AN ANALYSIS OF ENERGY EFFICIENCY IN INDIAN RAILWAYS: 1964-65 to 1982-83

Dissertation submitted in partial fulfillment of the requirements of the Degree of Master of Philosophy of the Jawaharlal Nehru University, New Delhi

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I hereby affirm that the research for this dissertation titled "An Analysis of Energy Efficiency in Indian Railways: 1964-65 to 1982-83" being submitted to the Jawaharlal Nehru University for the award of the Degree of Master of Philosophy was carried out entirely by me at the Centre for Development Studies, Trivandrum.

Trivandrum
28-10-1985

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Certified that this dissertation is the bonafide work of Sri S. Raju and has not been considered for the award of any other degree by any other University. The dissertation may be forwarded for evaluation.

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Chapter 1

INTRODUCTION

In recent years, especially since the 'energy crisis' in 1973-74, the energy problem has emerged as one of the most important issues confronting most economies of the world. Undoubtedly, the OPEC played a major contributory role in placing energy at the fore-front of global economic issues by its decision to raise sharply the price of petroleum products, first in 1973-74 and recently in 1979-80. The impact has been more severely felt by the oil importing countries like India, and brought about a rethinking concerning energy consumption behaviour.

In India, about half of its present total commercial energy needs are met by oil and, for about 40% of our oil requirements we depend on imports.[1/] The most important and serious implication of raising oil imports is the strain on our balance of payments and inflationary pressure on domestic prices. When viewed in the context of our capacity to finance these imports out of foreign exchange earnings, the situation appears very serious. For example, about 64.49% of our export earnings in 1982-83 was spent to import oil alone.[2/] The Working Group on Energy Policy (1979)[3/] has noted that, if past trends continue, the consumption of petroleum products in India would reach 93 million tonnes by 2000 A.D. Of this, 73% of total oil requirements would have to be met from imports. In short, neither now, nor in the future will we be anywhere near self-sufficiency with respect to oil, the single most important source of commercial energy. This means that we have to forgo the major chunk of our scarce foreign exchange for the purpose of importing oil even in future. This supports the need for proper energy substitution and improving energy use efficiency. Since there is a close inter relationship between energy consumption and economic growth (particularly industrialisation and modernisation of transport and agriculture) the importance of such considerations will only increase with time.

Energy Consumption Pattern in India

Industry and transport are the two most important energy consuming sectors. They together account for nearly three fourths of total commercial energy consumption and this share changed only marginally after 1953-54, as is evident from Table 1.1. Therefore, any change in energy consumption in either of these sectors will affect the energy consumption pattern of our country. In the transport sector the relative importance of oil has been increasing as against in industrial sector where its share showed decreasing trend due to faster increase in electricity consumption. In the transport sector oil consumption increased by about 79% between 1953-54 and 1978-79, while it registered only 146% increase in industrial sector. In 1978-79 more than fifty percent of oil was consumed by transport sector lone. Thus from the point of view of oil consumption and its conservation, transport sector requires special attention.

Table 1.1: Sector-wise Total Commercial Energy Consumption 1953-54 to 1978-79

(MTCR)

Sector	1953-54	1960-61	1965-66	1970-71	1975-76	1978-79
Household	12.7 (21.3)	20.8 (20.6)	26.5 (18.0)	35.5 (18.0)	37.4 (14.8)	40.3 (13.7)
Agriculture	1.8 (3.0)	3.6 (3.8)	6.3 (4.3)	9.1 (4.6)	18.1 (7.2)	31.3 (10.6)
Industries	22.4 (37.3)	39.7 (39.2)	60.8 (41.4)	76.3 (38.7)	101.8 (40.3)	113.4 (38.5)
Transport	21.5 (35.8)	34.2 (33.8)	49.7 (33.8)	64.6 (32.7)	85.5 (33.8)	93.2 (31.7)
Others	1.7 (2.8)	2.9 (2.8)	3.7 (2.5)	11.8 (6.0)	9.9 (3.9)	16.1 (5.5)
Total	60.1 (100.0)	101.2 (100.0)	147.0 (100.0)	197.2 (100.0)	252.7 (100.0)	294.3 (100.0)

Source: Report of the Working Group on Energy Policy, Government of India (1979)

Note: Figures in brackets are percentage share of each sector.

MTCR stands for Million Tonnes of Coal Replacement.

Energy Consumption Pattern in Transport Sector

The transport sector in India uses prime fuels such as oil, coal and electricity for tractive effort. Two modes of transport, railways and roadways are, the principle users of commercial energy accounting for over 95% of the total consumption.

over 95% of the total consumption.

Though, the share of the commercial energy consumed in transport sector to total commercial energy consumed in the economy has remained somewhat steady around 33% from 1953-54 to 1978-79, the composition of energy sources has changed within the transport sector (Table 1.2). The most striking aspect is that, while in 1953-54 only 40.8% of transport sector's energy needs were met by oil, but its share increased sharply to 83.9% by 1978-79. This shift occured while the share of electricity remained same at 2.60% and the share of coal decreased from 56.4% in 1953-54 to 13.3% 1978-79. This, it seems, is one of the most important factor which needs attention and should lead to rethinking on the energy consumption pattern. This is so not only because of the financial or foreign exchange burden on the economy, as already indicated, but also because of the fact that oil is a non-renewable energy resource, for which global scarcity has set in. Total estimated confirmed oil resources are around 91,500 million tonnes, that is 32 times production of 1981 (2900 m tonnes). Therefore, even if the rate of growth of oil demand is checked the oil reserves are not expected to last beyond the turn of this century. None would, therefore, be optimistic about the availability of oil even at exorbitant price in the future. Under such circumstances the direct impact would be greater on the transport sector which is the single largest oil consumer in India.

Changes in the energy consumption pattern in the transport sector evolved mainly as a result of energy substitution and changes in the relative importance of road transport compared to railways. Different modes of transport use different energy sources at different efficiency levels. For instance, road transport depends on oil for motive power unlike railways which have an option among coal, diesel and electricity, and uses more oil to produce given mount of output compared to railways.[4/] Therefore, any change in the relative importance of transport modes will lead to changes in energy consumption pattern.

Table 1.2: Commercial Energy Used in Transport Sector

(MTCR)

Year	Coal	Diesel	Electricity	Total
1953-54	12.10(56.4)	8.76(40.8)	0.60(2.8)	21.46
1960-61	16.00(46.82)	17.37(50.83)	0.80(2.34)	34.17
1965-66	17.30(34.8)	31.26(62.9)	1.16(2.8)	49.72
1970-71	15.91(24.64)	47.23(73.14)	1.43(2.21)	64.57
1975-76	14.37(16.80)	69.29(81.00)	1.89(2.21)	85.55
1978-79	12.40(13.30)	78.18(83.90)	2.60(2.80)	93.18

Note: Figures in brackets indicate percentage share of each source of energy in total energy consumption in transport sector.

