost per GCV (E/X)**	Paise/kCal	79	82	83
G	**Variable cost for 500 MW Unit**	Rs/kWh	2.02	2.08	2.12

**The cost build up for landed coal is based on per ton of delivered coal*
#Coal washing charges includes the impact of yield of G13 coal due to washing up to 34% and 32%

The landed costs of coal or delivered cost of coal for various grades, yields, ash% have been considered to analyse the impact of washing on variable cost of power generation.

4.8 Economic impact of use of washed coal over unwashed coal at power station

Coal based power plants, with 75% contribution in total electricity generation in 2019, continue to play dominating role in electricity generation in India. The current Indian coal based fleet has capacity of 197 GW which consists of diverse unit sizes ranging from 210 MW to 800 MW, which can be grouped in to three categories as given in Table 10. To assess the economic impact of coal beneficiation, impact on variable cost of electricity generation due to use of coal washing has been analysed on three representative unit sizes of 300, 500 & 660 MW.

Table 10: Unit size wise classification of coal based capacity

Unit size (MW)	Total capacity (MW)
600 MW and above	71,350
~500 MW	46,650
350 MW and below	79,391
Total Capacity	197,391

4.8.1 Technical efficiency improvement

Washing of coal results in improvement of GCV of coal which reduces the amount of coal used to generate same amount of electricity. Apart from this benefit, improved quality coal reduces auxiliary power consumption (APC) to support unit generation as the system handles less volume of coal and ash. The major impact on APC reduction comes from boiler auxiliary and balance of plant (BOP) equipment such as coal handling plant (CHP), ash handling plant (AHP), etc.

Apart from APC improvement, coal beneficiation also impacts the heat rate, life of boiler auxiliaries, O&M cost etc. of generating units. Various studies such as ADB[28], ORF study on "Coal beneficiation in India"[29] suggest significant improvement in these aspects. During the course of this study, TERI consulted BHEL, largest manufacture of thermal power plant in India, for the analysis of these technical efficiency improvements.

4.8.2 Simulation Study for typical 500 MW unit

BHEL carried out a simulation study on a 500 MW subcritical plant designed for 42% ash, 0.49% Sulphur & GCV of 3400 kcal/kg. During the simulation, the subcritical 500 MW plant was fired with washed coal having 32% ash, 0.60% Sulphur & GCV of 4500 kcal/kg and the impact on plant efficiency, auxiliary power consumption, chemical consumption in FGD, life of equipment, etc., have been reported. A typical configuration for boiler, turbine, generator, mills ducts, CHP, AHP, etc, have reportedly been considered for the simulated run. The final results of the simulation are as follows:

- Boiler efficiency will have a marginal gain of about 0.5%. But the Main steam and Reheat temperature is expected to be lower by 15^0C.

[28]https://www.adb.org/sites/default/files/project-document/72146/26095-ind-tacr.pdf
[29]https://www.orfonline.org/wp-content/uploads/2017/07/ORF_Report_CoalBeneficiation_FinalForUpload.pdf

- Turbine efficiency is expected to be lower by 0.38% due to lower Main steam and Reheat steam temperatures. Overall, plant heat rate will marginally deteriorate resulting in drop in cycle efficiency expected to be about 0.12%.
- Equipment for emission control such as ESP & FGD will also have relatively better & efficient performance. ESP will be typically able to operate with one lesser field for meeting the environmental norms. With respect to FGD, savings in terms of operational cost will be observed. FGD chemical consumption will be lower by 9%.
- Coal mills grinding elements & burner nozzles will also have better operating life and it is expected that an increase of about 50% – 100% may be observed depending on actual washed coal compositions.
- Improvement is expected in Auxiliary Power Consumption (APC) with firing of washed coal in the equipment listed below:
  - For boiler & its auxiliaries (ESP, Fans, Mills): APC is expected to be reduced by about 10%.
  - For turbine & its auxiliaries: Increase in APC is expected to be increased by 0.87%.
  - For BOP packages (CHP & AHP): APC is expected to be reduced by about 20% for each of the packages as coal being fired is reduced by about 25%.
  - FGD power consumption will be lower by 12%.
  - Total savings in APC is approximately 2 MW i.e. 5.5% reduction.

These results from BHEL simulation cannot be generalised and the results will differ depending on the unit size, actual unit configuration, age, coal characteristics, washed coal composition, etc.

While the BHEL simulation study carried out for specific fuel condition and specific unit configuration shows a loss in heat rate due to firing of high GCV coal in units designed for lower GCV coal, pilot studies conducted (Satpura, Ronghe committee, ADB and ORF study) suggest improvement in heat rate of units. In the present study we have considered an improvement of 5.5% of APC and improvement of 0.02% boiler efficiency (for every 1% reduction in Ash %)[30].

[30]https://www.eecpowerindia.com/codelibrary/ckeditor/ckfinder/userfiles/files/Session%202%20Module%202%20Coal%20Properties%20and%20Effect%20on%20Cobustion.pdf

4.8.3 Economic impact on variable cost of power plant

Impact of higher GCV, improved heat rate, reduced APC and higher coal cost is estimated on the variable cost of power generation. Unit size wise normative heat rate and APC have been considered as per CERC Tariff Regulations 2019-24[31]. Also, energy charge rate (ECR)/ variable cost has also been calculated based on the methodology provided in the aforesaid CERC tariff regulations.

Impact on variable cost of power generation can be seen mainly in two ways, first in terms of quantity of coal reduction because of various reasons such as improvement in GCV, heat rate, and APC of power plant due to improved heat value of fired coal, second due to increased coal cost due to washing.

Net Impact on variable cost = Quantity / volume difference ↑ + Rate difference ↓

Positive impacts on variable cost

Savings in coal quantity due to

1. Improved GCV
2. Improved Heat Rate
3. Less APC consumption

Savings due to reduction of coal quantity can also be seen in

1. ROM coal
2. Transportation of coal
3. Saving in Taxes on coal

Negative impacts on variable cost

Loss / Rate variance due to

Washing of coal, which includes the impact of clean coal yieldS3

To assess the impact of coal washing on variable cost of power generation, difference between variable cost of cost electricity generation using washed and raw coal has been calculated.

Increase/decrease in Variable cost = Variable cost of washed coal (VC_{WC}) - Variable cost of raw coal (VC_{RC})

In this study, above equation is used to estimate the impact of washing on variable cost / ECR of power generation. Negative change implies that the variable cost of power generation using raw coal is higher than the variable cost using washed coal and a positive impact on variable cost implies that the variable cost of power generation using washed coal is lower than the variable cost using raw coal.

Negative value i.e. decrease in variable cost = VC_{WC} is lower than VC_{RC} (i.e. gain/benefit if washed coal is used for power generation)

Positive values i.e. increase in variable cost = VC_{WC} is higher than VC_{RC} (i.e. loss if washed coal is used for power generation)

Higher the reduction in variable cost, higher will be savings in variable cost due to washing of coal.

[31] http://www.cercind.gov.in/2019/regulation/Tariff%20Regulations-2019.pdf

On the basis of above, results of one sample bringing out impact on variable cost due to various reasons for G-13 grade coal (3550 kCal/kg, 43% Ash) washed to output coal (GCV 4286 kCal/kg, 34% Ash) use in power generation is presented in table 11 and 12. A comparison is also made on the basis of distance i.e. for 500 km and 800 km.

Table 11: Change in variable cost due to APC, Heat Rate, GCV and Higher coal Cost

Particulars	UOM	For 500 km			For 800 km		
		660 MW	500 MW	300 MW	660 MW	500 MW	300 MW
Variable cost (Raw coal) VC_{RC}	**Rs/kWh**	1.90	**2.02**	**2.07**	**2.32**	**2.48**	**2.53**
Variable cost (washed coal) VC_{WC}	**Rs/kWh**	**1.95**	**2.08**	**2.12**	**2.29**	**2.45**	**2.50**
Increase / decrease in variable cost	**Rs/kWh**	**0.05**	**0.05**	**0.05**	**-0.03**	**-0.03**	**-0.03**
Break up of Increase / decrease in variable cost							
Impact of improved APC	*Rs/kWh*	*-0.01*	*-0.01*	*-0.01*	*-0.01*	*-0.01*	*-0.01*
Impact of improved Heat Rate	*Rs/kWh*	*0.00*	*0.00*	*0.00*	*-0.01*	*-0.01*	*-0.01*
Impact of Higher GCV	*Rs/kWh*	*-0.33*	*-0.35*	*-0.36*	*-0.40*	*-0.43*	*-0.43*
Impact of higher coal cost	*Rs/kWh*	*0.39*	*0.41*	*0.42*	*0.39*	*0.41*	*0.42*

In table 11, increase/decrease in variable cost due to washed coal usage has been worked out for four parameters - APC, Heat rate, GCV, and coal cost. From table 11 following can be inferred.

- From above table, variable cost has increased by Paisa 5/kWh if washed coal is being transported for a distance of 500 km, whereas if the same washed coal is transported at 800km it shows decrease in variable cost.
- For longer distances, 800km, impact of higher washed coal GCV on variable cost offsets the impact of cost of washing on variable cost. In table above, for G13 coal, the improvement in variable cost (Rs 0.43/kWh) due to improved GCV completely offsets impact of higher coal cost (Rs 0.41/kWh) , and hence makes washing of coal economically viable.
- Improved heat rate and APC has not much of significant impact on variable cost i.e. Paisa 1 -2 /kWh.

To estimate impact of distance on the same grade of coal, used for table 11, the impact on variable cost due to washed coal usage can also be seen on freight charges, taxes, ROM cost, etc., as lesser coal is required to generate same electricity.

Table 12: Change in variable cost due to Transportation, Taxes, ROM and cleaning cost

Particulars	UOM	For 500 km			For 800 km		
		660 MW	500 MW	300 MW	660 MW	500 MW	300 MW
Variable cost (Raw coal) VC_{RC}	**Rs/kWh**	**1.90**	**2.02**	**2.07**	**2.32**	**2.48**	**2.53**
Variable cost (washed coal) VC_{WC}	**Rs/kWh**	**1.95**	**2.08**	**2.12**	**2.29**	**2.45**	**2.50**
Increase / decrease in variable cost	**Rs/kWh**	**0.05**	**0.05**	**0.05**	**-0.03**	**-0.03**	**-0.03**
Break up of Increase / decrease in variable cost							

Particulars	UOM	For 500 km			For 800 km		
		660 MW	500 MW	300 MW	660 MW	500 MW	300 MW
Transportation cost impact	*Rs/kWh*	*-0.16*	*-0.17*	*-0.17*	*-0.23*	*-0.24*	*-0.25*
Taxes and Duty	*Rs/kWh*	*-0.07*	*-0.08*	*-0.08*	*-0.07*	*-0.08*	*-0.08*
ROM Coal	*Rs/kWh*	*-0.11*	*-0.11*	*-0.12*	*-0.11*	*-0.11*	*-0.12*
Impact of cleaning	*Rs/kWh*	*0.38*	*0.41*	*0.42*	*0.38*	*0.41*	*0.42*

In table 12, increase/decrease in variable cost due to washed coal usage has been seggregated in four parameters- transportation cost, taxes, ROM coal cost, and washing cost.

From the model based analysis (refer figure 8, picture presented in table 11 and 12), it can be inferred that a power plant getting beneficiated coal from a coal washery, which handles G13 ROM coal situated 500 km from the power plant, there will be an increase in the variable cost. On the other hand, if the same plant gets beneficiated coal from a washery situated beyond 600-650 km, there will be a reduction in the variable cost.

4.9 Net economic impact per unit of variable cost (ECR) of electricity generation w.r.t distance of coal transportation

The result of the net economic costs and benefits has been presented for different grades of coal with respect to distance of transportation in figure 8. The results are presented for a 500 MW unit, however the results show almost same trend for different unit sizes as there is not much of change in ECR due to heat rate and APC improvement in generating unit. The variation among different unit size for grade G13 coal can be seen in Annexure 5 for better understanding.

