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Internal and cross sectional benchmarking of electrical energy use in opencast coal mine

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Abstract
Electrical energy consumption in the opencast coal mine is very high. Electric shovels, pumps and coal handling plants consume 75% of the total electricity consumption of an opencast coal mine. In this paper, a modelling framework has been developed for electrical energy use benchmarking (internal as well as cross-sectional) of the mine. To develop a mine specific model for benchmarking electrical energy use statistical approach (linear regression method) has been applied. Specific power consumption (SPC) is used as a benchmarking index to assess the operating energy performance of a specific mine and multiple coal mines of India based on the field studies. Seasonal analysis of the electrical energy usage has also been analysed. Our results show the benchmark SPC as 0.50 kWh/t and the energy-saving potential as 10.7% for a single mine and the benchmark SPC of multiple coal mines as 0.52 kWh/t. The result concludes that SPC widely depends on its capacity and mining method and the developed model are useful for benchmarking and targeting for efficient electrical energy use in opencast mine.

Keywords
electrical, benchmarking, internal , cross sectional, specific power consumption, energy use, opencast mine

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ЭНЕРГЕТИКА, АВТОМАТИЗАЦИЯ И ЭНЕРГОЭФФЕКТИВНОСТЬ

Научная статья

Внутренний и перекрестный сопоставительный анализ потребления электроэнергии на угольных разрезах

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Аннотация
На угольных разрезах потребляется большое количество электроэнергии. Электрические экскаваторы, насосы и установки для перегрузки угля потребляют 75 % от общего объема электроэнергии. В данной работе представлена схема моделирования для проведения сопоставительного анализа (как внутреннего, так и перекрестного) потребления электроэнергии на предприятии. Для разра-

ботки модели сопоставительного анализа потребления электроэнергии на конкретном предприятии был применен статистический подход (метод линейной регрессии). Удельное потребление электроэнергии (УПЭ) используется в качестве контрольного показателя оценки энергоэффективности конкретного предприятия и нескольких угольных предприятий в Индии на основе полевых исследований. Также проведен сезонный анализ потребления электроэнергии. Согласно полученным результатам контрольный показатель УПЭ составляет 0,50 кВт-ч/т, а потенциал энергосбережения для одного предприятия – 10,7 %. Для нескольких угольных предприятий контрольный показатель УПЭ составляет 0,52 кВт-ч/т. Сделан вывод о том, что УПЭ в значительной степени зависит от производственной мощности, а разработанные метод и модель горных работ позволяют выполнить сопоставительный анализ и достичь эффективного энергопотребления на разрезах.

Ключевые слова

электрический, сопоставительный анализ, внутренний анализ, перекрестный анализ, удельное энергопотребление, потребление энергии, разрез

Благодарности

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Для цитирования

Topno S.A., Umre B.S., Aware M.V., Sahoo L.K. Internal and cross sectional benchmarking of electrical energy use in opencast coal mine. *Mining Science and Technology* (*Russia*). 2023;8(3):232–244. https://doi.org/10.17073/2500-0632-2023-03-100

Nomenclature

SPC	Specific power consumption, kWh/t
SPC_{BM}	Benchmark SPC, kWh/t
$SPC_{\mathrm{mine},\,BM}$	Mine Benchmark SPC, kWh/t
$SPC_{\min}$	Minimum SPC, kWh/t
E_c	Annual energy consumption, kWh
E_s	Energy-saving potential, %
Q_t	Annual composite production, t /y
Q_{coal}	Annual coal production, t/y
Q_{ob}	Overburden handled, t/y
ρ_{ob}	Bulk density of overburden, t/cu.m.
V_{ob}	Volume of overburden, cu.m./y

Subscripts and superscripts

a, *e*, *p*	Aggregate, equipment, progressive
i, *j*, *k*, *r*	month, year, equipment, mine

Abbreviations

Tr	Transformer
SECL	South Eastern Coalfields Ltd
BCCL	Bharat Coking Coal Limited
WCL	Western Coalfields Limited
CIMFR	Central Institute of Mining & Fuel Research
CSIR	Council of Scientific and Industrial Research

Introduction

Coal production is an energy-intensive operation in an opencast mine. Coal production in India accounts for 78 per cent of total mineral sector production. India produced 730.87 MT (million tons) of coal during 2019–2020[1] mined from both underground as well as surface mining methods. In India, about 94 % of the total coal production comes from opencast mining[2]. According to our review of data, it was found that the Specific Energy Consumption (SEC) of best practices opencast positive gradient mine in India is 123 MJ/t [1]. The Specific energy consumption of three large opencast mines of China when compared varies from 90–225 MJ/t [2]. Similarly, SEC for total operation for seven Canadian opencast mines varies from 97–256 MJ/t[3]. In India, the energy consumption in mining and quarrying consumes about 2.39 % of

[1] Ministry of Coal, Government of India. URL: https://coal.gov.in/index.php/major-statistics/production-and-supplies

[2] I bid.

[3] Canadian Industry Program for Energy Conservation (CIPEC). Benchmarking the energy consumption of Canadian open-pit mine. Report No. 2005. URL: https://www.nrcan.gc.ca/sites/www.nrcan.gc.ca/files/oee/pdf/publications/industrial/mining/open-pit/Open-Pit-Mines-1939B-Eng.pdf

industrial energy usage[4] and the US mining industry consumes about 12 % of total industrial energy consumption[5].

As the energy consumption in opencast mines is high involving energy-intensive operations such as drilling, loading, hauling, pumping, coal handling etc., its energy monitoring and performance evaluation is of paramount importance. Energy benchmarking is a powerful tool to assess the energy performance targeted towards a process, plant, commercial buildings etc. Benchmarking can be done by comparing the energy performance of similar plants including best practices in the specific sectors against one another also termed 'cross-sectional benchmarking'. Benchmarking is also feasible internally by time series analysis. The statistical approach has been applied by Boyd et al. for benchmarking energy in industrial sectors [3]. Cooke and Randal used a statistical method to establish an energy use benchmark by calculating energy consumption and production [4]. These approaches are defined as 'statistical energy benchmarking'. Model-based energy benchmarking for glass industries has been discussed by Sardeshpande et al. [5]. Beerkens et al. compared the specific energy consumption of glass furnaces for benchmarking the energy efficiency of glass furnaces [6]. Tan et al. developed an energy efficiency benchmarking methodology for the manufacturing industry [7]. Internal benchmarking of the industry has been done using linear Regression analysis of monthly energy consumption and production. Similarly benchmarking based on the best practices in terms of energy efficiency has been done for shopping centres in Gulf Coast region by Juaidi et al., [8]. From the above-mentioned review, it is learnt that there is a need for internal benchmarking as well as cross-sectional benchmarking to be applied for energy savings and enhancing energy efficiency. This fact has been supported by Wang et al. who revealed that there is no literature available on energy efficiency and benchmarking of mines [9]. Our attempt has been focused on Indian Coal mines. Techniques such as time series analysis, internal and cross-sectional benchmarking have been tried considering 4–5 years of field data.