Source: Report of The Working Group on Energy Policy, Government of India (1979)

In India the bulk of transport demand is met by railways and roadways, although other modes of transport such as, air transport, coastal shipping, internal waterways, pipelines, traditional modes of transport etc. also have a share in it. A significant development in the transport sector is the marked shift in the relative share of rail and road transport in total traffic after 1950-51. Although, in absolute terms, on both the modes of transport, traffic have registered substantial increase, the share of road transport in both passenger and goods traffic increased at a much faster rate than of railways.[5/] Therefore, as the relative importance of roadways increased, oil consumption increased faster.[6/]

Another reason for increase in the share of oil, is energy substitution in the railways which started at the beginning of 1960's and gained momentum since 1970's. The Indian Railways have adopted a policy of phasing out steam locomotives from the system and replace them with diesel and electric locomotives. As a result of this, train-kilometres run by steam locomotives decreased from 89% in 1965-66 to 53% by 1979-80 whereas the share of diesel locomotives increased from 1% in 1965-66 to 53% by 1979-80. This led to an increase in oil consumption and a relative decline in coal consumption. In Indian Railways after 1969-70 coal consumption started to decline in absolute terms while diesel consumption has been increasing from 1960-61 onwards.

The railways being more energy efficient[7/] compared to other modes of transport, especially in the case of long distance traffic, if the declining trend in the relative importance of railways compared to road ways could be reversed, this would lead to a substantial amount of energy saving.[8/] It is due to this reason that National Transport Planning Committee[9/] (NTPC) opined that "the real resource constraint in determining an optimal inter-modal mix for the future should not be availability of monetary funds as shortage of oil supplies". Accordingly they have suggested that "Transport planning should, therefore, aim at optimum energy conservation, and measures geared to this objective should be encouraged and strengthened". In line with this objective, they have recommended increased use of railways for transport activity. Such a change in modal composition for transport can be brought about only by a considerable improvement in rail service in terms of price and quality. That is, an energy conservation policy in the field of transport must therefore necessarily include a whole series of measures to improve the attractiveness of railways.

One of the most important factors influencing consumers' preference for a particular mode of transport is the cost of transportation and the quality of the service (transit time, safety, punctuality of delivery etc.). Cost of transport or price charged by the railways to some extend depends on the working expenditure. In the case of the Indian Railways one of the major components of working expenditure is expenditure incurred for the purchase of energy. Further, this component of working expenditure has been increasing over time. In 1950-51 energy cost was 14% of total working expenditure, whereas it increased to 24% by 1982-83. This in turn influence the price charged by railways for its service. Obviously, as a result of this the demand for railway transport will get affected adversely. And it will also eat up the finance for other developmental activities of railways necessary to improve the quality of railway service. Therefore, it is very important for the Railways to conserve energy and use energy more efficiently.

To summarise, energy conservation in the railways is important from the point of view of (a) conserving scarce and non-renewable energy resources, (b) to save our country from severe balance of payments deficit and (c) to cut down working expenditure due to avoidable energy consumption. This underlines the need for the railways to evolve comprehensive strategies to conserve energy combining energy and financial economies.

Energy conservation in railways is possible either by substitution of energy sources or by utilizing energy more efficiently. There are several studies analysing the energy substitution issues of railways in India. The first study on this is one by the Railway Ministry in 1963.[10/] This study aimed at analysing "relative merits of dieselisation and electrification under varying Indian conditions of terrain and traffic density so as to enable the Railway Board to formulate their future traction policy". The major problem with this study is that, the approach to cost calculation was mainly financial and included only those costs directly incurred by the Indian Railways. For instance,the economic cost of foreign exchange, scarcity values of factors of production etc. were not considered in the cost calculation. But this limitations were rectified by the NCAER[11/] study and later it was updated and modified by Raj Committee.[12/]

Our study will be concentrating on the other aspect of the energy conservation namely, energy use efficiency which has received inadequate attention. Little is known regarding how energy utilisation by different tractions (steam, diesel and electric) behaved over time. The only systematic account of energy efficiency of rail transport available is the NITIE[13] study under the auspices of National Transport Policy Committee of the Planning Commission.[14] This study done in 1980 calculated energy efficiencies of different tractions of Indian Railways on the basis of average figures of fuel consumption and tonne-kilometres for three years, 1974-75 to 1976-77. They estimated 'energy intensities' which is a proxy for energy efficiency measured as energy requirement per unit of transport output, tonne-kilometres. Since their objective was to compare the energy efficiencies of different modes of transport and tractions of railways, they did not calculate how energy intensities changed over time and the factors influencing energy intensities.

Another study which examines energy efficiency is the study by Ministry of Railways (1980).[15] Although it examines changes in the energy efficiency of steam traction it had not examined it for diesel and electric tractions, which are more important from the point of view of the volume of traffic hauled by at present and energy conservation.

Therefore, in this context, it may be very useful to conduct a detailed study which clearly examines energy efficiencies in Indian Railways and to analyse the factors responsible for changes in energy efficiency. In this study we will try to examine the energy efficiency both from the point of view of physical indicators as well as money values which are relevant not only from the point of view of railways but also from the point of view of the economy as a whole.

Objectives:

The main objectives of the study are the following:

i. To analyse the changing pattern of energy consumption in Indian Railways.

ii. To estimate energy use efficiency and energy cost per tonne-km of Indian Railways from 1964-65 to 1982-83 and to analyse its trends.

iii. To analyse the factors affecting energy cost per unit of transport output and to examine how and to what extent each of the factors influenced energy cost efficiency.

and iv. To bring out the factors influencing energy use efficiency and to examine how these factors influenced energy use efficiency of each type of traction.

Structure of the Study

This study is divided into six chapters, Chapter 2 deals with the scope and methodology used in this study. This also includes operational definitions of certain concepts which are frequently used in this study. Chapter 3 is devoted to the analysis of changing energy consumption pattern. Chapter 4 attempts to analyse the reasons for changes in energy cost per unit of transport output. Chapter 5 examines changes in energy intensities of each traction and reasons for the changes in it. Finally Chapter 6 gives the concluding observations and policy implications of the study.

Notes and References

1. Assocham Parliamentary Digest, 1985 April and 1984 July.

2. Report on Currency and Finance, 1982-83, Vol.I, R.B.I.

3. Report of The Working Group on Energy Policy, Government of India (1979).

4. Report of The Fifty Second Round Table on Transport Economics: Transport and Energy, European Conference of Ministers of Transport 1981, Round Table 52.