4.9.1 Results for net impact on variable cost with distance of washing for various grade of coal

Increase/decrease in variable cost due to use of washed coal in a generating station has been analysed using an integrated value chain framework/modeling. This analysis has been carried out for G11, G12, G13 ROM grade of coal washed up to 34% and 32% ash. Also, impact of distance between washery and power plant on variable cost has been analysed using this model. The results from the analysis in presented in figure 8.

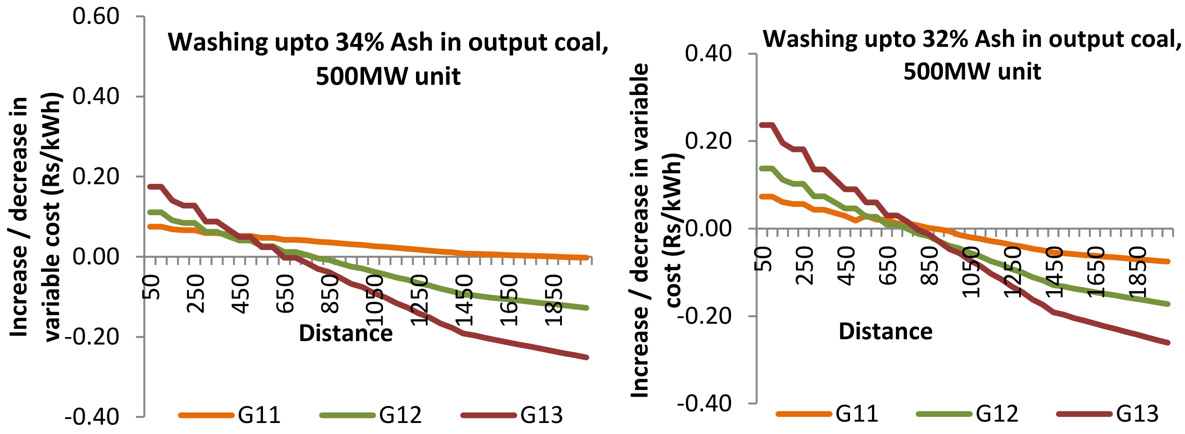


Figure 8: Impact on variable cost of power plant for using washing coal upto 34% and 32% ash

From the graph shown in figure 8, it can be inferred that the benefits of coal washing, up to 34% ash in output coal, offsets the cost of washing at distance of 600 and 700 km for G13 and G12 grade and around 1500 km for G-11. The difference observed in washing upto 34% and 32% is the distance for G11. Benefits of coal washing of grade G11 (35% ash) coal offset cost of washing at a distance of about 850 km if washed up to 32% ash and 1500 km if washed up to 34%.

Sensitivity by taking reject rebate of Rs 250/Ton was also carried out during this exercise. This resulted in reduction in washing cost and therefore in variable cost of washed coal. However the nature of above graph remains the same, but reduction in variable cost due to the usage of washed coal occurred at lesser distances i.e. 500-600 km onwards for G-12 and 13 grade coal.

4.10 Sensitivity Analysis

Due to significant variability arising due to (i) quality of RoM coal & cost of transportation from mine to washeries, (ii) yield of clean coal and (iii) transportation distance of washed coal to power stations, it is essential to analyse the impacts of various sensitivities on variable cost of generation with washed coal. A sensitivity analysis has been carried out to assess impact of freight charges from mine to washery, impact of clean coal yield, and transportation distance on variable cost of power generation with the following values/boundary conditions:

- G12 and G13 grade ROM coal for various yield percentages has been considered in view of the following.
    - *Bulk of the thermal coal washed in India is G13.*

- *Further, pilot test carried out at NTPC, Dadri as reported by CEA was also carried out with G13 raw coal and an assessment will help in comparing the estimates, thus arrived from sensitivity analysis, with the results provided by CEA.*

- Two cost scenarios with Rs 60/T and Rs 160/T have been considered for transportation of G12 and G13 grade coal from mine to washery.
- Under each coal grade and transport cost scenarios, yields of 85% and 65% (+/- 10% of the mean yield of 75% as per data received from CMPDI for G13 coal when washed up to 34%) have been considered.
- The sensitivity analysis has been presented for distances ranging from 50 to 2000 km.

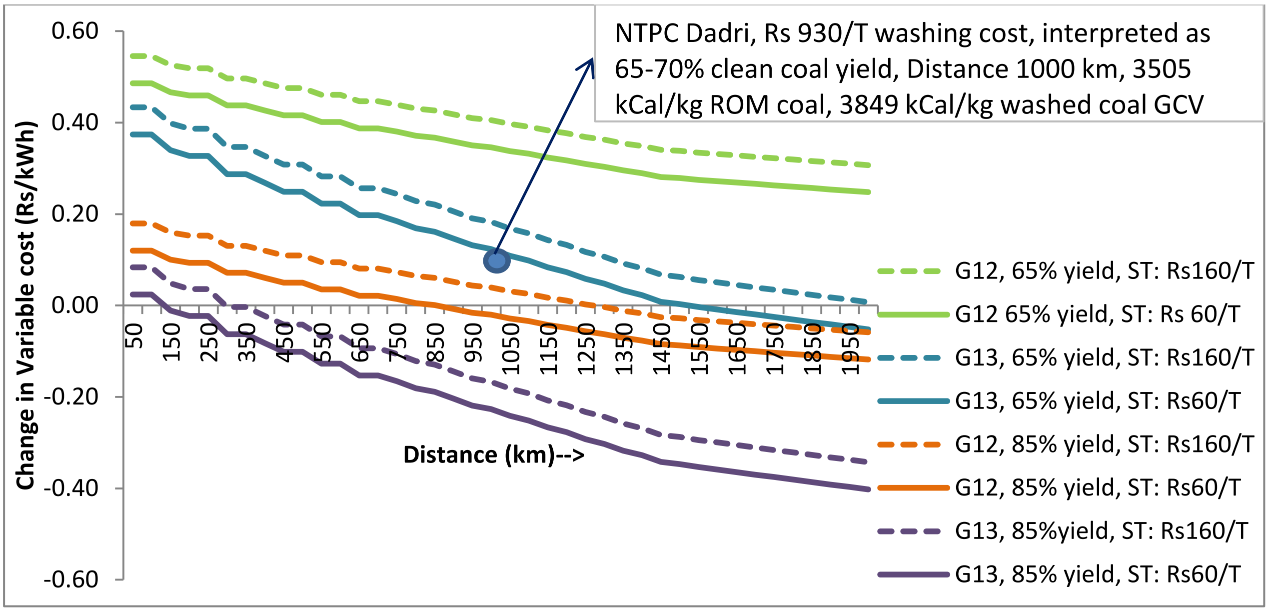


Figure 9: Change in Variable cost of power generation w.r.t surface transportation, yields, and distance between washery and power plant

From figure 9 following can be inferred:

- Higher the yield of beneficiated coal, higher will be the benefit from using washed coal.
- For G13 coal having (a) 85% yield and transportation cost of Rs 60/tonne, use of washed coal is beneficial if it is transported beyond 250 km (approx.) (freight charges : Rs 706/tonne) and (b) lower yield of 65%, use of washed coal will be beneficial if it is transported beyond 1550 km (freight charges : Rs 2885/tonne).
- Similarly, G12 coal with yield of 85% will be beneficial if it is transported beyond 850 km (freight charges: Rs 1773/tonne). A lower yield of G12 coal, 65%, will result in increase in variable cost even when used for longer distances (more than 2000 km).
- Increase in surface transportation cost by Rs 100/Tonne resulted in increase in variable cost by Rs 0.06/kWh under both the above yield scenarios (dotted lines)

- The pilot study conducted at NTPC Dadri reported a washing cost of around Rs 930/Ton for raw coal having GCV of 3507 kCal/kg and ash of 37.48% (which corresponds to G13 ROM coal) giving ash of 31.82% and GCV of 3849 kCal/kg. This indicates that the yield is around 65% - 70%, which apparently seems low as compared to yield arrived at using CMPDI data. Due to lower yield of clean coal and/or higher washing cost, variable cost from use of washed G13 coal increases variable cost by approximately Rs 0.13/kWh (TERI analysis) for the electricity generated at NTPC Dadri project.

Key Takeaways:

- Use of washed coal is beneficial for power plants if power plants are receiving coal over longer distances that are more than 600kms.
- However, at a higher yield than theoretical, inferior grade (G12 and lower) washing up to 34% can be beneficial even at shorter distances of the order of 300 km.
- Lesser the cost of the transportation from mine to washery, viability of use of washed coal emerges even at shorter distances.
- Higher the yield of clean coal (more than 75%), higher will be the benefit from using washed coal.

4.11 Comparison of change in ECR of some of power plants with ECR as per model

Increase in the washing cost due to type of washing technology, yield of clean coal, surface transportation, etc., have a significant bearing on overall change in ECR/variable cost of power generation using washed coal. In order to mimic the conditions close to the data provided by NITI Aayog in respect of two power plants, namely Dadri and Kota, model has been run with conditions close to the coal characteristics, yield using CMPDI correlation analysis (as presented in figure 5) and washing and transport costs as presented in the subsequent paragraph. Table 13 presents the analysis for NTPC Dadri and Table 14 for Kota thermal power station.

The estimations have been provided for two scenarios, (i) using at derived yield for G12 coal and (ii) at a yield corresponding to the washing cost provided in the literature provided by NITI. G12 coal has been considered for the modeled calculations keeping raw coal cost comparatively in same range as given in NITI Aayog data. Washing of G12 coal gives a change in GCV of 436kCal/kg which is near to the NTPC Dadri and KTPS's coal GCV improvement. The reason behind not considering G11 and G13 grade for comparison is that G11 grade coal has higher raw coal cost and G13 coal washing gives higher GCV impact than that is given in the NTPC and KTPS data.

Table 13: Impact on ECR for NTPC, Dadri due to actual washing cost vis-a-vis theoretical calculations

SN	Particulars	UOM	In NITI Aayog study	TERI Analysis based on	
				Modelled yield	Lower yield
1	Unit Size	MW	490	500	500
2	GCV Washed Coal	kCal/kg	3793	4286	4286
3	GCV Raw coal	kCal/kg	3472	3850	3850
4	Difference in GCV (2-3)	kCal/kg	321	436	436
5	Ash Washed Coal	%	34%	34%	34%
6	Ash Raw Coal	%	40%	40%	40%
7	ECR Washed coal#	Rs/kWh	3.20	2.44	2.70
8	ECR Raw Coal#	Rs/kWh	2.85	2.46	2.46
9	Change in ECR	Rs/kWh	0.35	-0.02	0.24
Coal Cost break up					
10	Yield of clean coal	%	-	86%	70%
11	Raw coal cost	Rs/MT	1617	1654	1654
12	Washing cost (incl. yield)	Rs/MT	834	416	860
13	Freight Charges	Rs/MT	2076	2043	2043
14	Landed cost of Raw coal	Rs/MT	3693	3697	3697
15	Landed cost of Washed coal	Rs/MT	4527	4113	4557

#in actual data, net heat rate taken for ECR calculation is 2678 kCal/kWh. NTPC Dadri has given gross heat rate of 2384kCal/kWh in pilot study conducted and result submitted to CEA. Taking 6.25% APC, net heat rate is calculated as 2543kCal/kWh which is significantly different from the 2678kCal/kWh submitted in NITI Aayog's data. For modeled calculations net heat rate has been considered as 2558 kCal/kWh for raw coal use and 2543 for washed coal use.

Modeled calculations for NTPC Dadri show that, at model yield of 86% for washing of G12 grade coal decrease the ECR by Rs 0.02/kWh, whereas at lower clean coal yield of 70% (to represent same washing coat as in actual) there will be increase in ECR of about Rs 0.24/kWh. The difference between change in ECR in actual (35 Paise/kWh) and modeled (24 Paise/kWh, at lower yield) is primarily due to higher GCV improvement in modeled calculations.

The same analysis has been carried out for Kota thermal power station (KTPS), Rajasthan. At a lower yield than the modeled yield and higher surface transportation cost, calculations show increase in variable cost by Rs 0.17/kWh as compared to Rs 0.29/kWh presented in the earlier NITI Aayog assessment.