Further, an analysis about mines indicates that Sahoo et. al [10, 11] has evaluated the energy efficiency of dump trucks in opencast mine. SEC have been used as an energy efficiency indicator for assessing the energy performance of mine dewatering systems [12], and for benchmarking energy efficiency of energy intensive industries in Taiwan [13]. Topno et al. used SPC as a performance indicator for benchmarking electrical energy consumption in a coal mine [14, 15]. In the present paper, benchmarking electrical energy use of opencast coal mine has been attempted by comparison method to know the performance of mine in different periods (yearly). The principal objective is to evaluate its best operational practices and set targets for the coming year. Energy performance during different operational conditions, round the year, has also been studied to get the practical benchmark for the opencast mine. A modelling framework has been developed for benchmarking using a statistical approach that remains applicable for mine. The model is extended further for electric energy usage in similar opencast mines in India. The model is tested in a large opencast coal mine of India using time series data by a statistical approach. Aggregate annualized data, as well as equipment wise data, have been analyzed to predict the benchmark SPC. The benchmark so obtained gave us the minimum power required for the mining process, which is the best practice followed within the mine during the past years. Energy-saving potential (plant) has been assessed that leads to continuous improvement and increased efficiency. The present paper is an extended work of energy efficiency benchmarking of power consumption in opencast mine by Topno et al. [14]. Apart from benchmarking in a mine, cross sectional benchmarking has been included.

1. Mining processes and energy usage

The mining process in an opencast mine includes drilling, blasting, excavation, transportation, crushing and sizing of the coal (Fig. 1). The coal extraction process from the mine could be either conventional, manual or mechanized. The major operating equipment in large opencast mine include high capacity electric rope shovels for loading operations, high capacity dump trucks for transportation of ore, diesel excavators, dozers and electric pumps for dewatering. The coal handling plant in opencast mine use crushers and vibrating screens to get sized coal as per the requirement of user. It is evident that to perform all major unit operations, input energy is needed. For bulky and heavy-duty mining operations in opencast coal mines, electrical power and diesel power (used as fuel in machines) are the major energy sources. The electricity consumption in shovel-dumper operated opencast mine accounts for 52 % of total energy supplied to the mine.

[4] Government of India, Ministry of Statistics and Programme Implementation, Energy statistics 2018: Central statistics office. URL: http://mospi.nic.in/publication/energy-statistics-2018

[5] US Energy information and administration, US Industrial sector energy consumption by type of Industry. URL: https://www.eia.gov/energyexplained/use-of-energy/industry.php

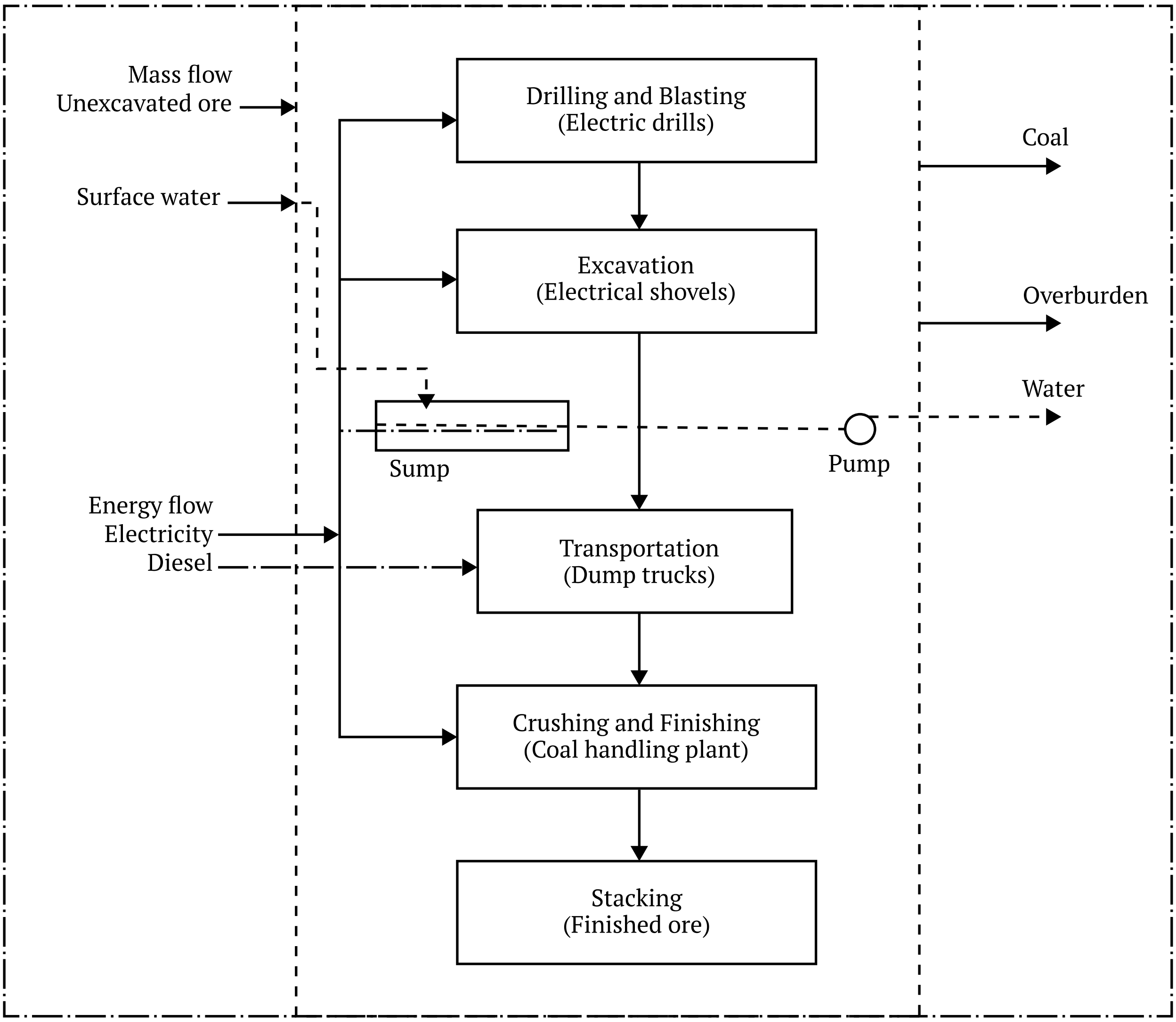

Fig. 1. Mining process of an opencast mine [14]