5. Report of National Transport Policy Committee, Planning Commission, Government of India, (1980).

6. As we discussed earlier, since road ways fully depend on oil and it requires more oil per unit of output compared to railways, obviously this shift will lead to increased oil consumption.

7. Report of National Transport Policy Committee, op.cit.

8. Report of The Fifty-Second Round Table on Transport Economics: Transport and Energy, op.cit.

9. See reference 5 above.

10. Study of Electrification and Dieselisation on Indian Railways, Ministry of Railways, Government of India, (1963).

11. Economies of Diesel and Electric Traction, NCAER, (1970).

12. Study of Relative Economies of Diesel and Electric Traction on Indian Railways, Ministry of Railways, Government of India, (1978).

13. Energy Intensities of Transportation Modes: A Study Conducted for The National Transport Policy Committee (1980).

14. See reference 5 above.

15. Report of The Study Group on Economy in Energy Consumption: Coal, Ministry of Railways, Government of India (1980).

CHAPTER 2

SCOPE AND METHODOLOGY OF THE STUDY

In the introductory chapter we saw the importance of studying the changing pattern of energy consumption, and particularly energy efficiency in the Indian Railways. However, quantitative measurement of 'energy efficiency' is beset with conceptual and methodological difficulties. In this chapter, we will try to discuss the methodology followed in our proposed analysis and will define the concepts used. But before going into this in detail, some background information regarding Indian Railways is presented.

Growth of Indian Railways

In the middle of the nineteenth century railways in India were constructed mainly to serve the ends of the colonial administration. But gradually their sphere was enlarged to subserve the economic and commercial needs of the country as a whole.

After independence, with the partition of India in 1947, out of a total 65,000 Kms of track length over 11,000 kms went to Pakistan, along with the two railway workshops of Mougulpura and Saidpur. Apart from this the Second World War had run down the railway system badly and there were a large number of overaged engines, coaches, wagons and unrepaired tracks. This is clear from the fact that 27% of wagons, 30% locomotives and 36% of passenger coaches were overaged and should ordinarily have been consigned to the scrap heap.[1/] At that juncture Indian Railways had almost reached the breaking point and were forced to keep trains running until replacement would be made. Further, bridges and tracks needed very heavy repairs or renewals. This necessitated imposition of speed restrictions at hundreds of points, resulting in slowing down of the flow of rail traffic. This in turn led to increase in energy consumption per unit of transport output. For instance, in 1950-51 the rate of coal consumption to move 1000 tonne of goods over one kms in Broad Gauge was 192.2 lb, but as a result of the rehabilitation work done during Five Year Plans it came down to 186.6 lb by 1959-60 i.e.a fall of 3%.

Even under such circumstances, the bulk of transport in India was borne by the railways, especially bulk commodities such as coal, iron ore, steel, other ores, cement etc,, which are necessary for our industrialisation. Therefore, it was necessary to improve the railway system rapidly for the achievement of the objectives of national plans. The Five Year Plans of Indian Railways were, therefore, drawn up on this basis and in the First Five Year Plan 50% of the total outlay for transport sector was for rehabilitation of depleted assets and indigenous development of railways. But the movement capacity was greatly strained and at the end of the First Five Year Plan rail transport demand was well ahead of the supply.

Thereafter, all the plans of Indian Railways aimed at development and modernisation, inorder to increase transport capacity to cater to the transport demands of the time, and additional traffic likely to be generated. For this purpose, they have increased the transport capacity by improving wagon capacity, locomotive capacity, passenger coaches, doubling of tracks etc. This can be observed from the Table 2.1. Moreover,

Table 2.1: Indices of Growth of Transport Capacity

Year	Wagon Capacity	Passenger Coaches	Tractive Effort of Locomotives
1950-51	100	100	100
1955-56	118	122	117
1960-61	152	154	144
1965-66	206	174	175
1968-69	217	194	180
1976-77	256	200	193
1977-78	259	202	199
1978-79	262	205	202
1979-80	266	208	205
1980-81	269	209	201
1981-82	265	208	206
1982-83	264	206	192

Source: Indian Railway Year Book, Ministry of Railways, (1982-83)

All these modernisation activities together improved efficiency in the utilization of the existing capacity of the railway system. This is reflected in the utilization figures for wagon, passenger coaches, locomotives and track, given in the Appendix I. All these efficiency parameters show progress in this respect. But it is far from clear, as we said in the introduction, how the energy efficiency of different tractions in Indian Railways changed over time. At this point let us discuss some of the problems involved in the calculation of energy efficiency.

Indicators of Energy Efficiency

Energy efficiency relates energy consumption and outcome of the activities for which energy is used. In railways, energy efficiency indicates the relationship between quantity of energy used and outcome of vehicle propulsion, that is, transportation output. The most commonly used measure of energy efficiency is 'energy intensity' which measures energy needed to produce a given unit of transport output. It is conventional to take the ratio of the total energy consumption to transportation output.

As already mentioned, railways use three forms of energy to produce motive power, and each form is quantified using different units of measure. For our purpose, it is important to aggregate all these different energy forms. Therefore, a common unit of measure is required to aggregate different forms of energy, expressed in different units. Using the common unit of measure, different energy forms can be brought into a common scale of reference for the purpose of comparison and aggregation. Different standard units are used by different countries and agencies, (Examples of them are BTU, Joule, Calorie Coal equivalent etc.[3/]) Since these units are interchangable, selecting an unit of measure is only a matter of convenience. For our purpose, we may use calorie, which is defined as the heat required to raise the temperature of one gram of water from 14.5° c to 15.5° c at constant atmospheric pressure.[4/] The conversion rates used to change different units of energy into caloric values are presented in the Table 2.2.

Table 2.2: Energy Conversion Factors

Fuel	Unit(Original)	K.Cal Equivalent
Coal	1 tonne	5.9297000 K.Cal x 10^6
Diesel	1 kilo litre	9.1303680 K.Cal x 10^6
Electricity	1 kilo watt hour	0.0008600 K.Cal x 10^6

Applying these conversion factors to their respective estimates of energy consumed provides calorie value of energy consumed.

Energy efficiency is defined as the ratio of the total energy consumption to transportation output/service. As for the denominator in this ratio, unlike the material outputs, transport output cannot be measured in either in terms of its volume, mass or length because of its distinctive characteristics. While quantifying transportation output, two most pertinent characteristics of transport output, such as quantum transported and distance transported, have to be taken into account. Therefore, the measure used to quantify transportation output should be able to capture both the dimensions of transport output. The most common measure for this purpose, is gross tonne-kilometre which represents transportation of one tonne of goods/passenger over one kilometre (GTK). This includes the weight of the motive unit, vehicle and contents. It is important to consider the weight of the vehicle and motive unit apart from pure transportation output while calculating energy intensity, for, energy intensity appears to be a function of total weight and distance moved. That is, even if the train is moved empty (without passenger or freight) locomotive have to haul the vehicle and itself, for this purpose also it consumes energy. Therefore, it is preferable to consider the gross-tonne kilometre (GTK) in calculating energy intensity, rather than net-tonne kilometres where only weight and distance of goods or passenger alone is considered.