Table 14: Impact on ECR for KTPS, Rajasthan due to actual washing cost vis-a-vis modeled calculations

SN	Particulars	UOM	In NITI Aayog study	TERI Analysis based on	
				Modelled yield	Lower yield
1	GCV Washed Coal	kCal/kg	4200	4286	4286
2	GCV Raw coal	kCal/kg	3950	3850	3850

3	Difference in GCV (1-2)	kCal/kg	250	436	436
4	Ash Washed Coal	%	34%	34%	34%
5	Ash Raw Coal	%	42%	40%	40%
6	ECR Washed coal	Rs/kWh	2.50	2.34	2.51
7	ECR Raw Coal	Rs/kWh	2.21	2.34	2.34
8	Change in ECR (6-7)	Rs/kWh	0.29	0.00	0.17
Coal Cost break up					
9	Yield of clean coal	%	80%	86%	80%
10	Raw coal cost	Rs/MT	1558	1654	1654
11	Washing cost (incl. yield impact)	Rs/MT	693	416	711*
12	Freight Charges (800km)	Rs/MT	1844	1866	1866
13	Landed cost of Raw coal	Rs/MT	3402	3520	3520
14	Landed cost of Washed coal	Rs/MT	4095	3936	4231

*including additional surface transportation of Rs 100/MT, washing cost Rs 50/MT, rebate on reject of Rs30/MT to mimic the KTPC coal washing cost.

ECR is a function of specific coal consumption and landed price of coal at the power station. Further specific coal consumption is a function of GCV and unit heat rate. Lower the yield from washing of coal, higher will be landed price of coal. Hence any change in yield will hence affect the cost of washing and finally the price of washed coal thereby affecting the ECR. Figure 9 has captured the extent of variability of the yield on the variable cost/ECR. In line with the above relationship, the difference in reported ECR (in NITI assessment) and estimated ECR (TERI analysis) arises primarily because of the gap of the yield and washing cost. In case of NTPC, the washing cost reported was INR 834/tonne while modeled nearest cost were INR 416/tonne and INR 860/tonne. Similarly in case of Kota Thermal Power Stations, the reported washing cost was INR 693/tonne while the nearest estimates of G12 coal are INR 416/tonne and INR711/tonne.

The improvement in the GCV from washing also varies from the reported data and that estimated from the TERI model. The improvement reported for NTPC Dadri station was 321 Kcal/tonne while that of Kota was 250Kcal/tonne. However the improvement in GCV from washing from TERI model has been found to be 436Kcal/kg. The relative less improvement in GCV has a far greater impact on ECR than that modeled by TERI.

The GCV-ash% relationship for raw and washed coal, yield of washed coal and cost of washery (or landed price of washed coal at power station) hold the key towards arriving at a judicious and more meaningful conclusion so far impact on ECR is concerned. The sample data point from only three power stations is too scanty to make any effective and compelling conclusion. From a strict statistical analysis viewpoint these data points are highly insignificant to arrive at any statistically robust estimates of ECR impacts.

4.12 Economic Impact on Fixed cost of Power plant

The impact on fixed cost due to reduction in capital cost for a power plant operating on washed coal will only be there in the new power plants. On the basis of consultation with BHEL, 2% improvement in capital cost of power plant, designed for usage of washed coal, is considered for overall impacts in fixed cost. This improvement is equivalent to 5-6 paisa/kWh (at normative PLF of 85%) reduction in fixed cost of power plant

Also, there will be additional benefits by use of washed coal such as 30% reduction in land requirement for ash disposal in power plant using 34% ash coal instead of 41%[32]. Furthermore, an ash reduction of 7% results in a reduction of about 2900 Ha of land for fly ash disposal, and in reduction of water consumption for ash disposal of 131 MSCM (DrManoj Kumar, 2016).

4.12.1 Coal Washing and emission standard

The coal beneficiation process which is generally used to remove the contaminants also comes with environmental benefits. The process aims at reducing the ash content & remove smaller amounts of other substances such as sulphur and other air pollutants. In order to counter the growing emissions from power sector & their impact, Ministry of Environment Forest & Climate Change (MoEF&CC) amended emission norms for SPM & introduced new norms of SO_2, NOx& Mercury in December, 2015. As per the specified limits, pre-installed Electrostatic Precipitator (ESP) will require additional fields to achieve specified PM level and Flue Gas Desulfurization (FGD) & Selective Catalytic Reduction (SCR) will be needed to control SO_2&NOx emissions respectively.

4.12.1.1 Impact on ESP

These pollution control equipment involve high capital investment upfront. For compliance of new PM norms, ESP retrofitting is required for 66 GW out of 197 GW[33]. ESP retrofitting costs around Rs 5-10 lakh/MW, which translates to ~2-3 paise/kWh increase in fixed charges component of tariff.

For a typical 210 MW unit, complying with old PM norm of 100 mg/Nm^3, washing of coal (5-6% ash reduction) reduces PM concentration by 20% but is not sufficient to comply with new norm of 50 mg/Nm^3. Hence retrofitting/replacement of ESP fields is needed to comply with the new norms. This compliance can be achieved in two ways, either by coal washing and smaller ESP retrofit / new control equipment, or by large ESP retrofit/ new control equipment. However, this analysis requires details of cost of retrofitting, under various kinds of coal, distance of plant from washery, etc.

[32] https://www.orfonline.org/wp-content/uploads/2017/07/ORF_Report_CoalBeneficiation_FinalForUpload.pdf
[33] https://www.indian-utility-week.com/__media/Report/Gov-of-India---Quarterly-Review-Report.pdf

Consultation with BHEL brought out that the ESP designed for 100 mg/Nm^3 with conventional Indian coal (unwashed), when fired with washed coal is able to meet both 100 mg/Nm^3 and 50 mg/Nm^3 criteria without any change in existing ESP. However, to meet 30 mg/Nm^3 criteria, existing ESP will require installation of one extra field.

The outcome from the study of one plant can be different for other generating stations and cannot be generalized due to existing ESP design, collection efficiency of ESP, type of coal used, etc. It is, therefore, recommended that a plant specific study is needed to analyse impact of coal washing along with emissions abatement cost required for pollution control equipment to comply with new emission norms.

4.12.1.2 Impact on FGD

For SO_2 control, FGD is being considered as the primary option for which FGD planning has already been done for 166 GW, feasibility study has been completed for 136 GW, NIT having been issued for 95 GW, bids awarded for 13 GW and FGD already commissioned at around 2 GW capacity (CEA, 2019)[34]. Technology will come at the cost of Rs. 45 lakh/MW for capacities ranging from 210-800 MW and will require 1-1.3% of increased APC and additional operating cost depending upon reagent, additional water requirement, and man power for O&M and by-product handling (CEA guidelines, 2015). Only reagent can cost up to 0.15 INR/kWh and other elements will be additive to this.

Washing may also lead to reduction in SOx emission. ROM coal may contain pyrites. The amount of pyrite present is likely to be reduced in a washed coal. A study by Cropper et al (2012)[35] reported that washed coal can reduce emissions of SO_x by 25% while other study reported that Indian coal constitutes around 50-70% of pyritic Sulphur which can be removed to the extent of 50% relative to total Sulphur content of raw coal[36]. The 25% reduction of sulphur in raw coal reduces SO_2 emission by 30%. Hence the capital cost required for FGD reduces significantly.

Though literature suggests that washing of coal results in reduction in dust concentration and SO_2 emission. However, in view of large variation of sulphur in Indian coal, adequacy of washing for meeting new environmental norms is required to be assessed on case to case basis, and calls for much detailed assessment with sampling of data from different mines to analyze the impacts on Sulphur content of coal post washing.

4.13 Coal blending versus washing of coal

Blending of high grade coal with low grade raw coal is one of the propositions other than washing of coal that can reduce the ash in the delivered coal to power plant. Indian coal

[34] http://www.cea.nic.in/reports/others/thermal/umpp/fgd_newnorms.pdf
[35] https://papers.ssrn.com/sol3/papers.cfm?abstract_id=2093610
[36] https://www.sciencedirect.com/science/article/pii/B9780128126325000094

being higher in Ash% requires higher proportion of high grade coal to achieve ash% less than 34%. In India, mostly G10, G11, G12 and G13 coal is used for power generation. For blending purpose a higher grade, which is having less ash content, is required to be mixed with lower grade of coal in such a way that resultant coal will have ash not exceeding 34%.

To analyse the cost benefit / loss of blending of coal over washing of coal, an analysis has been carried out (refer Table 15). In the analysis, cost comparison has been made between blending of G9 (Avg. GCV: 4750 kCal/kg) and G13 (Avg. GCV: 3550 kCal/kg) Raw Coal and Washing of G13 coal. In the simulation study, blending of coal has been done is such a manner that the delivered coal will have 34% ash. Quantities of G9 and G13 coal required for 1 tonne of delivered coal (34% ash coal) have been calculated using energy and mass balance method.

Table 15: Cost comparison between blending of G9 and G13 Raw Coal and Washing of G13 coal

S.No.	Particulars	UOM	Value
Cost of Blending			
1	Quantity of ash in 1 tonne of G9 coal	tonne	0.28
2	Quantity of ash in 1 tonne of G13 coal	tonne	0.43
3	For 34% ash coal (target), G9 coal required for blending with G13 coal	%	61%
A	ROM Cost of 0.61 tonne of G9 coal	Rs/MT	695
B	ROM cost of 0.39 tonne of G13 coal	Rs/MT	319
C	Royalty	Rs/MT	142
D	Sizing charges	Rs/MT	87
E	MMDR - central fund (2% of Royalty)	Rs/MT	3
F	MMDR - central fund (30% of Royalty)	Rs/MT	43
G	Subtotal assessable value (A+B+C+D+E+F)	Rs/MT	1288
H	GST compensation cess	Rs/MT	400
I	GST (5%)	Rs/MT	64
J	Surface transportation	Rs/MT	60
K	**Total cost of Blended coal (G+H+I+J)**	**Rs/MT**	**1813**
Cost of G13 washed coal (washing up to 34% Ash)			
L	ROM cost of G13 coal	Rs/MT	817
M	Royalty	Rs/MT	114
N	Sizing charges	Rs/MT	87
O	MMDR - central fund (2% of Royalty)	Rs/MT	2
P	MMDR - central fund (30% of Royalty)	Rs/MT	34
Q	Subtotal assessable value (L+M+N+O+P)	Rs/MT	1055
R	GST compensation cess	Rs/MT	400
S	GST (5%)	Rs/MT	53
T	Subtotal (Q+R+S)	Rs/MT	1508
U	Washing cost for 75% yield	Rs/MT	688
V	Surface transportation charges	Rs/MT	60
W	**Total cost of washed G13 coal (T+U+V)**	**Rs/MT**	**2256**
X	**Difference between blend coal and washed coal (K-W)**	**Rs/MT**	**-443**
Y	**% increase (X/K)**	**%**	**24%**

The analysis for this particular case shows that blending of coal at power station is 24% cheaper than the washed coal. However, blending of coal has many limitations as well. For many cases, blending of coal to achieve 34% ash content in coal may be costlier (such as in case of blending of low grade coal with very high grade of coal or imported coal) than the washing of coal. So, viability of blending of coal shall be assessed taking the following aspects into consideration:

- Availability of superior quality of coal – as Indian coal is higher in ash content, a higher proportion of high-grade coal will be required to maintain 34% ash. So availability of the same higher grade coal is also very important. Also, Power plants, which are designed for higher grade of coal, may not be in a position to surrender the same and production of high grade coal will have to suitably increase.
- Use of blended coal, in case where higher grade coal may be required to be supplied from a longer distance / different source, will result in higher variable cost, which will in turn put the power station at a disadvantage in merit order scheduling & dispatch.
- Current FSA structure – Power plant that are using lower grade ROM coal will be required to have another FSA for higher grade of coal for blending, in case the generating company does not have any FSA for required grade (higher) of coal taking limitation of annual contracted quantity (ACQ) in to consideration.
- Position of intermixing of different grades of coal – intermixing of coal whether at power plant end or mine end is also one of the factors required to be taken in to consideration.