1.1. Electrical energy usage in opencast mine

As said above, energy input to the mine is diesel and electricity. Because of mobility, most or all HEMM's has Diesel as energy input mainly for operation whereas the electrical equipment, to which we targeted our study, are cables shovels, drills, crushers and coal handling plant (CHP) pumps and mine lighting. The energy consumption profile of an opencast coal mine (shovel-dumper combination) having a Coal Handling Plant (CHP) in terms of percentage has been depicted in Fig. 2. The share of electric operated shovels and CHPs is highest (more than 50 % of the total electrical energy input of the mine). Pumps contribute to 18 % of energy share, thus affecting the specific power consumption of the mine. This energy consumption is further linked with the rainfall that occurred in the mine area and pump usage i.e. running hours of the pump (s).

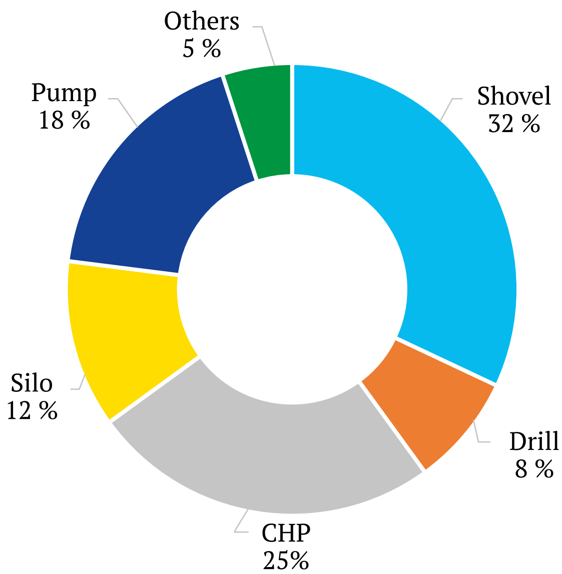

Fig. 2. Energy profile

1.2. Electrical energy distribution

Like the energy usages, the distribution of electrical energy has equal importance. 'High voltage' and 'Medium voltage transmission systems, are the two most important electrical distribution systems in nearly all the surface mines (an open-pit mine). High-voltage distribution line feeds most quarries since the electrical loads are generally located far from distribution mains. In the present case electrical power is supplied from 132/33 kV grid substation through step-down transformers (2 Nos. @ 36 MVA each). Primary voltage of 33 kV is common for mining equipment like electric shovels and drills. Coal handling plant, pumps and lightings are fed through medium/low lines of 6.6 kV/3.3 kV/440V. The single line diagram of the electrical distribution is shown in Fig. 3.

2. Methodology

Benchmarking for power consumption of open-cast coal mines has been done using a 'statistical approach'. Following two methods have been used:

1. Internal benchmarking (within the mine).
2. Cross-sectional benchmarking.

2.1. Internal Benchmarking

A statistical model is developed for specific power consumption (SPC) benchmarking from past data of power consumption and composite production. A flow diagram of the methodology (Fig. 4) shows the steps involved and the stages of model is described in Fig. 5. This is significant to note here that the energy has been used for handling both overburden and coal (a mineral). A composite production is considered for energy performance assessment and internal benchmarking i.e. within the mine.

The formula used for the specific power consumption (SPC) and monthly/yearly progressive consumption of process, equipment or a mine is described in the following paragraphs using equations 1 to 8 for detailed understanding further.

Progressive SPC of each process/equipment

The specific power consumption (SPC) for each progressive year (j = 1, 2...4) of all equipment/processes (drills, electric shovels, coal handling (CHP), pumps) is calculated using Eq. (1)

$$SPC_{j,k} = \frac{\sum_{k=1}^{n} E_{c,j,k}}{Q_{t,j}} \quad (j = 1, 2, 3...), \qquad (1)$$

where each equipment (k) is noted for shovels ($k = 1$), drills ($k = 2$), CHP ($k = 3$), Silo pumps and other miscellaneous equipment and E_c is the total yearly energy consumption for each equipment/process $k = 1, 2; ..., n$; Q_t is total composite production (the sum of coal production (Q_{coal}) and overburden handled (Q_{ob})) for $j = 1, 2...4$ and (Q_t):