It is clear from the introductory chapter that both physical and financial aspect of the energy efficiency are important. Energy intensity calculated on the basis of the above mentioned operational definition (energy intensity is the ratio of the total energy consumption, measured in K.Cal., to transportation output, measured by the GTK hauled) reflects only physical dimension of energy efficiency. In order to capture the effects of energy price changes on the financial economy of rail transport energy intensity measured in physical terms have to be supplemented with price information and expressed in monetary terms. For this purpose the energy cost per unit of GTK is calculated, which is termed as energy cost index (ECI) in this study.

Having explained the basis of estimation of energy efficiency used in this study, let us now discuss at what level of aggregation we should calculate energy intensities. Energy intensity measures the energy required to move an unit of GTK by a given vehicle. For an entire system the average value of these measures gives total energy 'intensities' of the particular mode of transport or traction. However, total energy 'intensities' conceals wide variations in energy intake, depending on differences in operating conditions such as speed, load, type of service etc.[5/] Further, it is quite likely that operating conditions are different among different modes. Therefore, apart from total energy intensities, we will also calculate energy intensities of each mode of traction separately, which will enable us to compare changes in energy intensities of different tractions.

Scope of Present Study

Energy is used in Indian Railways mainly for vehicle propulsion, vehicle manufacture etc. But vehicle propulsion requirement constitutes about 95% of the total consumption of railways. Due to this quantitative importance, the present study is restricted to the energy consumption of vehicle propulsion only. This does not imply that energy consumption for other purpose, non-propulsion, is necessarily less important. On the contrary it may be more important in a context where comparative energy economy or energy cost of different modes of transport are considered, particularly when total energy requirements of different modes are compared. For instance, a particular mode say water transport may require lesser investment in permanent ways (such as roads or rails) and other fixed assets in comparison with other surface modes. Hence even if propulsion energy intensity of water transport has the same magnitude as surface modes, it may have a lower energy intensities measured in overall terms than in terms of energy needed for propulsion only. But we do not propose to do any inter-modal comparison of energy intensities for different modes of transport, therefore, we restrict our study to the energy intensities of vehicle propulsion alone.

There are different types of rail service in Indian Railways, generally categorised into three viz., suburban service, non-suburban service and rail car service. It is well known that the operating conditions of railcars and suburban trains are entirely different from the general main line trains. These differences in operating conditions have their bearing on the energy consumption behaviour. Therefore, in order to avoid the wide variations in the energy intensities calculation we exclude the energy consumption and transport output of rail cars and suburban trains, and concentrate only non-suburban traffic, which constitutes 100% of freight traffic and 91.6% of passenger transport.

Data Base

We base our study on the data obtained from the various publications of Indian Railways such as Annual Report and Accounts, Annual Statistical Statements, Indian Railway Year Books etc. Apart from this we have collected data and other information from the official records and files of the Railway Ministry as well. Adequate data required for our purpose is available only from 1964-65 onwards.[6] Therefore, we limit our time period of observation from 1964-65 to 1982-83.

One problem arising out of the published data on energy consumption, given in the Annual Statistical Statements is that these figures are not given for passenger and freight services seperately. Rather, it is classified into three heads, viz., energy consumption by passenger, mixed trains and freight trains.[7] Therefore, we are not in a position to disaggregate our analysis into passenger and freight trains seperately, which might have been more meaningful.[8]

The data used in this study is mainly from Annual Statistical Statements[9] of various years. Thus unless otherwise mentioned the data would be from this source.

Notes and References

1. G.S. Khosla, Railway Management in India, 1972 Thacker, Bombay.

2. Report of The Railway Fuel Economy Enquiry Committee, Vol.I, Ministry of Railways, Government of India (1953).

3. For details see; Ashok V. Desai; Energy Output and Consumption in India — A Methodological Review, Working Paper No.97, Centre for Development Studies, Trivandrum 1979.

4. Ibid.

5. This issue, that is how the operating conditions of each mode of traction influence energy intensities, is the subject matter of the fifth chapter of this study. Therefore, we do not elaborate it here.

6. For example electricity consumption figures are not available for pre-1964-65 period.

7. Mixed trains are those train services scheduled to carry passenger and other traffic booked at goods rates. If the volume of goods are more in the train then it is classified into goods and mixed category and other wise passenger and mixed category.

8. Due to wide variations in the operating conditions of these two types of services the energy consumption behaviour is also likely to be different, therefore, the aggregation of freight and passenger trains would conceal interesting informations. Hence, a disaggregation into passenger and goods traffic may provide more meaningful results to interpret.

9. Annual Statistical Statements, Ministry of Railways, Government of India, Various issues from 1964-65 to 1982-83

Appendix I

The capacity utilisation of wagons, passenger carriages, locomotives and track can be reflected in the net tonne kms per wagon capacity per annum, passenger kms per 1000 seating capacity, net tonne kms per engine hour and net tonne-kms per route km or passenger kms per route km respectively. These are presented in the below given Tables

Table 1

Year	Net tonne-kms per tonne of wagon capacity per annum		Passenger kms per 1000 seating capacity	
	B.G	M.G	B.G	M.G
	(In terms of 4-wheelers)		(In millions)	
1950-51	11,833	9,021	-	-
1960-61	16,558	10,125	61.2	44.4
1965-66	15,567	12,255	65.4	47.6
1976-77	16,754	12,843	87.3	63.3
1980-81	16,285	11,013	105.2	71.0
1982-83	18,464	13,091	114.4	75.7

Source: Indian Railways Year Book, 1982-83

Note : BG = Broad Gauge; MG = Metre Gauge

Table 2

Year	Net tonne kms per engine hour		Net tonne-kms (millions) per route km	
	B.G	M.G	B.G	M.G
1950-51	3,282	1,238	1.50	0.25
1960-61	4,170	1,766	2.76	0.54
1965-66	4,446	2,194	3.40	0.76
1976-77	6,047	3,005	4.35	0.87
1980-81	6,295	3,345	4.34	0.80
1982-83	7,259	3,865	4.79	0.86

Source: Same as Table 1

Chapter 3

CHANGING PATTERN OF ENERGY CONSUMPTION IN INDIAN RAILWAYS

Since the inception of Indian Railways in the year 1853, it has grown into a giant system to become one of the largest railways of the world and the principale mode of transport in India. Through the Five Year Plans, it has been creating additional capacity and using capacity more intensively. As a part of its modernisation programme to meet growing transport needs, coal based locomotives are being replaced with diesel and electric locomotives. The technology of locomotives has also undergone rapid changes leading to increase in its 'tractive' efficiency, and traffic capacity.1/ Along with this modernisation process, its energy consumption pattern had also undergone marked changes. It is the objective of this chapter to analyse the changing pattern of energy consumption in Indian Railways.