4.14 Case study: Market potential of reject based electricity generation from FBC plants

As discussed in the previous chapters, the co-produced rejects during the washing process could potentially be utilized in FBC based plants either completely or with appropriate blending with raw coal considering the technical specifications of FBC boilers. Currently, the FBC plants are installed for captive purposes, which can generate electricity from rejects having ash content up to 65% and GCV in the range of 1500 – 2200 kCal/kg. However, most of the FBC plants blend rejects with raw coal to achieve design coal characteristics.

From the stakeholder interaction and literature survey, it was found that the price of rejects based power generation from FBC falls in the range of 2.5 and 4.5 Rs/kWh[37]. Also, the electricity tariff for industrial consumers (for washeries as well as other industrial plants) is in the range 5.5 to 6.0 Rs/kWh in major coal bearing states such as Bihar, Jharkhand & Orissa. It shows that FBC plants can produce less costly electricity from

[37] https://fossil.energy.gov/international/Publications/Coal_Beneficiation_Workshop/DT_OP_CCL_presentation.pdf

rejects (complete usage or blending with raw coal), and is a viable option for captive purposes than procuring from grid.

The cost of rejects based electricity generation from FBC can reduce further with lower capital cost of FBC plant, better quality of rejects and when operating at high PLF in parallel with grid connected plants.

Chapter 5: Environmental Impact Assessment of Coal Washing, use of Washed Coal for Power Generation and Rejects

The environmental impacts associated with three different stages of coal washing have been presented in the following sections. Impacts associated with coal washery operations, usage of washed coal for power generation and utilization of rejects have been detailed and assessed.

5.1 Environmental Impact associated with coal washery operations

Coal washing processes, unless properly handled, has the potential to cause pollution of air, water and soil. Environmental impacts of coal washing, therefore, is an area of concern from the environment point of view and it is required to assess whether the benefits arising from use of washed coal are outweighing the impacts generated from operating coal washeries.

5.1.1 Effluent Water and its environmental impact

Coal washery effluents contain large amount of suspended solids and high COD values which hold potential for severe water pollution and siltation of river bed. However, the coal washeries as per the environmental guidelines[38] have to adhere to the following norms

1. Water consumption shall not exceed 1.5 NM^3 per tonne of raw coal.
2. The efficiency of setting ponds of the waste-water treatment system shall not be less than 90%.
3. The coal washeries shall maintain the close circuit operation with zero discharge. In case of any problems such as monsoon, cleaning;
4. The effluent discharge at final outlet should comply with the prescribed norms.
5. Under no circumstance the industry shall discharge wastewater to outside.

In the study, we assume that the washeries are complying (as there are no reports on non-compliance) with the effluent discharge norms and so, we have considered overall environmental impact related to effluent discharge as nil. Also, cost of water effluent treatment/ water pollution abatement cost such as effluent treatment plant (ETP), sewage treatment plant (STP) etc. is internalized in the capital cost of washeries, while operating cost for water treatment such as cost of flocculant as chemical for water treatment and electricity consumption are also internalized.

[38] http://ospcboard.org/wp-content/uploads/2017/03/9-GUIDELINES_FOR_COAL_WASHERIES.pdf

5.1.2 Model Analysis of Electricity consumption and CO_2 impacts

An comparative analysis was undertaken to assess the impact of CO2 emission from power generation using raw coal (for Grade G11, G12, G13, G14) vis-à-vis electricity generated from rejects including CO2 emission associated with electricity consumption during coal washing. To carry out the analysis, a power station having annual coal consumption of 1 million tonne has been considered. The electricity that can be generated from raw coal with grades G11, G12, G13 and G14 have has been estimated at 1729 MU, 1604 MU, 1479 MU and 1354 MU respectively.

Table 18: Calculations for one million tonne of different grades of coal

SN	Particulars	UOM	G11	G12	G13	G14
1	Raw Coal Quantity	Tonne	1,000,000	1,000,000	1,000,000	1,000,000
2	Ash% in Raw Coal	%	36%	39%	43%	47%
3	Ash % in Washed coal	%	34%	34%	34%	34%
4	Yield of clean coal	%	96%	86%	75%	63%
5	Washed coal Quantity	Tonne	960,000	860,000	750,000	630,000
6	Quantity of Reject	Tonne	40,000	140,000	250,000	370,000
7	Power consumption in washery	MU	3.0	3.3	3.6	4.0
8	CO2 generated by washery's power Consumption	MT	2.49	2.74	3.01	3.31
9	Water consumption in washery	Mil m3	1.5	1.5	1.5	1.5
10	Specific coal consumption of Raw coal	kg/kWh	0.58	0.62	0.68	0.74
11	Specific coal consumption of Washed coal	kg/kWh	0.56	0.56	0.56	0.56
12	Specific coal consumption of Reject	kg/kWh	2.5	2.22	2.08	1.91
13	Power generation using Raw coal (P_{RC})	MU	1729	1604	1479	1354
14	Power generation using washed coal (P_{WC})	MU	1718	1540	1343	1129
15	Power generation using Reject (P_{RJ})	MU	11	63	120	194
16	Difference in power generation (P_{RC}-(P_{WC}+P_{RJ}))	MU	0	2	16	31
17	CO_2 generation by raw coal cons.	MT	1.54	1.43	1.32	1.21
18	CO_2 generation by washed coal cons.	MT	1.53	1.37	1.19	1.00
19	CO_2 generation by reject cons.	MT	0.02	0.07	0.13	0.20
20	Cost of CO_2 from Raw coal	Mil INR	3.41	3.16	2.91	2.67
21	Cost of CO_2 from Washed coal	Mil INR	3.38	3.03	2.64	2.22
22	Cost of CO_2 from Rejects	Mil INR	0.04	0.14	0.28	0.45
23	Aux power savings at power plant end	MU	5.9	5.5	5.0	4.6
24	Power consumption in washery	MU	3.0	3.3	3.6	4.0
25	Net saving (23-24)	MU	2.9	2.2	1.4	0.6

The specific coal consumption of raw coal for power generation from G11, G12, G13 and G14 grade coal is 0.58 kg/kWh, 0.62 kg/kWh, 0.68 kg/kWh, and 0.74 kg/kWh respectively. The increase is attributed to reduction in GCV and the consequent increase in the coal requirement as we move from G11 to G14.

However, if the coal of these grades was washed to 34%, the total volume of clean coal that would have been generated based on analyzed maximum yield would be 0.96 million tonne, 0.86 million tonne, 0.75 million tonne and 0.63 million tonne respectively in the order of the grades mentioned above. Given the characteristics of the coal, particularly GCV and ash content after washing have been assumed to be same, the specific coal consumption falls to 0.56 kg/kWh and remains same for each grade as presented in table 18. The electricity generated from using washed coal is 1718 MU, 1540 MU, 1343 MU and 1129 MU.

The estimated volume of rejects generated for these grades are 0.04 million tonne, 0.14 million tonne, 0.25 million tonne and 0.37 million tonne. This is arrived at using the energy mass balance for individual grades of coal. The volume of electricity generated using rejects from washing of coal G11 to G14 has been estimated to be low because of poor calorific value and high ash content. Practically, no electricity is possible to be generated using these rejects without blending. However, for theoretical purpose, the same has been estimated at 11 MU, 63 MU, 120 MU and 194 MU. **From the analysis as presented in the table, it can be inferred that the total electricity from raw coal is higher than the electricity generated from washed coal as well as electricity generated from reject. However, the gap is nil for G11 and reaches to 31 MU for G14.**

The APC saving was estimated from using washed coal of grade G11 to G14 to the tune of 5.9 MU, 5.5 MU, 5.0 MU, and 4.6. On the other hand electricity consumption from washing 1 million tonne of raw G11 to G14 coal grades is 3.0 MU, 3.3 MU, 3.6 MU, 4.0 MU respectively. The net savings have been estimated at 2.9 MU, 2.2 MU, 1.4 MU and 0.6 MU. **The incremental benefit in CO_2 emissions due to APC reduction at power plant end compared to electricity consumption at washery end is 3.64 KT, 2.92 KT, 2.12 KT, & 1.46 KT per million tonne of coal consumption for G-11 to G-14 grades of coal respectively.**

5.2 Environmental benefits from the use of washed coal for power generation

The use of raw coal with high ash content has major environmental impacts in the form air pollution caused by CO_2 , oxides of nitrogen (NOx), oxides of sulphur (SOx) and air-borne inorganic particles such as fly ash, carbonaceous material (soot), suspended particulate matter (SPM) and other trace gas species. When burning unwashed coal for power generation, large amount of particulate matter, sulphur dioxide, nitrogen oxide and mercury is released that adversely impacts health of many people in various ways. This impact can be reduced by the use of washed coal as it is high in calorific value compared to unwashed coal, thereby reducing consumption and overall emission (ADB 1998).

The use of washed coal has the potential to reduce CO_2 emissions arising from the power plants. The study conducted at the NTPC's Dadri Power Plant which used washed coal with around 31-32% ash revealed that more than 600,000 tonnes per year of CO2 emissions can be reduced both from coal combustion. Thus it can be stated that the use of washed coal in thermal power plants can have significant environmental benefits like the reduction in carbon emissions per unit energy generation through improved thermal efficiency. With the use of washed coal which can be combusted efficiently with less air, the formation of NOx could also be reduced. Further the use of low ash coal could also result in reduced particulates in the flue gas leading to reduced load in Electrostatic Precipitator (ESP) and possibly enhancing life of ESPs.

5.2.1 Environmental benefit from the reduction in carbon emissions

The environmental benefits from reduction in CO_2 emissions have been assessed across three scenarios. Under the BAU scenario (S1), emissions from all the thermal power plants was estimated as per the actual coal consumption in 2018 (CEA database), however the levels of coal consumption reduces in the other two washed coal scenarios (S2-34% ash content, S3-30% ash content) to produce the same level of electricity. The specific coal consumption improvement in washed coal scenario leads to a difference in the total CO2 emissions at the country level to produce the same amount of electricity.

In the context of this study, it is pertinent to identify the environmental benefits of use of washed coal from the reduction in both local as well as global pollution but here the impact of CO2 could only be assessed due to the lack of data on local environmental pollution[39]. For the estimation of the impact of global pollution, the emission inventory estimates of CO2 were estimated for 2018 and under the three different scenarios.

Out of the total installed capacity of 344,002 MW in 2018, more than 50% has been coal sourced (CEA 2019) and the total coal sourced electricity generation was 985 TWh. Thus to meet this generation of 985 TWh, specific coal consumption under each scenario was estimated based on plant wise assessments of coal consumption and ash content. The coal consumption under each scenario in 2018 is shown in Figure 10.

[39]Since the data of the power plants with ESP installation and without ESPs could not be procured, so the impact on the local pollution could not be assessed. Additionally, the TPPs which have installed ESPs would not require washed coal if they are complying with the existing air pollution norms.

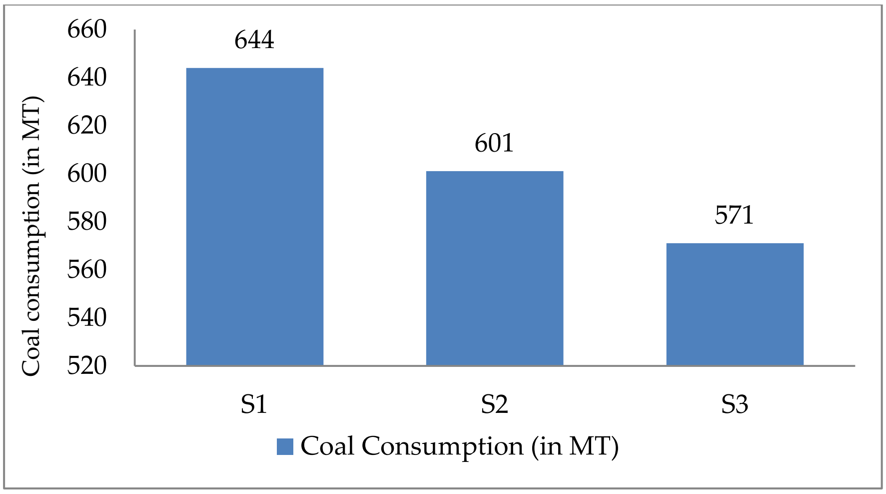


Figure 10: Coal consumption in 2018 under each scenario

Source: TERI analysis

The overall coal consumption under the policy scenario (S1) was the highest with total coal consumption of 644 MT as it also involves the TPPs which continue to use the raw coal according to prevailing practice. However, the coal consumption decreases to 601 MT in S2 due to the use of washed coal with 34% ash and further to 571 MT in S3 with the use of coal with 30% ash content. Using these amounts of coal consumptions, the CO2 emissions in each scenario were respectively estimated using emission factor 1.04 tCO_2/ MWh (CEA 2018). The total CO2 emissions at power plants end in each scenario for 2018 are given in Figure 11.