$$Q_t = Q_{coal} + Q_{ob}, \qquad (2)$$

where

$$Q_{ob} = \rho_{ob} V_{ob}. \qquad (3)$$

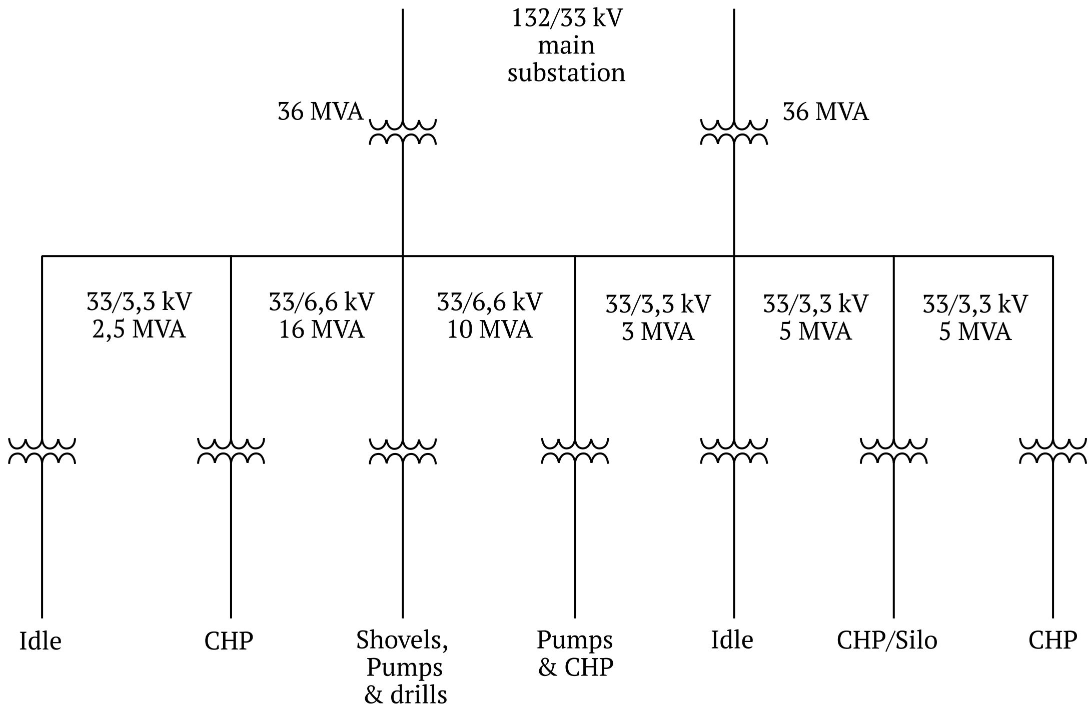

Fig. 3. Electrical distribution of an opencast coal mine

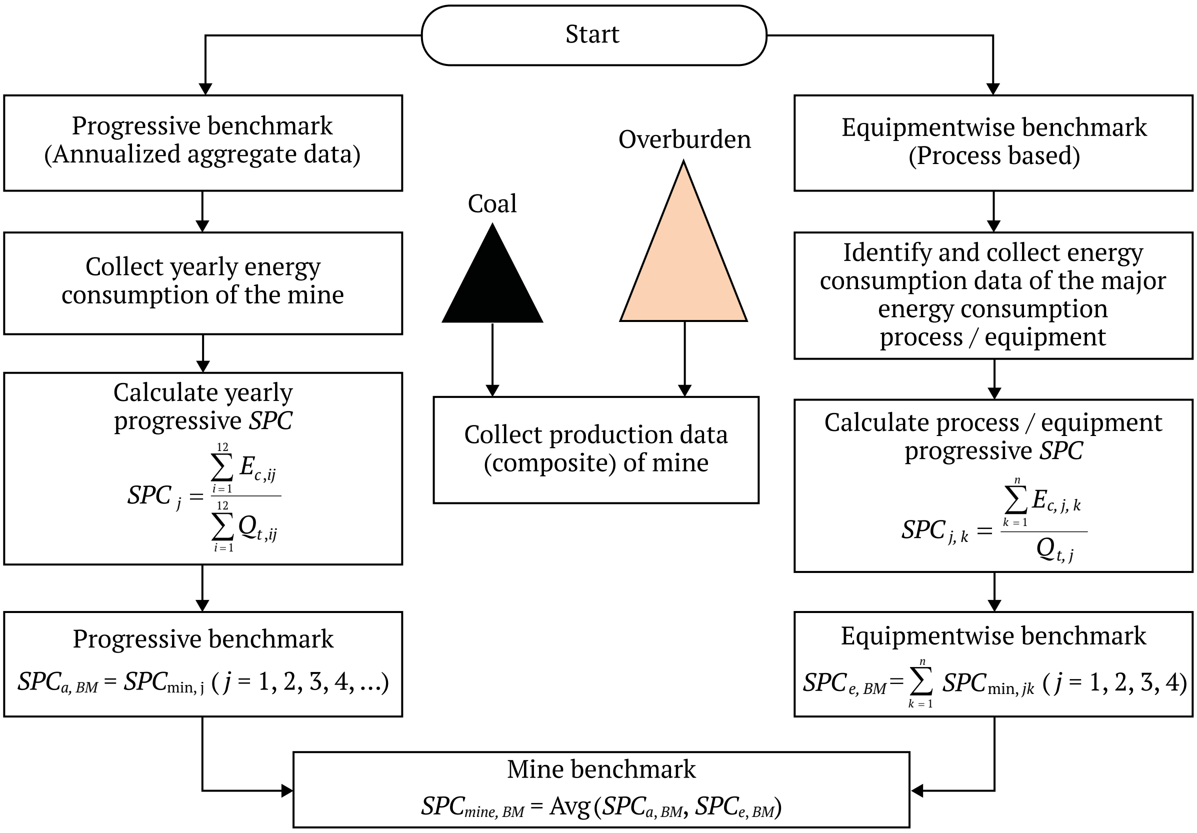

Fig. 4. Benchmarking methodology

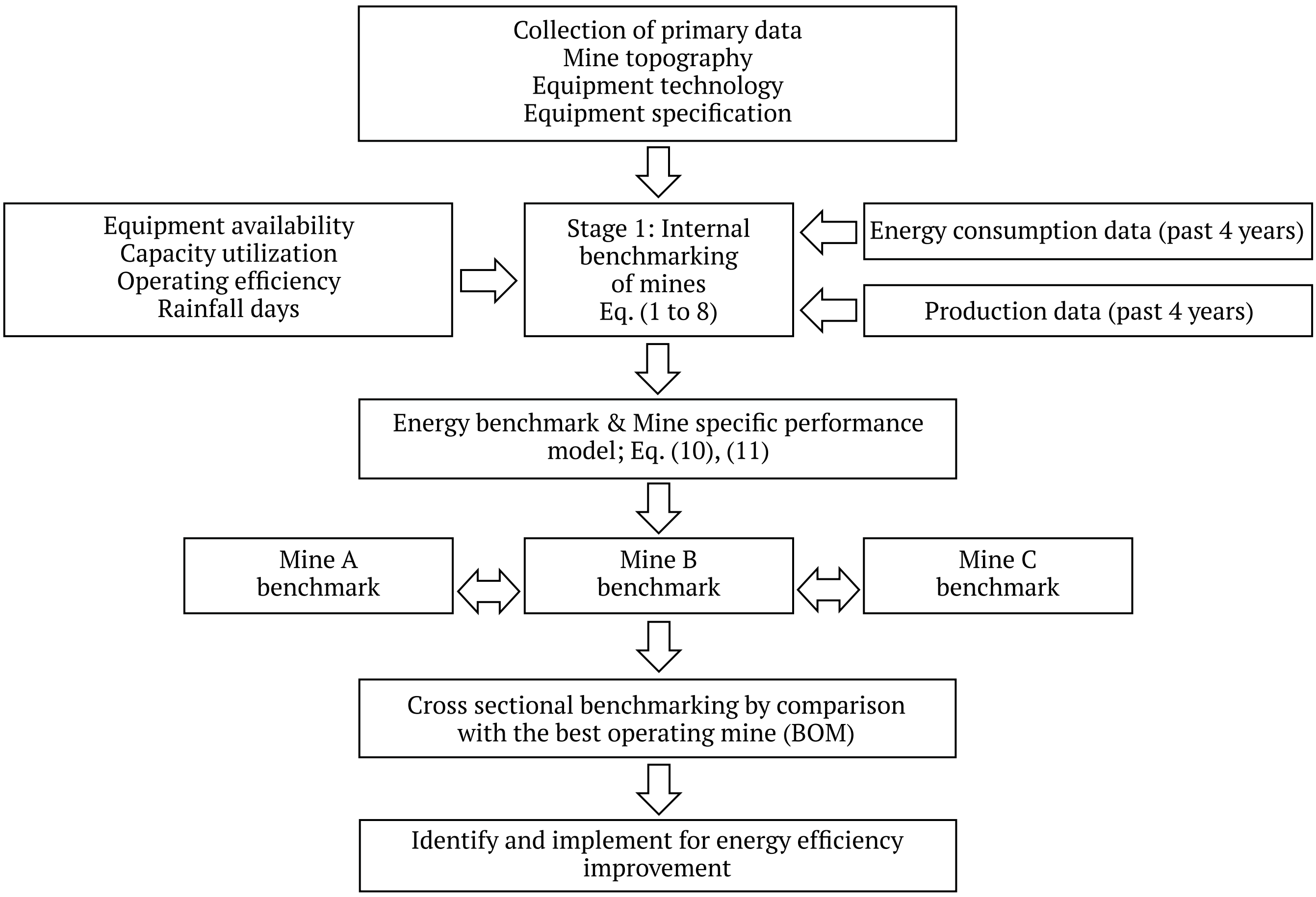

Fig. 5. Steps and the stages of the statistical model

Monthly and Yearly Progressive SPC of mine

SPC in kWh/t is defined as the ratio of total electrical consumption (E_c) to the composite production (Q_t) of a specific month/year. It has been evaluated using aggregated data of monthly/yearly energy consumption and composite production. Both, monthly as well as annual progressive SPC i.e. SPC_i & SPC_j has been studied to analyze the variations.

The monthly SPC is given as:

$$SPC_i = \frac{E_{c,i}}{Q_{t,i}} \quad (i = 1, 2, 3, ..., 12), \tag{4}$$

where $E_{c,i}$ – the energy consumption for ith month of the year and $Q_{t,i}$ – the composite production for the corresponding month.

The yearly progressive SPC (SPC_j) of j^{th} year is given as:

$$SPC_j = \frac{\sum_{i=1}^{12} E_{c,ij}}{\sum_{i=1}^{12} Q_{t,ij}} \quad (j = 1, 2...4). \tag{5}$$

Mine Benchmark

The benchmark SPC of the mine ($SPC_{\min e, BM}$) for the upcoming year is calculated from the average of the benchmark obtained from the Progressive SPC of each process/equipment and that obtained from the yearly progressive SPC of the mine.

The progressive SPC benchmark of equipment/process ($SPC_{e, BM}$) is estimated as

$$SPC_{e, BM} = \sum_{k=1}^{n} SPC_{\min, jk} \quad (j = 1, 2...4). \tag{6}$$

Yearly benchmark SPC for the mine is obtained by comparing progressive SPC of past 4 years and is obtained as:

$$SPC_{a, BM} = SPC_{\min, j} \ (j = 1, 2, 3, 4). \tag{7}$$

Hence, the overall benchmark of the mine is given as Eq. (9).

$$SPC_{mine, BM} = \text{Avg}\,(SPC_{e, BM}, SPC_{a, BM}). \tag{8}$$

2.2. Cross-sectional benchmarking