In the first hundred years of its existence, the railways in India had depended almost entirely on steam traction except for small scale electrification in Bombay and Madras suburban areas.2/ Most of the railways in the world started with steam based engines. But gradually along with the general change in technology, there has been a shift from steam motor power to diesel/electric traction on railways all over the world. The advantages of electric and diesel locomotives over the steam locomotives, especially on the heavy traffic areas, are well-known. Steam engines have relatively low speed, low capacity to haul heavier load, in addition coaling and watering facilities have to be provided enroute etc. Apart from this, relatively less time for servicing, repair and inspection required in diesel and electric traction helps better utilisation of locomotives. These superiorities of diesel and electric locomotives induced different agencies and countries to undertake rapid dieselisation and electrification.

Changes in Traction-mix

In India with the increased demand for rail transport as a result of rapid industrialisation and growth of agriculture, it became evident that if Indian Railways were to shoulder satisfactorily the increasing burden, a transformation of railway system was necessary. Steam engines, which hauled almost entire traffic in 1950-51, were found unequal to the task of hauling heavier trains at faster speeds. Therefore, as a part of modernisation diesel and electric engines were introduced to carry out transportation activity more efficiently with the existing capacity-wagon, passenger coaches and track capacity.

This shift away from steam to diesel and electric locomotives took place in our country only after 1959. With the commissioning of steam plants at Bhilai, Durgapur and Rourkela a rapid increase in traffic took place on the already crowded section of Eastern and South Eastern Railways. In order to cater to this increasing traffic, electrification/dieselisation was considered essential. This process of dieselisation/electrification started in steel-coal belts of Eastern Railways gradually spread in all directions of the country mainly carrying, coal, iron and steel, minerals, lime stone, foodgrains etc. From 1968-69 onwards, passenger trains also started using diesel and electric locomotives.

The stock of diesel and electric locomotives with Indian Railways increased from 17 diesel and 72 electric locomotives in 1950-51 to 2638 and 1157 in 1982-83 respectively (Table 3.1). In the case of steam locomotives after reaching the highest level of 10711 locos in 1964-65 stock of it started declining and it reached 6292 in 1982-83. It was also decided by the Indian Railways to discontinue manufacture of steam locomotives from 1972 and to retain the existing engines till they become obsolete.[3/] As a result, during the period from 1950-51 to 1982-83 the relative share of steam engines decreased from 98.9% of total stock of locomotives to 62.4% and share of diesel and electric engines increased from 0.2% and 0.9% to 26.1% and 16.4% respectively (Table 3.1). Following the changes in the traction-mix pattern, energy consumption pattern have registered notable changes.

Table 3.1: Stock of Locomotives in Indian Railways

Year	Steam	Diesel	Electric	Total
1950-51	8120 (98.9)	17 (0.2)	72 (0.9)	8209
1955-56	9026 (98.4)	67 (0.7)	79 (0.9)	9172
1960-61	10312 (95.6)	181 (1.7)	289 (2.7)	10782
1964-65	10711 (91.3)	621 (5.3)	403 (3.4)	11735
1965-66	10613 (90.2)	727 (6.1)	422 (3.6)	11762
1966-67	10428 (89.3)	776 (6.7)	479 (4.1)	11683
1967-68	10226 (88.2)	892 (7.7)	513 (4.4)	11631
1968-69	10046 (86.6)	996 (8.6)	602 (5.4)	11594
1969-70	9700 (85.1)	1091 (9.6)	602 (5.4)	11393
1970-71	9387 (83.8)	1169 (10.5)	639 (5.7)	11195
1971-72	9222 (82.5)	1288 (11.5)	668 (6.0)	11178
1972-73	8963 (81.0)	1431 (12.9)	669 (6.0)	11063
1973-74	8847 (79.1)	1610 (14.4)	729 (6.5)	11186
1974-75	8682 (77.7)	1702 (15.3)	796 (7.1)	11180
1975-76	8496 (76.2)	1803 (16.2)	847 (7.6)	11146
1976-77	8345 (74.8)	1903 (17.1)	901 (8.1)	11149
1977-78	8215 (73.4)	2025 (18.1)	945 (8.5)	11185
1978-79	8082 (72.3)	2126 (19.0)	974 (8.8)	11182
1979-80	7856 (70.9)	2243 (20.1)	1036 (9.3)	11135
1980-81	7469 (68.5)	2403 (22.1)	1104 (10.1)	10976
1981-82	7245 (66.7)	2520 (23.2)	1104 (10.1)	10869
1982-83	6292 (62.4)	2638 (26.1)	1757 (16.4)	10687

Note: Figures in brackets are percentages of total stock of locomotive.

Source: Various Annual Statistical Statements of Indian Railways.

The quantity of energy consumed in a traction depends on the output (G.T.K.) hauled by that traction and the energy needed per unit of output. Since the latter differs considerably between tractions, the fraction-mix pattern has a bearing on the energy consumption pattern. Therefore, it is quite important to examine how the output of each traction behaved over time leading to changes in the traction-mix pattern.

The indices of growth of traffic output of each traction is presented in Table 3.2.[4/] The Table shows an increase in output of electric and diesel tractions as against declining trend in the steam traction. This reflects the progressive dieselisation and electrification policies of Indian Railways. During the period under investigation, the index of G.T.K (1964-65 = 100) in electric traction increased to 479.14, compared to 452.59 in diesel traction, the former recording the highest percentage increase. On the other hand, the index of GTK in steam traction decreased sharply to 34.16 (1964-65 = 100). Though, electric traction showed rapid change, diesel traction is the single largest traction, accounting for 57.41% of total GTK hauled by Indian Railways, whereas the electric traction accounts for only 26.97% of total GTK (Table 3.3 and Fig.3.1). Till 1969-70 steam traction hauled little more than half of the total traffic of the railway system, but after that it declined gradually and by 1982-83, it reached 15.61% (See Fig.3.1). In the process of shifts in the traction-mix pattern diesel traction accounted for highest share. This traffic reallocation in favour of diesel traction was mainly due to the financial economy[5/] of diesel traction over electric traction, below a certain density of traffic.[6/] The