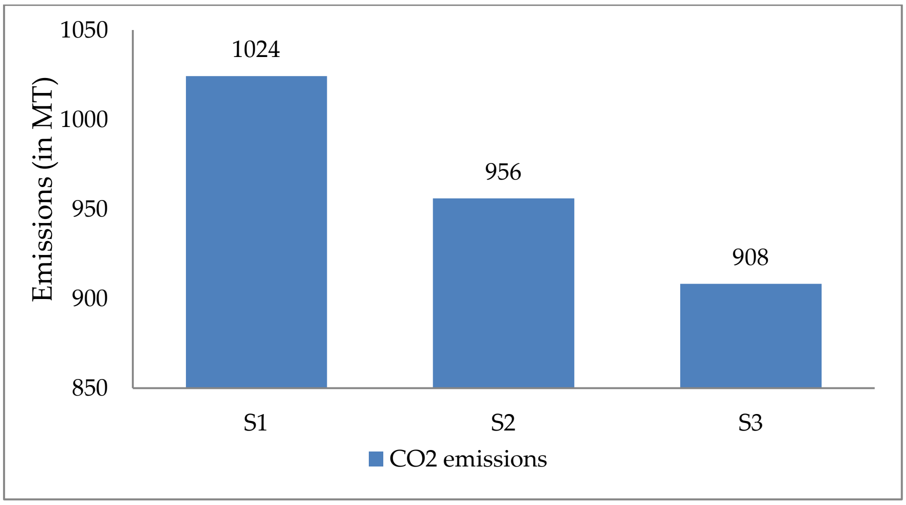


Figure 11: CO_2 emissions in 2018 under each scenario

Source: TERI analysis

The emissions in S1 are the highest due to the maximum amount of coal consumption in this scenario, followed by S2 and S3 wherein the coal consumption declines because of the use of higher quantum of washed coal.

5.2.2 Social cost of carbon and the incremental environmental benefits

The cost of climate change due to emission of CO2 has been estimated in this study using the social cost of carbon based on estimates presented in (Nordhaus, 2017)[40]. Social cost of carbon (SCC) represents the economic cost caused due to an additional tonnage of CO2 emissions or its equivalent in the atmosphere. Various models are used to estimate the monetary value associated with the cost of CO2 emissions, using multiple assumptions, associated with economic growth, world economy, future emissions and its impacts. This study uses the estimates from Nordhaus (2017), which uses the DICE (Dynamic Integrated model of Climate and the Economy) framework. The cost of carbon used in this study for 2016-17 (at constant prices 2013-14) is USD 2.6/tCO2 or INR 153/tCO2 (using 2016 exchange rate). We inflate using the GDP deflator to arrive the SCC for the year 2018. Using the above estimated CO2 emissions and the cost of carbon mentioned, the emissions were monetized and thus the difference under each scenario was used to estimate the incremental environmental benefit.

The incremental benefit of use of washed from its current scenario is presented in Table 19.

Table 19: Estimated incremental environmental benefit (in Rsbn)

Incremental Environmental Benefit			
Year	**S1-S2**	**S1-S3**	**S2-S3**
2018	10.5	17.8	7.3

Source: TERI analysis

Estimated benefit from social cost of carbon from use of 34% washed coal for 2018 is INR 10.5 bn while the benefit from use of the 30% washed coal is INR 17.8 bn. These environmental benefits were expressed per unit of electricity generated to estimate the net incremental benefits (Table 20).

Table 13: Net incremental environmental benefit (in Rs/kWh)

Incremental Environmental Benefit			
Year	**S1-S2**	**S1-S3**	**S2-S3**
2018	0.01	0.02	0.01

Source: TERI analysis

5.3 Comparative environmental impact assessment of use of washery rejects in CBFC vis-à-vis their use in TPS

Coal washing leads to generation of substantial quantity of rejects. The rejects have been found to have an average ash content that ranges between 55%- 85% with GCVs of 500 –

[40]https://www.pnas.org/content/114/7/1518#T2

2200 kCal/kg. Based on literature review and discussion with selected stakeholders regarding the current applications of rejects, it was learnt that they end up getting used in

1) FBC plants
2) Filling voids in mines, &
3) Other applications (e.g. brick kilns, road construction etc.)

A brief description of use of rejects in these applications is presented below,

1. **FBC plants**: Most of the captive power plant owners operating in proximity to washeries opt for CFBC technology due to its capability to convert these rejects (having low energy content ranging1200-2000 kCal/kg) into electricity, which otherwise would have been left unutilized. These power stations, using rejects as fuels, too need to adhere to emission norms for PM, SO_2, NO_xas notified by the MoEFCC. In practise, rejects are blended with high grade coal to prepare for a better feed in CFBC boilers.
2. **Landfill**: There are significant amount of very low-grade reject generation after washing process, which do not qualify for combustion (i.e rejects having GCV less than 1000 kcal/kg or ash above 80%). Such rejects are reportedly disposed off in an environmentally sound manner for backfilling purposes with proper safety measures.
3. **Other applications (e.g. brick kilns, road construction, etc.)**: There is a significant amount of rejects (having GCV between 1000- 1500 kCal/kg) which does not qualify for usage in FBC plants but have a market mainly in small industries like brick kilns, road construction, etc. The washeries reportedly auction these rejects to such consumers where it may be burnt in unregulated manner.

The utilization of these rejects in various applications can also cause additional environmental impacts which can have the potential to neutralize or negate the environmental benefit gained through the use of washed coal in place of the use of raw coal in thermal stations. Therefore, to study this in detail in the presence of the potential application of rejects, a comparative environmental assessment of the use of washery rejects in CBFCs has been undertaken along with use of washed coal for power generation vis-à-vis sole use of raw coal in conventional TPSs. If RoM (unwashed) coal is used for electricity generation, these rejects are in effect transported along with raw coal which is consumed at thermal power stations. Impact analysis due to use of coal rejects in combustion in other unregulated sectors has not been undertaken as part of the study because of non-availability of information on usage of rejects and emissions there from.

5.4 Study Methodology

Comparative assessment of emissions from utilization of rejects in CFBC and use of the washed coal vis-à-vis raw coal in TPSs has been performed based on three scenarios as presented in figure 12. Under scenario 1 (S1), TPSs using unwashed coal having ash content greater than 34% have been considered and their PM and CO2 emission has been estimated.

SOx and NOx have not been considered here. Under Scenario 2 (S2+F1), the power stations are assumed to use washed coal having ash content of 34%. Rejects thus generated from washing of the coal to bring ash content down to 34% have been assumed to be fully consumed in FBC based power plants. Emission inventory of PM and CO2 under S2+F2 is thus calculated. Finally in the third scenario, rejects have been considered in FBC technology with no pollution control equipment and consequent inventory is estimated. Finally the total emissions and emission per unit of electricity generated under the three scenarios have been compared.

Scenario description

Scenario (S1)	Scenario (S2+F1)	Scenario (S2+F2)
• **S1**- Considered those thermal power plants consuming greater than 34% ash content continue to consume high ash coal (>34%)	• **S2** - Considered those thermal power plants consuming greater than 34% ash coal starts consuming washed coal of 34% ash content, & • **F1** -100% utilization of rejects in FBC plants complying to emission norms.	• **S2** - Considered those thermal power plants consuming greater than 34% ash coal starts consuming washed coal of 34% ash content,& • **F2** - 100% utilization of rejects in FBC plants in uncontrolled manner having no PCEs.

Figure 12: Scenario Description

5.3.1 Detailed approach for emission estimation for scenarios

Emission of carbon dioxide and particular matter for three scenarios (i.e. S1, S2+F1, S2+F2) have been estimated based on the methodology given below.

1. Particulate emissions:

   $\sum Epm = \sum [Pc]a \times Ac\times (1–fbr)\times M \times(1–REa)$ ……………….. (1)

Equation (1) is used to estimate the particulate emissions. Where, Epm is the emission of particulates, [Pc]a is annual coal or reject consumption in TPS or an FBC plant, Ac is ash content of Coal or rejects , fbr is the ratio of bottom to fly ash for thermal or FBC plants, M = particulate mass fraction (0.4 for PM2.5 to PM10 and 0.75 for PM10 to total particulates following Mahtta et al., 2016), REa is the efficiency (%) of installed emission control equipment in thermal or FBC plants.

2. Carbon dioxide emissions: CO2 emissions of thermal power stations were calculated using the formula given below:

   $\sum CO_2=\sum[Pc]a \times GCV \times EF \times OF$ ………………. (2)

Where: CO2 emission of the station in a given year, [Pc]a amount of fuel of type consumed annually, GCV Gross calorific value of the fuel, EF is CO2 emission factor of the fuel based on GCV, OF is Oxidation factor of the fuel.

5.3.2 Key assumptions

The broad assumptions considered for the study are listed below; analysis specific assumptions are presented in detail in the subsequent sections.

Table 21: Assumptions taken for estimation of emissions

Components	Data /Assumption
Quality of raw coal at power station	Power station specific ash content in raw coal and has been used from secondary data sources GCV has been estimated from Ash-GCV relationship published in NIT – Rourkela study
Bottom to fly ash ratio and ESP efficiency of thermal or FBC plants	BFR for • thermal power plants is 0.25 and • reject consuming CFBC is 0.4 as per secondary literature and consultation; Removal efficiency of ESP is • 99.8% for S1, S2, and F1, • 0% i.e. no ESP in F2
Rejects quality and utilization in FBC plants	Assumed reject quality having ash content of 65% & GCV 1800 kcal/kg,

5.5 Comparative analysis of environmental impacts across scenarios

The quantity of rejects discarded from washing of raw coal has been estimated using ash% to clean coal yield relationship (as derived from data provided by CMPDI). The raw coal and washed coal consumption under S1 and S2 (as described in section 5.2.1) has been estimated using TPS specific coal consumption and reported electricity generation in these units for the year 2018. The total raw coal, washed coal consumed in power plants and the estimated generation of rejects from washing are given in table 22.

Table 14: Coal consumption & Electricity Generation for S1, S2 & F1 scenarios

	Coal Consumption (MT)	Electricity Generation (MU)
Raw Coal	357	524140
Washed Coal	311	500217
Rejects	46	29636 (100% uptake)

Using formulae (1) and (2), plant-wise emission inventory has been estimated for raw coal and washed coal under scenario S1 and S2 and as well for reject utilization in FBC technologies under F1 & F2. The results are presented in table 23.

Table 15: Scenario results for emissions

	Scenario 1	Scenario (S2 + F1)	Scenario (S2 + F2)
Quantity (MT)	357	357 (311 + 46)	357 (311 + 46)
Electricity Generation (MU)	524140	529854	529854
PM_10 (kT)	52.26	57.72	9029
CO2 (MT)	517.40	527.20	527.20
PM_10 per unit of electricity generated (g/kWh)	0.099	0.108	17.04
CO2 per unit of electricity generated (kg/kWh)	0.987	0.994	0.994

Utilization of rejects in CFBC played an extremely important role while analyzing emissions, and it is evident from the above analysis that even small share of rejects used without PCEs or if used in unregulated sector has the potential to sink the overall agenda of environmental improvement from washing of coal.

5.5.1 Comparative assessment of CO2 emissions

It can be inferred from the above table that if the thermal power plants use washed coal having ash 34% and all the associated rejects are utilized in CFBC plants (S2+F1), then the CO_2 emission per unit of electricity generated is slightly higher compared to S1 (0.987 kg/kWh vs 0.994 kg/kWh). The picture in regard to CO2 emission per unit of electricity generated in S2+F2 scenario also remains same (0.994 kg/kWh).