The cross-sectional benchmarking, for SPC, can be calculated or modelled using Eq. (9). This remains applicable for similar coal mines having shovel-dumper combination only and gets affected with the methodology of extraction (mining), equipment used, coal/ore/material handled and operational practices of the electric equipment:

$$SPC_{BM} = SPC_{\min, r} \ (r = 1, 2, 3, ..., m). \tag{9}$$

3. Case study

The statistical approach of benchmarking has been applied for evaluating a large opencast coal mine named, *Dipka Opencast Coal Mine*, located at Korba in the Chhattisgarh state of India. The mine is owned by M/s South Eastern Coalfields Ltd (SECL) – A Government Public Sector Company and is considered as an important and productive colliery of India. The input data of energy consumption, production (material handled by the mining equipment and utilities) was collected as primary data from the field visit of the *Dipka mine* during different periods of this study. The connected electric load of the mine is 38.49 MW that includes, 6.6 kV electric shovels of 42 m³ & 10 m³ bucket capacity; 3.3 kV/440 V pumps; Coal handling plant; Silos, and other electrical loads. The annual power consumption of the mine is 49 GWh (2014–2015). The installed production capacity of the mine is 25 MTPA and has an average stripping ratio of 1 : 1 which means one cubic meter volume of coal extraction will require 1 cubic meter overburden removal.

3.1. Energy performance

Dipka mine deploy different equipment in coal production. The equipment-wise SPC has been calculated from the electrical energy consumption of individual equipment operating in the mine using Eq. 1. given in the previous section. Fig. 6 shows the yearly variation of average SPC for each equipment. The average SPC has been considered for benchmarking due to the seasonal variation of electrical load. The minimum, maximum and average SPC of shovel, drill, pumps and CHP for the mine is analysed and the SPC band for mine equipment is shown in Fig. 7. The equipment operating and its energy characteristics is given as Table 1.