Fig.3.1: Gross-tonne Kilometres in different tractions

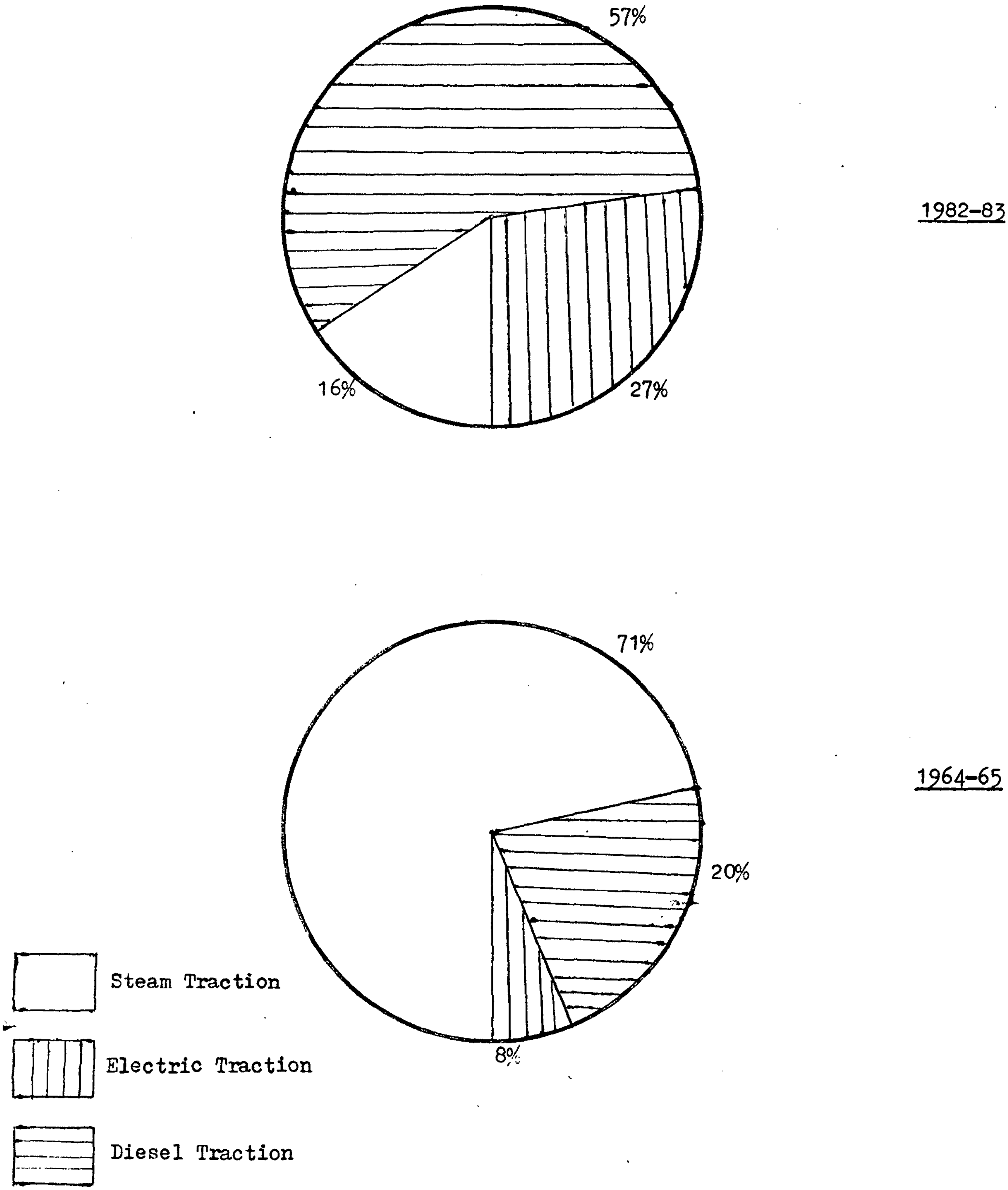


Table 3.2: Indices of Growth of GTK

Year	Steam Traction	Diesel Traction	Electric Traction
1964-65	100.00	100.00	100.00
1965-66	98.44	129.01	131.55
1966-67	92.97	142.74	148.92
1967-68	89.18	158.67	171.80
1968-69	85.21	183.02	198.48
1969-70	82.75	198.93	220.69
1970-71	78.35	213.48	218.65
1971-72	76.26	234.78	232.81
1972-73	73.16	248.33	248.61
1973-74	62.05	245.28	226.30
1974-75	61.58	258.91	252.71
1975-76	64.92	294.05	312.20
1976-77	60.78	331.09	359.13
1977-78	58.63	355.17	368.86
1978-79	50.23	366.20	357.99
1979-80	45.80	386.87	350.15
1980-81	40.90	403.60	357.21
1981-82	35.26	436.54	443.75
1982-83	34.16	452.59	479.14

Source: Computed from various Annual Statistical Statements of Indian Railways.

Table 3.3: Percentage of GTK by types of traction

Traction-mix pattern

Year	Steam	Diesel	Electric
1964-65	71.39	19.82	8.79
1965-66	65.43	23.80	10.77
1966-67	61.60	26.25	12.15
1967-68	57.76	28.53	13.71
1968-69	53.10	31.66	15.24
1969-70	50.11	33.43	16.46
1970-71	47.62	36.01	16.37
1971-72	44.83	38.31	16.86
1972-73	42.36	39.91	17.73
1973-74	39.29	43.09	17.64
1974-75	37.42	43.67	18.92
1975-76	35.09	44.12	20.79
1976-77	30.87	46.67	22.46
1977-78	28.93	48.65	22.42
1978-79	25.63	51.87	22.50
1979-80	23.33	54.70	21.97
1980-81	20.77	56.89	22.34
1981-82	16.70	57.40	25.89
1982-83	15.61	57.41	26.97

Source: Computed from various Annual Statistical Statements of Indian Railways.

recurring operating cost in electric traction is lower than diesel traction. However, electric traction is financially economical only after a certain level of traffic density since electrification requires heavy investment for the fixed tractive installations such as overhead contact lines, remote control equipments etc.7/ Therefore, there should be a fair amount of traffic operating on a route, so that the fixed cost can be distributed over a large freight base. 'Break-even levels'8/ were estimated by the Indian Railways mainly based on financial economy upto 1978. On most of the lines it was found that the volume of traffic was below the 'break-even level' and the railway authorities decided to dieselise these lines rather than to electrify.

Towards the end of 1970's, the continued energy crisis gave another dimension to the question of choice between the different tractions and the policy of electrification based on financial economy. This policy, was reconsidered incorporating future availability of non-renewable energy resources like diesel and its influence on foreign exchange reserves, apart from the financial economy of railways. It was felt that, inorder to conserve scarce non-renewable energy resources, and to reduce uncertainty regarding its availability and further, to reduce foreign exchange strain and working expense of railways rapid electrification was necessary.9/

Most of the advanced countries have already adopted this strategy (Table 3.4). But the Indian Railways have only completed electrification on 8.7% of its total route length carrying about 22.34% of total GTK.