5.5.2 Comparative assessment of PM emissions

While analysing PM emissions, it should also be noted that the share of electricity generated (2018) from thermal plants having emission norms of 30 mg/Nm^3, 50mg/Nm^3, 100 mg/Nm^3 is 7%, 82% & 11% respectively (Author's analysis[41]). Given that the amount of reject uptake of 46 MT (assuming 100% utilization), 4 GW of CFBC capacity has been estimated to be required. There is no data available on existing capacity of CFBC using rejects also the current practices consume rejects after blending, however from stakeholder consultation it is learnt that nearly 15-20% of reject can go in existing CFBC and 80-85% of new capacity will needed to be installed in order to consume overall rejects. Thus new CFBC installations have to comply with 30mg/Nm^3 norm which will have lesser impacts.

The analysis shows the increase in PM emissions from use of rejects in (S2+ F1) where PM emissions per unit of electricity generated is 0.108g/kWh compared to 0.099 g/kWh in S1 scenario. While if the rejects are used in FBC plant having no pollution abatement technology, the PM emissions reach level of 17.04 g/ kWh (around 172 times more than S1 scenario). Thus, it will be detrimental for the environment to use rejects in an uncontrolled/inefficient manner.

[41] CEA database, analysed from date of commissioning of each unit of PP

5.5.3 Sensitivity tests and analysis

Based on the primary data received from CIL and private washery, sensitivity analysis case study (given in Annex VI) has been developed for reject utilization in FBC boilers. Rejects generated from Indian washeries vary in characteristics due to type of raw coal,washing characteristics(NGMI), technology of washing, etc. Accordingly, the quality and quantity will differ which will determine its preferred application or utilization. In the absence of the washery wise data, a sensitivity analysis is undertaken by varying these parameters in line with the primary data received from selected washeries.

The parameters which play determining role in generating emissions are:

Table 16: Sensitivity Parameters

Sensitivities	1	2	3	4	5
Bottom ash to fly ash ratio	0.4	0.5	0.6		
Heat rate of FBC	2800	2900	3000	3100	
Ash content in rejects	55%	60%	65%	70%	75%
GCV of rejects	2000	1900	1800	1700	1600
Total percentage of reject consumption in FBC	100%	75%	50%		

Out of these parameters, two variables that have major impact on overall emissions i.e. ash content and bottom to fly ash ratio in different scenarios of reject utilization.

<u>Results</u>

Net impact on emissions per unit of electricity generated is shown in table 25.

Table 17: Sensitivity analysis

		Sensitivity Test: Ash % of rejects		**Sensitivity Test: BFR of CFBC**
Red – Net negative impact compared to S1 Green- negative impact is neutralized to S1		When reduced to 55% from 65%	When increased to 75% from 65%	When BFR increased to 0.66 from 0.4
Impact on CO2 per unit of electricity generated	S2 + F1	0.62%	-0.63%	No change
	S2 + F2	0.47%	-0.48%	No change
Impact on PM per unit of electricity generated	S2 + F1	5.69%	-5.44%	-20.24%
	S2 + F2	18.82%	-16.03%	-64.71%

1. **Ash Content:** Net impact shown here (please refer Annexure VII.1 for results) shows rejects having ash content in the range of 55%-60% can be used in CFBC with PCEs (as in scenario S2+F1) as it could generate more electricity at comparatively low emission level. After reduction in ash content net negative impact compared to S1 is neutralized for CO2 but not for PM. However, rejects having higher ash content leads to more emissions and should be disposed off for backfilling purpose in an environmentally sound manner in order to minimize its impact on environment.

2. **Bottom to Fly ash ratio:** For the sensitivity analysis, two extreme scenarios of bottom-ash to fly-ash ratio (BFR) ratio - 0.4 & 0.66 - are considered for CFBC technology as per BEE guidelines for CFBC boilers. From the above analysis (please refer Annexure VII.2 for results), it is clear that BFR is critical factor while assessing the overall PM emissions. It leads to 20% and 64% increase in PM emissions per unit of electricity generated in S2+F1 and S2+F2 scenario respectively when BFR changes from 0.4 to 0.66. The technology having low BFR is preferable for the consumption of rejects. The difference in BFRs of CFBC & boilers in thermal power plants (sub-critical, super & ultra-super critical) requires much detailed assessment considering its criticality in generating emissions load.

5.5.4 Environmental Impact of rejects used in unregulated sector

As per the current practices of utilization of rejects in unregulated sector, there is no clear picture available regarding the technology of application in which combustion is taking place. From the stake holder consultations, it is learnt that the uptake is mainly through the auction procedure and distributed to the miniscule industries like road construction, civil works, bricks, ceramics, etc. The functional unit of output generated is also changes across different industries as unit for power is per unit of electricity generated which will be different for other unknown sectors like amount of bricks produced, length of road laid, etc. Thus, the comparative assessment cannot be done for the usage of rejects and due to lack of evidence and clarity on the data provided by CIL for reject sales on quantity of consumption & technology/application of its usage, it is difficult to quantify the environmental impacts especially air pollution such as PM. Also, there is no proximate and ultimate analysis data of rejects available with the concerned stakeholders for assessing other pollutants. Thus, this calls for complete inventory of technologies and much detailed assessment of environmental impact of rejects usage in each of the unregulated sector.

While CO_2 generated will be same in both the cases of reject utilization as fuel i.e. when rejects are used in totally unregulated manner or in FBC with full compliance with the environmental norms, if it used for combustion purpose as fuel.

5.5.5 Conclusion

From the environmental analysis, it can be concluded that the utilization of rejects can have significant environmental impact which has the potential to negate the positive environmental benefit gained through the use of washed coal. However, certain measures can be taken to control the impact of rejects. Globally, filling rejects in mine voids is the most common practice for disposing washery rejects. The same can be followed for high ash/low GCV rejects through proper engineering solution such as substantially upgrading high ash rejects, through compacting, etc. From the sensitivity tests, it is found that use of high GCV rejects is desirable in FBC plants as it returns positive environmental impact per unit of electricity produced. However, if high GCV rejects are used in FBC boilers or in other sectors, proper pricing (based on calorific value and ash content) and adopting/mandating stringent emission norms as per consuming sector/technology need to be done. Framing uniform reject utilization policy helps in setting up compliance norms for the sale/disposal by washeries. This compliance should be ensured through proper monitoring of sale, piling stock & disposal wherein a penal mechanism could be introduced for non-compliance.

5.6 Other anticipated benefits

5.6.1 Reduced fugitive emissions during transportation

Emissions from the initial coal preparation phase of either wet or dry processes consist primarily of fugitive particulate matter (PM) as coal dust from roadways, stock piles, refuse areas, loaded railroad cars, conveyor belt pour offs, crushers, and classifiers. These emissions of coal particulates and other air pollutants mainly occur during loading, unloading and en route. It is estimated that about 50% of the coal dust losses occur during journey time and 25% at loading and 25% at unloading[42]. There is some loss also due to spillage.

These fugitive emissions tend to cause both health and environmental impacts in and around the surroundings. However the use of washed coal can reduce these emissions during the transportation process. The reduction in the fugitive emissions will further benefit the environment and health.

5.6.2 Reduced fly ash

The fly ash generated in thermal power plants due to the combustion of coal can cause hazardous impacts on the environment and even public health. Hence, the options are either to reduce the fly ash generation at source or to utilize the generated fly ash in environmental friendly applications such as cement industry, bricks and tiles, road development etc. To encourage its utilization, Government is taking various policy steps however, the uptake remains at low level till now. While using washed coal, as a result of the improved GCV compared to raw coal, the specific coal consumption reduces and thereby the fly ash generation. This also indirectly lowers the requirement of water to effectively handle the fly ash in landfills. However, the utilization of co-produced rejects in FBC plants has the potential to neutralize or negate the benefits gained through the use of washed coal.

[42] Environmental Impacts of Coal Transportation. (1987). Environmental Impacts of Coal Mining & Utilization, 73–80. doi:10.1016/b978-0-08-031427-3.50013-x

Chapter 6: Summary

The non-coking thermal coal available in India has high ash content, low calorific value and low sulphur. Use of raw, blended or beneficiated coal with ash not exceeding thirty-four percent on an annual average basis was mandated by MOEFCC from 1stJune, 2001 for (a) any thermal power plant located beyond 1000 km from the pit- head and (b) any thermal Power plant located in urban area or sensitive area or critically polluted area irrespective of their distance from the pit head. Plants using specified types of clean coal technologies were, however, exempted from complying with the afore-mentioned stipulations.

Earlier vide notification dated 2ndJanuary 2014[43], plants located at distances less than 1000 km were also mandated to use coal with ash not exceeding 34%. Stand-alone thermal power plants of any capacity or captive power plants above 100 MW located between 750-1000 km and 500-749 km from pit-head were also required to comply with aforementioned ash content limits in coal on quarterly average basis with effect from 1 January 2015 and 5 June, 2016 respectively.[44] Onus for supply of such coal was put on coal supplier as compared to power plants, which were hitherto required to use such coal. Main reasoning behind limiting the ash content in coal seemed to avoid transportation of inorganic mineral matter in coal which does not serve any purpose in power generation but is rather detrimental to power plant equipment. Better utilization of capacity of railway wagons and rail transportation network, environmental benefits in transportation of beneficiated coal with less ash content from the washery to power plant are other intended benefits.

On 7thDecember 2015[45], new environment pollution norms notified by Government of India for thermal power stations tightened the emission norms in respect of PM and norms for SOx, NOx and mercury were introduced. Graded norms have been specified for power plants commissioned (a) before 31st December 2003, (b) after 31st December 2003 up to 31stDecember 2016 and (c) from 1st January 2017.This called for retrofitting/replacement of ESPs in the existing power stations and appropriate design of ESPs in the new plants for control of PM as well as addition of Flue Gas Desulphurization (FGD) and Selective Catalytic or Non-Catalytic Reduction (SCR/SNCR) systems for de-NOx operations. Various power plants are at different stages of implementation, ordering or design.

While, beneficiation of coal through coal washeries brings down ash content in coal, it also improves GCV of coal, and so reduces the amount of coal to be transported from the

[43] MoEFCC 2014.Notification on Environmental Protection Rule.https://ercindia.org/archive.ercindia.org/files/erc_desk/MoEF%20CC%20OM%20Reg%20coal%20in%20TPP%2002012014_gsr02e.PDF

[44] The latest MoEF&CC vide notification dated 21st May, 2020 has waived the stipulation of washed coal usage without any condition of distance or ash content.

[45] MoEFCC 2015.Notification for new environmental regulations – 7th December –2015. http://www. indiaenvironmentportal.org.in/files/file/Moef%20 notification%20-%20gazette.pdf

railhead to the power station, and results in increased moisture. However, during pilot study in NTPC Dadri, increase in NOx level has been observed while firing washed coal in the generating unit.

Cost of washing coal largely depends on ash content of raw coal, level up to which ash content is required to be brought down through washing, yield of washed coal vis-à-vis rejects, which eventually increases the price of washed coal. Distance for which washed coal is to be transported is the other important parameter affecting the relative reduction in the price of landed cost of washed coal at the power stations.

Pricing of Run of mine (ROM) coal in India is based on grade of coal (G1 to G17) notified by CIL time to time. The GCV range in each grade of coal is 300 kCal/kg. Estimation of ash% for a particular grade of coal is a challenge since GCV of coal depends on four components – fixed carbon (FC), volatile matter (VM), inherent moisture (IM) and ash. It may happen that coal with a lower ash% has lower GCV as compared to coal with higher ash%. Developing correlation between GCV of coal and ash% has been a key challenge in the study. Due to variety of coal used in power sector in India, it is essential to use complete proximate analysis of coal for conducting a proper study. In the absence of the same, the present study has been carried out using correlation between ash% and GCV as established by NIT, Rourkela.

Coal washing yields operational benefits to power stations in terms of better flame stability, reduced operation and maintenance cost, increase in PLF, improved life of boiler auxiliaries such as burners and mills, etc. Since majority of power stations in India use washed coal along with raw or blended domestic and imported coal, good set of studies in regard to operational benefits of beneficiated Indian coal are required in addition to pilot studies or simulation model results before making generic recommendations for various typesof plants using variety of coal.