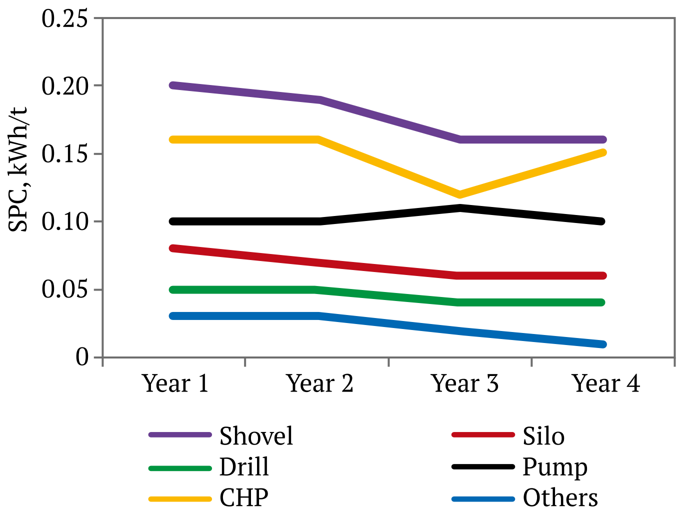

Fig. 6. Equipment-wise analysis of progressive SPC

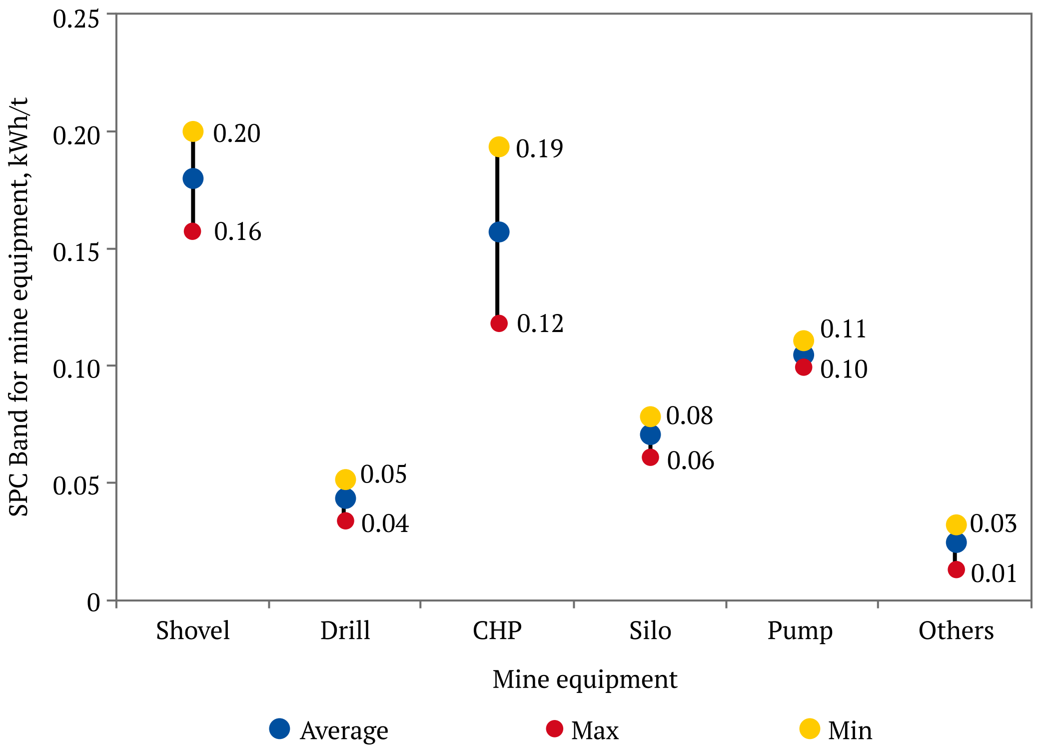

Fig. 7. SPC Band for mining equipment

Table 1

Equipment and energy characteristics of opencast mine (Case study)

Name of equipment	Process	Capacity	Make	Energy input	Energy usage, MUs/Kl/year*
Electric rope shovels	Excavation	42 cu.m	P &H and Bucyrus	Electricity (6.6 kV)	16
Electric shovel		5–10 cu.m			
Hydraulic shovels	Excavation	4,3 cu.m	BEML BE 1000	Diesel	1005
Payloader		0.96–10 cu.m			
Electric Rock drills	Drilling	–	–	Electricity (6.6 kV)	3
Hydraulic Rock drills	Drilling	6.3 inch dia, 8 m depth	IDM 30	Diesel	380
Large mining dump trucks	Transportation	240 t, 120 t, 100 t	BEML / Caterpillar / Terex	Diesel	6715
Large Dozers	Transportation	320 hp / 410 hp / 850hp	BH-35-II CAT834B Komatsu	Diesel	2899
Coal handling plant (CHP) and Silos	Crushing and sizing of coal	–	–	Electricity	20
Pumps	Pumping of mine water	2775 LPS	–	Electricity	10
Total energy consumption		–	–	–	49 MU

* MU = kWh in case of electricity consumption); Kl/year – in case of diesel consumption).

Table 2

Analysis of annual progressive SPC of coal mine

Year	Total Units consumed, kWh · 10^6	Coal, Mt	OB, Mt	Composite Production, Mt	SPC Composite, kWh/t
2011–2012	34.87	25.00	31.10	56.10	0.62
2012–2013	37.49	29.13	33.59	62.72	0.60
2013–2014	40.24	29.18	49.10	78.28	0.51
2014–2015	49.30	31.00	63.73	94.73	0.52
Average	40.48	28.58	44.38	72.96	0.56

Table 3

Analysis of annual progressive SPC of coal mine

Mines studied*	Annual energy, kWh · 10^6	Coal production, Mt	OB production, Mt	Composite production, Mt	SPC Composite, kWh/t
A	49	31	63.73	94.73	0.517
B	118	41	61.085	102.09	1.156
C	50	18.75	61.46	80.21	0.623
D	16.5	2.51	11.81	14.32	1.15
E	18	2.59	4.0145	6.60	2.727
F	8	1.34	2.077	3.42	2.339

* Means: Operating mines, Similar to the mine studied with different production capacity.

From Fig.7 it is clear that the minimum SPC of an electric shovel is 0.16 kWh/t and that of CHP is 0.12 kWh/t; for the pump is 0.10 kWh/t . The benchmark SPC of the mine based on the mining equipment and other utilities is 0.49 kWh/t. The SPC band for CHP is very wide due to variations in flow of coal input to the crushers and conveyors. For shovels, the SPC band is also high due to variations in operational practices and materials handled in the mine. The benchmark SPC by equipment-wise analysis is calculated as 0.49 kWh/t by comparing specific energy consumption data of all equipment.

3.2. Benchmark SPC within the mine

Progressive SPC of the mine is calculated from the annualized electrical energy consumption in the mine and the corresponding composite production. Analysis of annual progressive SPC of coal mining is given in Table 2. The average progressive SPC is 0.56 kWh/t of composite production whereas the minimum SPC is 0.51 kWh/t. Using Eq. (9) the benchmark SPC of the mine is estimated as 0.50 kWh/t.

3.3. Benchmark SPC for similar mines

The cross-sectional benchmarking of six operating mines (Mine – A, B, C, D, E, F) has been done by comparing the specific power consumption (Table 3)[6]. All these opencast mines of different capacities are the coal mines having similar features comparable with the mine, studied here.