Whereas countries like Switzerland, Austria and Frnace have already electrified more than 60% of the traffic. In India, plans for electrification are being implemented more rapidly in recent years and the Planning Commission has advised the Railways to carry out electrification of its route at the rate of 1000 route kilometres per year.

Table 3.4: Progress of Railway Electrification in Different Railways - 1980

Railways	Percentage of route electrified	GTK handled by electric traction as a percentage of total GTK
French National	28.6	78.30
Spanish	27.4	58.5
Swiss	99.5	99.9
Italian	53.2	89.1
Austrian	50.7	90.8
USSR	30.8	55.0
Indian	8.7	22.34

Source: D.B. Kerhalkar, 'Railway Electrification as a Measure of Energy Conservation and Cost Reduction', Urja, 1983, February

Changes in Energy Consumption Pattern

Along with the increase in GTK in diesel and electric tractions, consumption of diesel and electricity also registered increase, while consumption of coal registered a decreasing trend. In 1982-83 Indian Railways consumed 9.45 Million Tonnes of coal for traction purposes, after reaching the highest level of 15.9 Million Tonnes in 1965-66 (Table 3.5). But diesel and electricity consumption for traction purposes, which have been increasing through out, reached the level of 1227.24 Million Litres and 18,76,333 thousand KWH respectively in 1982-83.

If energy consumption for traction purpose is brought to a common scale for the purpose of comparison,[10] the following picture emerges. In 1964-65 about 97.22% of total energy consumption was accounted by coal, 2.32% by diesel and 0.46% by electricity (See Table 3.6 and Fig. 3.2). But this energy-mix pattern changed markedly by 1982-83. Out of the total energy consumed 81.38% was contributed by coal, 16.27% and 2.34% by diesel and electricity respectively. Thus it can be seen that in terms of energy consumption steam traction accounts for the greatest share, in contrast with its last position in terms of GTK followed by diesel and electric tractions. Share of energy consumption due to diesel showed the fastest increase registering 13.95% between 1964-65 and 1982-83. This is followed by electric traction accounting for 1.88% over time and decrease in the share of coal consumption was 16.29%.

It would be interesting to analyse the relationship between the GTK of each traction and the respective energy consumption. More specifically, let us compare changes in energy consumption pattern and traction-mix pattern. We have seen that GTK in steam traction decreased rapidly