Pilot studies (ORF[46], ADB studies[47], and Ronghe Committee) using washed coal in power stations carried out in the past show improvement in auxiliary power consumption (APC), unit heat rate (HR), availability/PLF. For the present study, BHEL carried out a simulation study for a 500 MW Unit which is designed for 42% ash, 0.49% Sulphur & GCV of 3400 kCal/kg. In the simulation study, coal fired with GCV of 4500 kCal/kg, 32% ash and 0.60% Sulphur showed deterioration in unit heat rate. Though, boiler efficiency is noted to increase by 0.5% for 10% ash improvement, but overall cycle efficiency is reported to have deteriorated by 0.12% due to reduction in main steam and re-heat steam temperatures. This leads to the conclusion that, studies for a good number of representative cases capturing unit size, actual unit configuration, age, coal characteristics, etc., are essential for drawing

[46] https://www.orfonline.org/wp-content/uploads/2017/07/ORF_Report_CoalBeneficiation_FinalForUpload.pdf
[47] https://www.adb.org/sites/default/files/project-document/72146/26095-ind-tacr.pdf

appropriate inferences and generic conclusions are not possible. Moreover, the studies show improvement in auxiliary power consumption (APC) of generating unit but there is variance in degree of improvement in APC in different studies. This again highlights the importance of plant specific assessment. The TERI analysis shows that the use of washed coal in power plants is economically beneficial for units if they meet three specified criteria's i.e.

- power plants receiving coal over long distances (over 600 km)
- RoM coal from mines with higher ash content (more than 39% i.e G-12 and lower grade)
- Washing yield more than (75%)

Washing of coal brings down burden of ash at ESP inlet which leads to reduction in emission of PM from stack. However, it needs to be analysed whether stack emissions comply with new environmental norms merely by washing of coal or retrofitting of ESP fields is also required. TERI's analysis showed that use of washed coal having 5-6% less ash in coal, in power generating station could reduce 20% PM emission from stack. However, this result is highly dependent on the assumptions in regard to bottom ash to fly ash ratio in boiler, collection efficiency of ESP, operational methodology of ESP, coal properties, etc. Analysis of cost applicable for reduction in stack emissions due to washing of coal to cost of ESP retrofitting to comply with new environment norms cannot be generalised, it rather needs to be unit specific.

The existing thermal power stations following old environment norms have following options to meet new environmental norms:

I. By coal washing alone, if possible.
II. By coal washing and smaller retrofit/new pollution control equipment.
III. A large retrofit / new pollution control equipment, with no coal washing.

It is extremely important to acknowledge here that the matrix of installed capacity of power plants, their unit configuration and vintage, operational health, coal quality , and location of power stations from mining and washing sites, etc. is quite complex. Such complexities in the Indian power sector call for the development of an integrated value chain framework and plant specific data analysis using that framework which will help in improved understanding of the impacts of use of washed coal over unwashed coal. Economic comparison of the three aforementioned options needs to be undertaken for each station / unit duly factoring in the relevant values as applicable along the value chain.

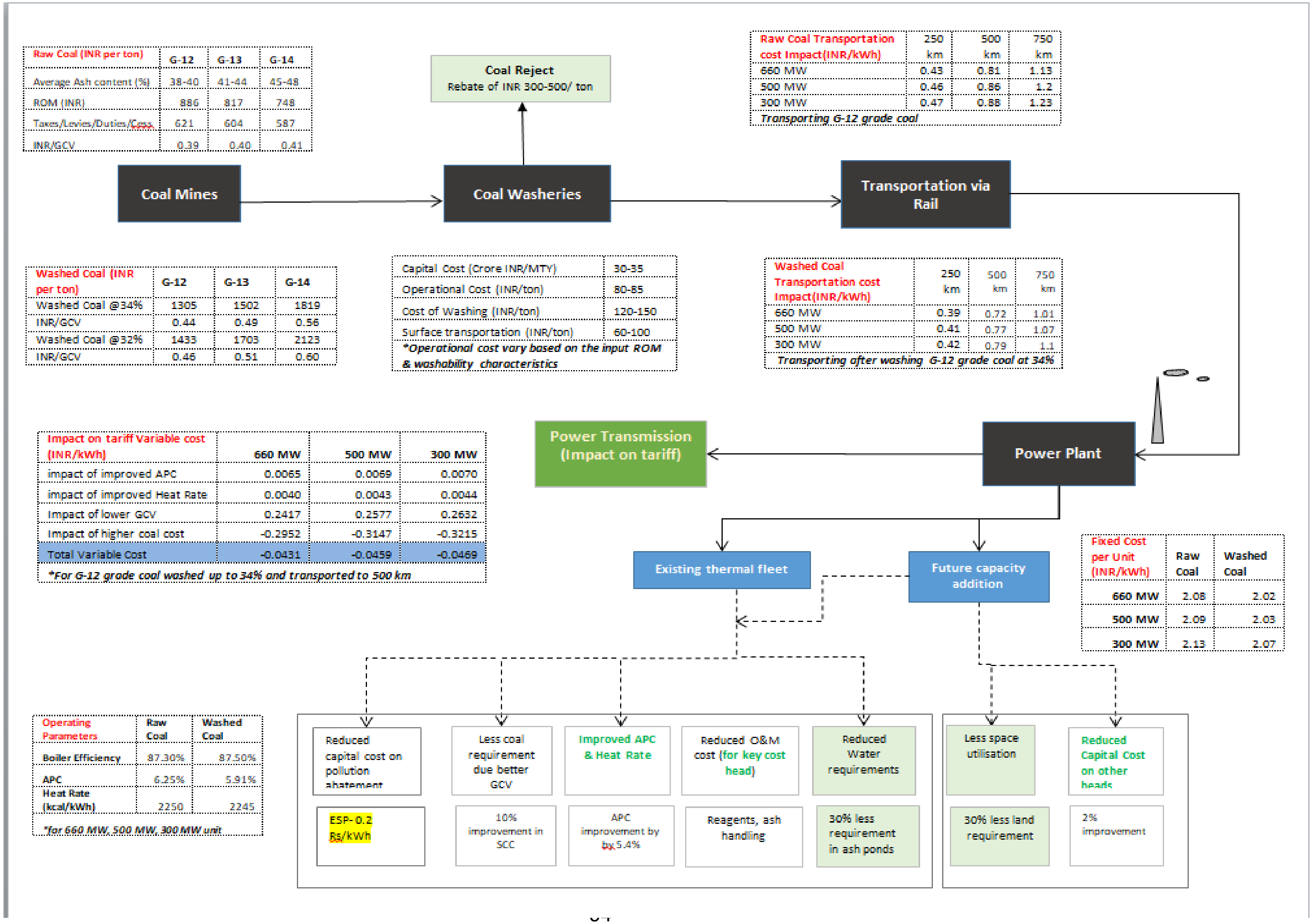
Another major emphasis associated with use of washed coal is its environment improvement potential due to the reduction of overall coal consumption at power plant owing to improvement in specific coal consumption for power generation. India in its Intended Nationally Determined Contributions (INDC) submitted to UN Framework Convention on Climate Change in October 2015, committed to undertake clean coal policy measures to combat global warming. Earlier studies have shown that the use of beneficiated coal leads to lower global warming impact due to its higher thermal efficiency. As per

TERI's analysis, a transition towards enhanced use of beneficiated coal having ash content of 34% leads to reduction of CO2 emission by 6% from the emission estimated current coal mix. A reduction of CO2 emission of 11% has been estimated to be achieved if the ash content in the washed coal is reduced to 30% from current coal mix. The monetised benefits for the emission reduction under the two scenarios have been estimated at INR 10.5 bn and INR 17.8 bn respectively. This will translate to Rs. 0.01/kWh and Rs. 0.02/kWh respectively. A comparative analysis of reduction in CO_2 emission due to lesser APC vis-à-vis CO_2 emission from electricity consumption for washery operations shows the incremental benefit of 3.64 KT, 2.92 KT, 2.12 KT, & 1.46 KT per million tonne of coal consumption for G-11 to G-14 grades of coal respectively. There will also be reduction in secondary CO2 emissions from lesser energy consumption in transportation due to reduction in quantum of coal to be hauled.

It is important to underline that the unregulated/uncontrolled use of washery rejects will negate the environmental benefits accrued from use of washed coal in thermal power plants. As per TERI's analysis, for the power plants consuming higher ash coal (>34%), the combined environmental impact per unit electricity from the use of washed coal and co-produced rejects with 100% utilization in FBC plants are slightly greater than those plants using raw coal when used in controlled manner. However, from the sensitivity tests, it is found that the usage of high GCV or low ash rejects in FBC plants with retrofitted ESPs and PCEs can be considered for usage as it can result in neutral environmental benefit per unit of electricity produced. Hence, there is a need to ensure that the washery rejects are used in a manner that has zero or minimal environmental impacts with the help of regulations, uniform reject utilization/disposal policy and stringent emission norms in those potential applications.

Reduction in coal quantity to be transported for giving same heating value in power generation and the attendant reduction in ash leading to reduced land requirement for ash disposal are positive spin-offs of the use of washed coal. Pending availability of comprehensive and granular data, means to be adopted by each power station to comply with new environmental norms for thermal power stations may be left to the power station/power utility as an interim measure. In the absence of holistic operational improvement cum economic analysis based on transparently measured and documented data, use of washed coal based on economics or constraints such as land for ash dumping, ash water requirement, etc., is required to be carried out. An integrated value chain framework has been developed for assessment of associated costs and benefits. Plant specific inputs to this framework would help each plant to decide best option for meeting new environmental pollution norms. And, given the fact the new notification has waived off the stipulation of washed coal usage in power plants based on the distance and ash content criteria, the adopted methodology in the study will help analyze the individual plants to meet the environmental norms in cost effective manner vis-à-vis plant can assess the economic effectiveness of washed coal usage across the value chain using plant specific inputs to arrive at the judicial decision for opting washed coal usage for power generation. Proper pricing of washed coal with specified GCV range and ash percentage holds the key for making it a win-win situation for coal supplier as well as power producer.

Annexure I (Economic Assessment): An Integrated value chain framework and economic impacts from use of washed coal



Raw Coal (INR per ton)	G-12	G-13	G-14
Average Ash content (%)	38-40	41-44	45-48
ROM (INR)	886	817	748
Taxes/Levies/Duties/Cess	621	604	587
INR/GCV	0.39	0.40	0.41

Raw Coal Transportation cost Impact(INR/kWh)	250 km	500 km	750 km
660 MW	0.43	0.81	1.13
500 MW	0.46	0.86	1.2
300 MW	0.47	0.88	1.23
Transporting G-12 grade coal			

Washed Coal (INR per ton)	G-12	G-13	G-14
Washed Coal @34%	1305	1502	1819
INR/GCV	0.44	0.49	0.56
Washed Coal @32%	1433	1703	2123
INR/GCV	0.46	0.51	0.60

Capital Cost (Crore INR/MTY)	30-35
Operational Cost (INR/ton)	80-85
Cost of Washing (INR/ton)	120-150
Surface transportation (INR/ton)	60-100
**Operational cost vary based on the input ROM & washability characteristics*	

Washed Coal Transportation cost Impact(INR/kWh)	250 km	500 km	750 km
660 MW	0.39	0.72	1.01
500 MW	0.41	0.77	1.07
300 MW	0.42	0.79	1.1
Transporting after washing G-12 grade coal at 34%			

Impact on tariff Variable cost (INR/kWh)	660 MW	500 MW	300 MW
impact of improved APC	0.0065	0.0069	0.0070
impact of improved Heat Rate	0.0040	0.0043	0.0044
Impact of lower GCV	0.2417	0.2577	0.2632
Impact of higher coal cost	-0.2952	-0.3147	-0.3215
Total Variable Cost	-0.0431	-0.0459	-0.0469
**For G-12 grade coal washed up to 34% and transported to 500 km*			

Fixed Cost per Unit (INR/kWh)	Raw Coal	Washed Coal
660 MW	2.08	2.02
500 MW	2.09	2.03
300 MW	2.13	2.07

Operating Parameters	Raw Coal	Washed Coal
Boiler Efficiency	87.30%	87.50%
APC	6.25%	5.91%
Heat Rate (kcal/kWh)	2250	2245
**for 660 MW, 500 MW, 300 MW unit*		

Annexure II: case study by CMPDI & NPC at Satpura thermal power plant

The study carried out by Central Mine Planning &Design Institute (CMPDI) and National Productivity Council (NPC) in 1988-89 at Satpura TPS of MPEB using 34 percent washed coal in one 210 MW unit brought out the following findings.