4. Results and discussions

The estimated benchmark SPC for the case study is 0.50 kWh/t. However, the monthly SPC has wide variation throughout the year due to monsoon and the average minimum SPC for the off-rainy season is 0.43 kWh/t and for the rainy season, it is 0.52 kWh/t. The average progressive SPC is 0.56 kWh/t. Comparing the benchmark SPC and average SPC, the electrical energy saving potential is calculated as 10.7 %. The energy-saving areas can be identified by a detailed investigation based on a field trial of equipment operating in the mine using sophisticated energy audit instruments. A performance trial was conducted on P&H electric shovel operating in Dipka opencast mine and the SPC was calculated from the actual material handled and energy consumption for validation of the result. The SPC of an electric shovel alone is calculated as 0.18 kWh/t and accounts for 36 % of the total electricity consumption.

[6] CIMFR studies and technical communications on energy efficiency and benchmarking in Opencast mines. 2015.

4.1. Mine-specific energy performance model

The linear regression method has been used to obtain the correlation between specific power consumption (*SPC*) and composite production (*Q*) and the analysis results are summarized (Fig. 8). The variations of SPC with the composite production have been plotted. The scatter plot shows the relationship between the yearly aggregated progressive specific power consumption (SPC_a) and composite production (Q_t) and is given as Eq. (10) (the R^2 value of linear regression is 0.791):

$$SPC_a = -0.002Q_t + 0.771. \qquad (10)$$

The linear trend has a negative slope and indicates that SPC decreases with an increase in composite production. The above linear model can be used for the prediction of SPC with an increase or decrease in production rate. From Fig. 9 it is clear that energy consumption increases with the increase in composite production whereas SPC decreases due to optimum utilization of the mining equipment deployed at the mine. The model can be used to predict the SPC of the mine for varying material handling rates. A modelling framework was developed by Topno et al. [15] for assessing energy performance of electric shovel operating in the same opencast mine and the results obtained for *SPC* is 0.12 kWh/cu.m.

For another mine specific model given as Eq (11); a linear regression model from the actual aggregated past data of specific power consumption and composite production for a mine of different topography, equipment and energy characteristics as given in Table 4.

$$SPC_a = -6\times10^{-8}Q_t + 1.8995. \qquad (11)$$

Fig. 10 shows the linear model with different x-coefficient and constant. The constant and x-coefficient changes from mine to mine depending on both mine topography, equipment and their energy characteristics.

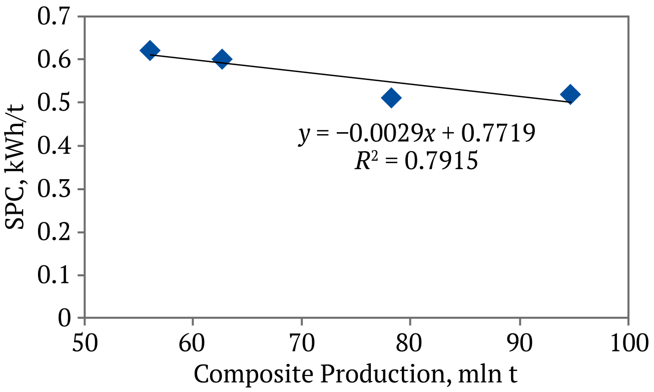

Fig. 8. Variation of SPC with production

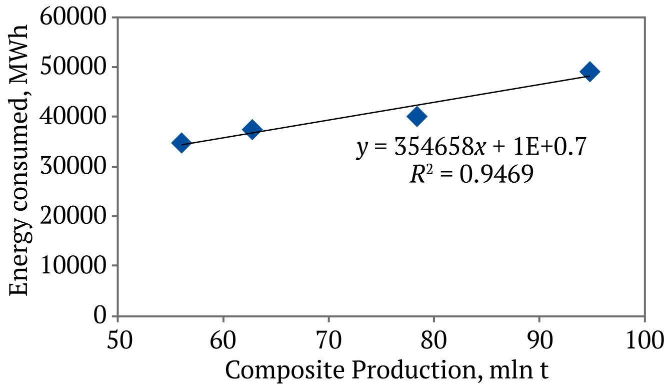

Fig. 9. Variation of electrical energy consumption

Table 4

Mine equipment and energy characteristics of Mine D

Name of equipment	Process	Capacity	Energy input	Energy usage (MUs)/Kl/year
Electric shovel	Excavation	2.4 Cu.m / 5 Cu.m / 10 Cu.m	Electricity (3.3 kV & 6.6 kV)	16.5 MU
Electric Rock drills	Drilling	160 mm		
Coal handling plant (CHP) and Silos	Crushing and sizing of coal	–		
Pumps	Pumping of mine water	732 lps.	Electricity 3.3 kV / 415 V	
Hydraulic shovels Payloader)	Excavation	3.5 Cu.m	Diesel	1557.6
Hydraulic Rock drills	Drilling	160 mm	Diesel	871.6
Medium mining dump trucks Scania dumpers	Transportation	(60 t, 50 t, 35 t)	Diesel	3106.6
Dozers	Transportation	320 hp/BD155 410 HP/BD355	Diesel	978.1

* MU = Million units (Million kWh in case of electricity consumption); Kl/year = kilo litres/year (in case of diesel consumption).

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The specific power consumption in the present models given in Eq (10) and Eq (11) shows its variation at different composite production for two opencast mines of different capacity, equipment characteristics as well as their energy consumption profiles. The equipment and energy characteristics affect the energy performance of the mine.

4.2. Seasonal analysis of SPC

A time-series data of monthly SPC has been plotted in Fig. 11. The analysis shows that the specific power consumption is higher during the month of July-October than the period between November-June. The composite production during these months is lower due to the effect of monsoon on mining operation and poor capacity utilization of electric shovels, drills etc. Further, the SPC is higher due to the increased load of pumps used for dewatering. The monthly minimum SPC of the off-rainy season and the rainy season plot (Fig. 12) shows that the average SPC varies from 0.43 kWh/t to 0.52 kWh/t. The seasonal analysis of SPC helps the mine management to prepare a monsoon plan to reduce energy consumption by optimizing the pump and machine operation schedule.

4.3. Benchmarking of similar coal mines

The results obtained by comparison of different opencast coal mines, studied by CSIR-CIMFR[7] for different energy efficiency projects are presented in Table 3, Fig. 13.

The aggregated SPC of similar coal mines varies between 0.52 kWh/t to 1.15 kWh/t, minimum being 0.52 kWh/t. As large mines (production capacity more than 30 Mt) makes use of high capacity electric shovel which are the major electrical consuming equipment (36 %). In smaller mines, producing 1.3 Mt to 2.6 Mt of coal, the SPC varies between 1.15 to 2.72 kWh/t.