Parameter	From (RoM Coal)	To (with washed coal)	% Improvement
i) Improvement in PlantUtilisation Factor (PUF)	73%	96%	31.51%
ii) Improvement inGeneration in MU/day	3.71	4.83	30.19%
iii) Reduction in Specific Coal Consumption in Kg/Kwh	0.77	0.553	28.18%
iv) Elimination ofSpecific support fuel in ml/unit generated	5 ml	NIL	No need for support fuel
v) Reduction in Rejects	0.3-0.4%	0.03%	91.43%
vi) Increase in Boiler Efficiency	86.57%	89.51%	3.40%
vii) Reduction in Smoke & Dust Emission in g/m3	ESP inlet:29.78	17.23	42.14%
	ESP Outlet:1.57	0.299	80.96%
viii) Reduction in AlphaQuartz	14.5%	11%	24.14%

- **By CEA at NTPC Dadri power plant**

The analysis of the NTPC's Dadri Power Plant which used washed coal with around 34-35 percent ash from Central Coalfield Ltd.'s Piparwarwashery revealed the following results:

- Increase in operating hours up to 10percent
- Increase in PLF up to 4percent
- Increase in PUF up to 12percent
- Reduction in breakdown period up to 60percent
- Increase in overall efficiency up to 1.2percent
- Increase in generation per day 2.4 Million units (MU or million kWh)

Annexure III: Latest Data from NTPC Dadri power plant (as received from CEA)

Assessment of impact of washed coal carried out at NTPC Dadri power plant

To assess the actual performance of washed coal, a study was carried out at NTPC Dadri Power plant in its Stage-2 Unit-5 (490 MW unit size). However, as coal at Dadri is received from different sources, it is difficult to analyse the exact impact of only washed coal or raw coal on plant parameters.

To study the impact of washed coal, 100% CCL washed coal and CCL raw coal was fired on 03.02.20 and 22.01.20 respectively for 4 to 5 hours. The following data has been compiled for this period:

Parameter	Unit	03.02.2020	22.01.2020
		Washed Coal	**Raw Coal**
Load	MW	283	281
GCV	Kcal/kg	3849	3507
Avg. Heat Rate	Kcal/kWh	2380	2384
Sp. Coal	kg/kWh	0.618	0.680
Total coal	T/H	175	191
Total Air	T/H	1090	1162
Draft Power	kWh	4073	4357
Heat Rate	Kcal/kWh	No change	
Water consumption	KL/kWh	No change	
SO2	mg/Nm3	1143	1210
NOx	mg/Nm3	470	380

Table: Comparison of operating parameters

<u>Landed Cost of Coal</u>

Type of coal	Coal cost (Rs/Tonne)	Freight (Rs/Tonne)	Landed cost (Rs/Tonne)	Cost/1000 K.Cal
Washed Coal	2910	2160	5070	1.32
Raw coal	1980	2160	4140	1.18

Annexure IV: Cost heads from mine to power plant for different grades and levels of washing for plants situated at 1000km from washeries

G 12 grade coal washed up to 34% ash	Coal Mine		Transportation		Washery		Transportation		Power Station
Quantity (Ton)	1	>>>	1	>>>	0.86	>>>	0.86	>>>	0.86
GCV (kCal/kg)	3850		3850		4286		4286		4286
Ash(%)	39%		39%		34%		34%		34%
Price (Rs/Tonne)	1594		60		416		2225		4295

G 12 grade coal washed up to 32% ash	Coal Mine		Transportation		Washery		Transportation		Power Station
Quantity (Ton)	1	>>>	1	>>>	0.81	>>>	0.81	>>>	0.81
GCV (kCal/kg)	3850		3850		4445		4445		4445
Ash(%)	39%		39%		32%		32%		32%
Price (Rs/Tonne)	1594		60		549		2225		4427

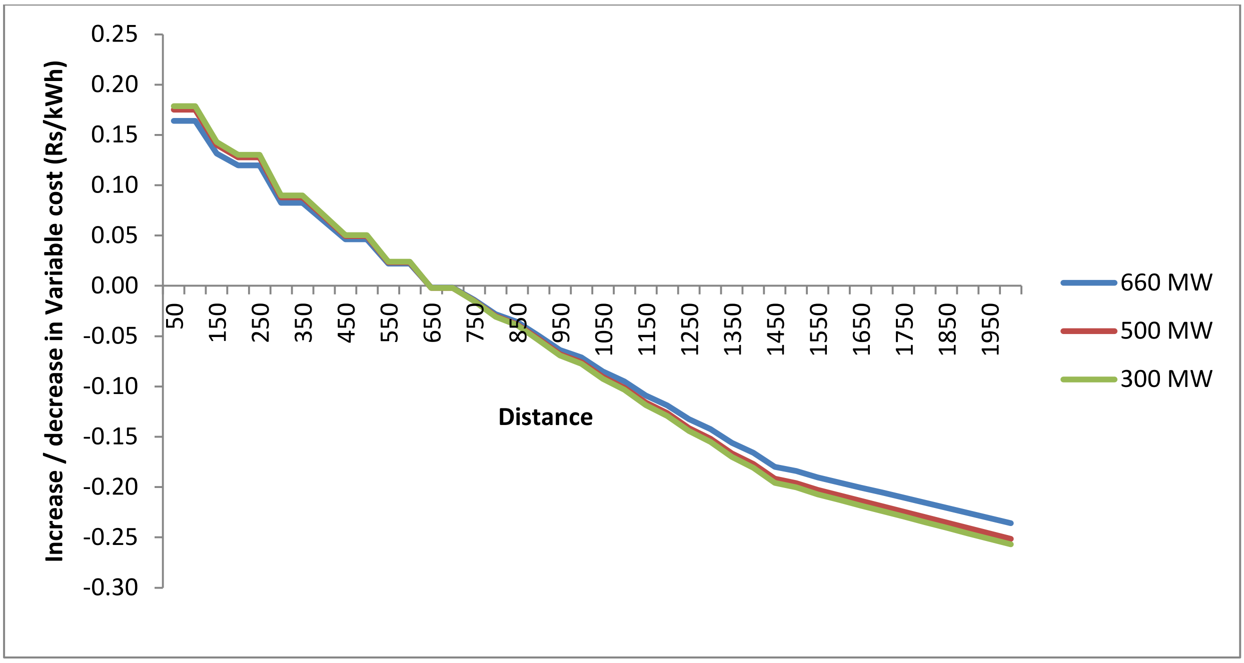
G 13 grade coal washed up to 34% ash	Coal Mine		Transportation		Washery		Transportation		Power Station
Quantity (Ton)	1	>>>	1	>>>	0.75	>>>	0.75	>>>	0.75
GCV (kCal/kg)	3550		3550		4286		4286		4286
Ash(%)	43%		43%		34%		34%		34%
Price (Rs/Tonne)	1508		60		688		2225		4480

G 13 grade coal washed up to 32% ash	Coal Mine		Transportation		Washery		Transportation		Power Station
Quantity (Ton)	1	>>>	1	>>>	0.69	>>>	0.69	>>>	0.69
GCV (kCal/kg)	3550		3550		4445		4445		4445
Ash(%)	43%		43%		32%		32%		32%
Price (Rs/Tonne)	1508		60		890		2225		4682

G 14 grade coal washed up to 34% ash	Coal Mine		Transportation		Washery		Transportation		Power Station
Quantity (Ton)	1	>>>	1	>>>	0.63	>>>	0.63	>>>	0.63
GCV (kCal/kg)	3250		3250		4286		4286		4286
Ash(%)	47%		47%		34%		34%		34%
Price (Rs/Tonne)	1422		60		1076		2225		4782

G 14 grade coal washed up to 32% ash	Coal Mine		Transportation		Washery		Transportation		Power Station
Quantity (Ton)	1	>>>	1	>>>	0.57	>>>	0.57	>>>	0.57
GCV (kCal/kg)	3250		3250		4445		4445		4445
Ash(%)	47%		47%		32%		32%		32%
Price (Rs/Tonne)	1422		60		1382		2225		5088

Annexure V: Unit size wise illustration of impact on variable cost due to coal washing of G13 coal washed upto 34%



Annexure VI: Case study of reject generation from different washeries, its utilization and contribution to emissions

Case Study for Existing, three washeries generating different quantity and quality of rejects and assessed emissions based on their utilization in CFBC plants. Two washeries are operated by CIL (piparwarwashery and bina washery) and another one is a private washery from Talcher area.

	Case 1 PiparwarWashery (CIL) - 2018 actual data	**Case 2 Bina Washery (CIL) - 2018 actual data**	**Case 3 Private Washery (Talcher area)**
Coal Washing capacity (MTY)	6.5	4.5	4
Raw coal (MT)	6.442794471	3.808	3.8 (at 95% utilization)
Clean coal Yield %	99.84%	83.59%	73.5%
Washed Coal (Ton)	6432486	3183000	2793000
Reject (Tons)	10510	625000	1007000
Ash% of raw coal	38%	NA	43.00%
Ash % of rejects	55%	70%	65%
GCV of rejects (kcal/kg)	2500	1400 shared by CIL very low grade rejects	1800
Reject Utilization in CFBC boilers			
Generation (MU)	8.5	306.8	593
Capacity (MW) required at normative generation	1.15	41.2	79
	Currently sold to local industry through e-auction, 5886.13 is utilized out of 10510 tons (56%)	1 unit of 40 MW, currently being not utilised as very low grade	3 units of 25MW each
PM *emissions* (kT)	0.003	0.206	0.359
CO2 emissions (kT)	9.96	355	686.99

**Yellow highlighted numbers are assumptions where actual data was not available*

Annexure VII: Sensitivity analysis of the reject quality parameters on emissions in different utilization scenarios

Sensitivity Analysis

1. Ash Content: Three ash content of rejects i.e 55%, 65%, & 75% and respective GCVs are considered for this case of sensitivity analysis

BFR = 0.4	Scenario 1	Scenario (S2 + F1)			Scenario (S2 + F2)		
		55% ash & 2000 GCV	65% ash & 1800 GCV	75% ash & 1600 GCV	55% ash & 2000 GCV	65% ash & 1800 GCV	75% ash & 1600 GCV
Electricity Generation (MU)	524140	533147	529854	526561	533147	529854	526561
PM_10 (kT)	52.26	54.96	57.72	60.49	7646	9029	10412
CO2 (MT)	517.40	527.20	527.20	527.20	527.20	527.20	527.20
PM_10 per unit of electricity generated (g/kWh)	0.099	0.103	0.108	0.114	14.34	17.04	19.77
CO2 per unit of electricity generated (kg/kWh)	0.987	0.987	0.994	1.001	0.988	0.994	1.001

2. BFR ratio: Two scenario of extreme extent of bottom to ash ratio (BFR) ratio i.e. 0.4 & 0.66 are considered according to BEE guidelines for this case of sensitivity analysis.

Reject Ash Content = 65% , GCV = 1800	Scenario 1	Scenario (S2 + F1)		Scenario (S2 + F2)	
	FBR = 0.25	FBR = 0.4	FBR = 0.66	FBR = 0.4	FBR = 0.66
Electricity Generation (MU)	524140	529854	529854	529854	529854
PM_10 (kT)	52.26	57.72	69.41	9029	14873
CO2 (MT)	517.4	527.20	527.20	527.20	527.20
PM_10 per unit of electricity generated (g/kWh)	0.099	0.108	0.131	17.04	28.07
CO2 per unit of electricity generated (kg/kWh)	0.987	0.994	0.994	0.994	0.994