4.4. Energy-saving potential

Estimation of the electrical energy saving potential, by comparing the progressive benchmark SPC ($SPC_{p,\ BM}$) and annualized average ($SPC_{a,\ Avg}$) is possible for a coal mine and this calculation is done using Eq. 12 given below.

[7] CIMFR studies and technical communications on energy efficiency and benchmarking in Opencast mines. 2015.

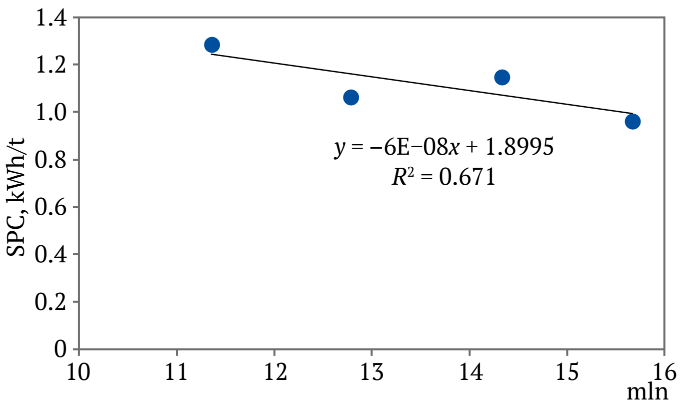

Fig. 10. The linear model with different x-coefficient and constant

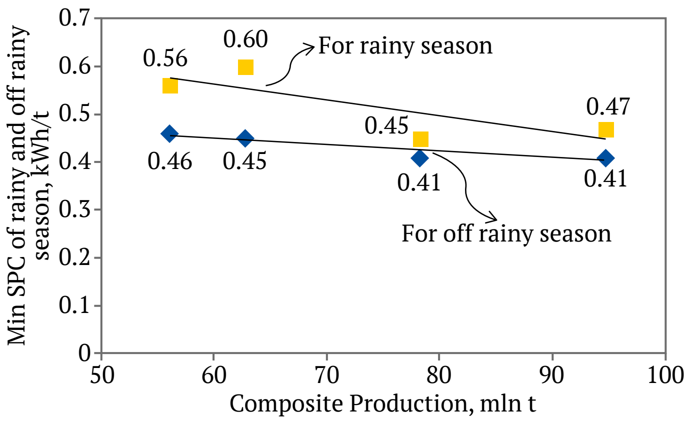

Fig. 12. Monthly SPC for the off-rainy and rainy season

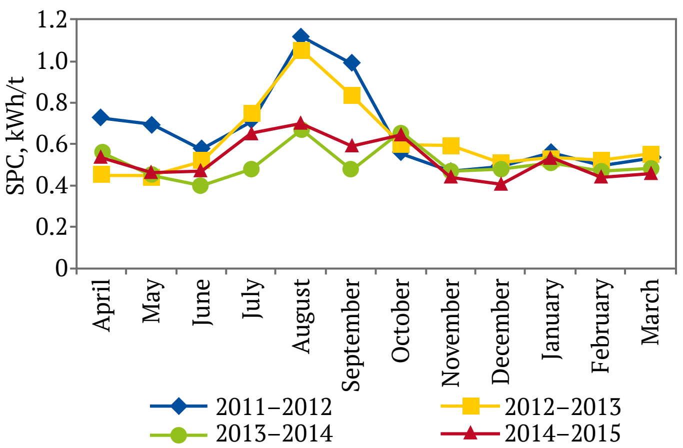

Fig. 11. Seasonal analysis of SPC

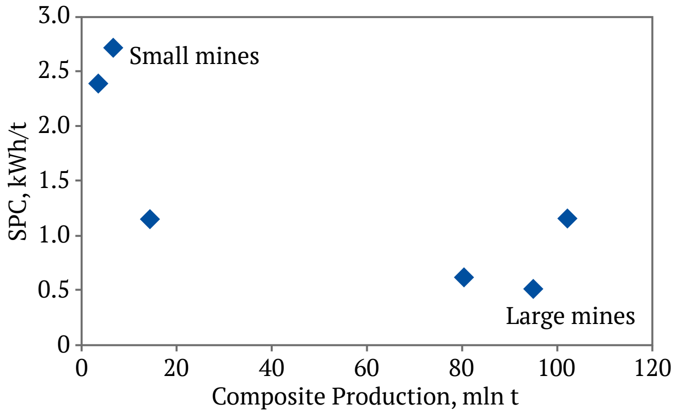

Fig. 13. The results obtained by comparison of different opencast coal mines

$$E_s = \frac{(SPC_{a,\,Avg} - SPC_{p,\,BM}) \cdot 100}{SPC_{a,\,Avg}}, \qquad (12)$$

where ($SPC_{a,\,Avg}$) is the average of annual progressive SPC and is given by Eq. (13)

$$SPC_{a,\,Avg} = \frac{\sum_{j=1}^{4} SPC_j}{4}. \qquad (13)$$

As per Eq. (12), the energy-saving potential of the mine is 10.7 % for the studied mine, which vary on each progressive year, based on the analysis of four years of data and the actual operating condition of the mine.

Conclusions

Benchmarking energy consumption is an effective tool to assess and compare the energy performance of the mines. Opencast surface mines, producing coal (or other minerals) are the industrial beneficiaries of the benchmarking. Both, internal benchmarking and cross-sectional benchmarking can be used by the mine management to identify the key areas that require performance improvement to reduce energy consumption and set up targets for the mining sector, to reduce industrial energy consumption. In this research paper, benchmarking work of the electrical energy usage for a large opencast mine of India has been done and the progressive benchmark SPC is estimated as 0.50kWh/t.

A new method of comparison and modelling using past operating data for each process as well as aggregated data of composite production and energy consumption, have been applied for various surface coal mines of both small size and large size. Linear regression methods have been used for solving the present mine specific data. Especially, coal mines of the Indian mining industry are targeted to predict the benchmark SPC. The benchmark obtained by internal benchmarking is useful to assess the energy efficiency of a specific mine and the SPC obtained by cross-sectional benchmarking is useful to assess the best performing mines with the best practices. The energy-saving potential of the mine has also been assessed.

In brief, it is concluded that the energy performance evaluation of a specific mine or a group of mine is feasible by benchmarking models suggested in this paper for mining sector and benefits by assessing and implementing the energy saving potential.

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