Fig.3.2: Type of Energy Forms Consumed in Indian Railways

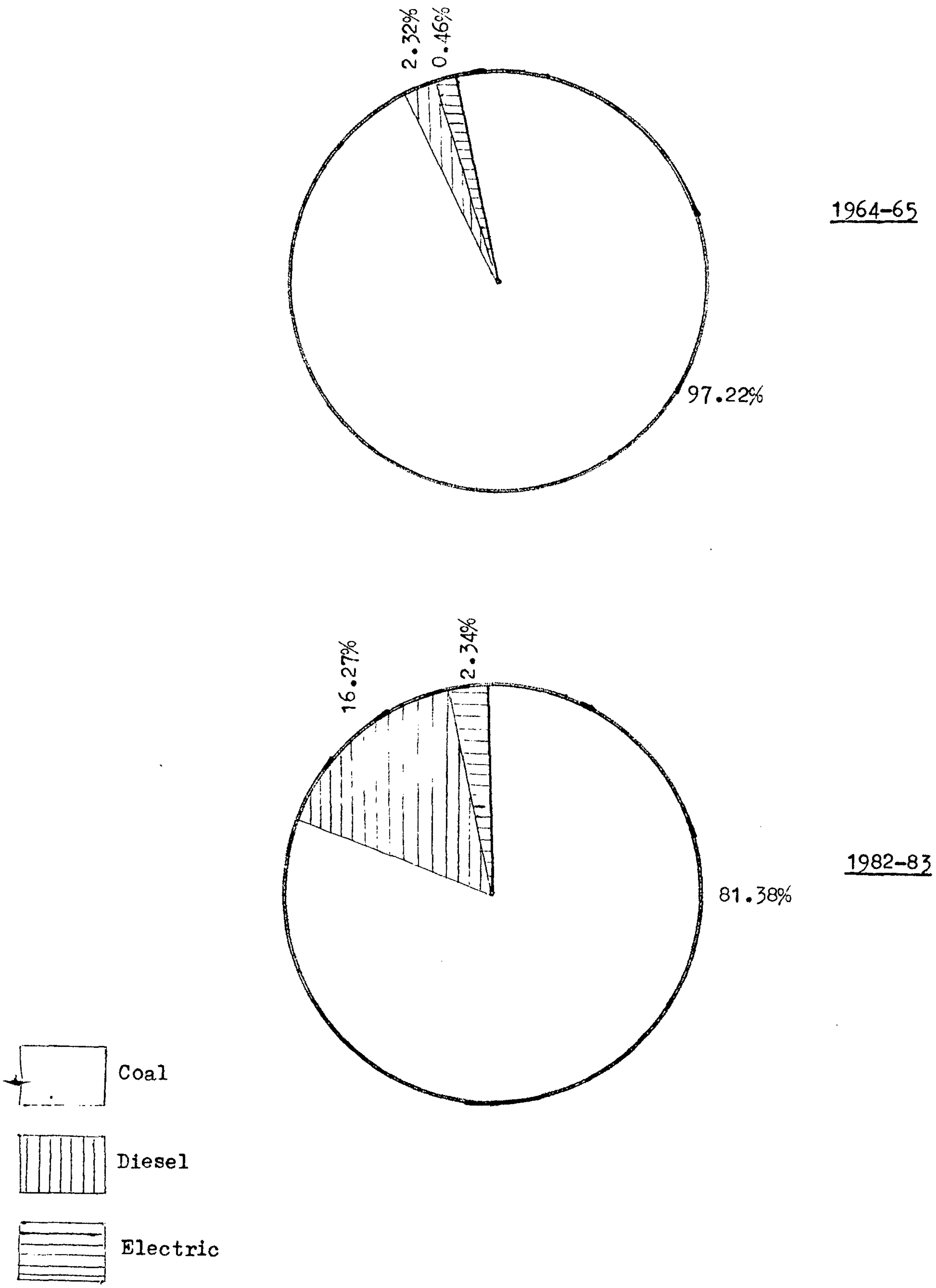


Table 3.5: Energy Consumption in Indian Railways

Year	Coal million tonnes	Diesel million litres	Electricity 000, Kilowatthours
1964-65	15.87 (100.00)	245.65 (100.00)	515771.34 (100.00)
1965-66	15.93 (100.38)	310.80 (126.52)	620620.85 (120.33)
1966-67	15.79 (99.50)	365.58 (148.82)	645761.35 (125.20)
1967-68	15.64 (98.55)	427.34 (173.96)	794161.50 (153.98)
1968-69	15.18 (95.65)	486.08 (197.88)	949436.40 (184.08)
1969-70	15.22 (95.90)	536.30 (218.32)	1041470.26 (201.92)
1970-71	14.34 (90.36)	569.03 (231.64)	966065.88 (187.31)
1971-72	14.25 (89.79)	626.98 (255.23)	1006527.56 (195.15)
1972-73	13.73 (86.52)	667.41 (271.69)	1060658.26 (205.64)
1973-74	12.69 (79.96)	683.14 (278.09)	968397.30 (187.76)
1974-75	12.82 (80.78)	716.45 (291.65)	1042977.95 (202.22)
1975-76	13.14 (82.80)	789.62 (321.44)	1295551.04 (251.19)
1976-77	12.18 (76.75)	846.65 (344.66)	1447451.87 (280.64)
1977-78	12.27 (77.32)	945.66 (384.96)	1542584.70 (299.08)
1978-79	11.63 (73.28)	952.62 (387.80)	1513844.06 (293.51)
1979-80	11.39 (71.77)	980.74 (399.19)	1574301.28 (305.23)
1980-81	11.09 (69.88)	1093.25 (445.04)	1640258.40 (318.02)
1981-82	9.83 (61.94)	1179.68 (480.23)	1817583.00 (352.40)
1982-83	9.45 (59.55)	1227.24 (499.59)	1876333.00 (363.79)

Note: Figures in brackets are indices

Source: Various Annual Statistical Statements of Indian Railways.

Table 3.6: Percentage of energy consumption by type of traction

Year	% share of coal in total energy	% share of diesel in total energy	% share of electricity in total energy
1964-65	97.22	2.32	0.46
1965-66	96.55	2.90	0.54
1966-67	96.01	3.42	0.57
1967-68	95.29	4.01	0.70
1968-69	94.49	4.66	0.86
1969-70	93.97	5.10	0.93
1970-71	93.38	5.70	0.93
1971-72	92.76	6.28	0.95
1972-73	92.75	6.89	0.03
1973-74	91.41	7.58	1.01
1974-75	91.09	7.84	1.07
1975-76	90.57	8.38	1.29
1976-77	88.95	9.52	1.53
1977-78	87.96	10.44	1.60
1978-79	87.33	11.02	1.65
1979-80	86.76	11.50	1.74
1980-81	85.23	12.94	1.83
1981-82	82.53	15.25	2.21
1982-83	81.38	16.27	2.34

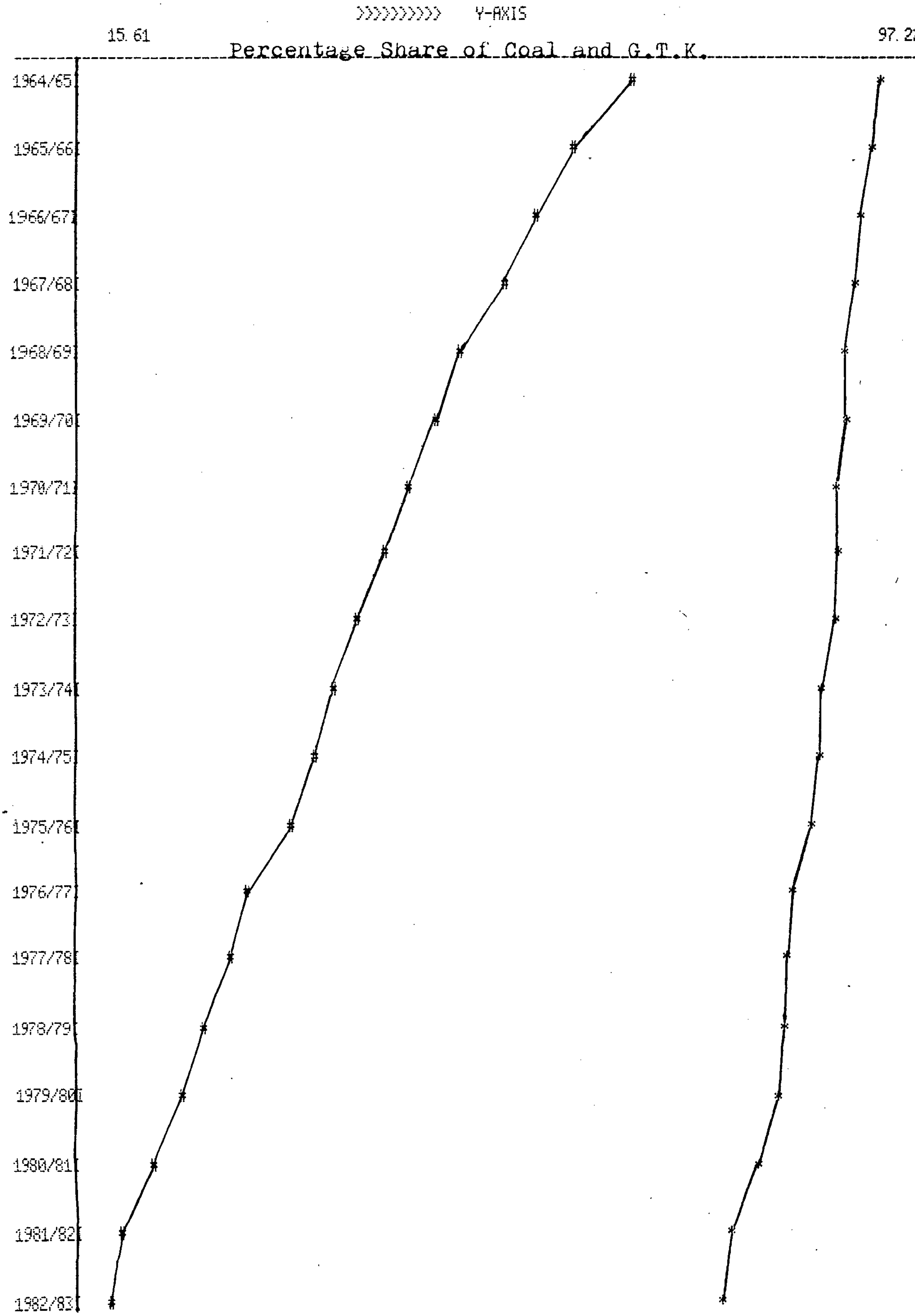
Source: Computed from various Annual Statistical Statements of Indian Railways.

over time. But it can be observed that energy consumption in this traction has not registered proportionate decrease. Thus, while the share of GTK of steam traction fell sharply to 15.16% in 1982-83 from 71.39% in 1964-65, its, corresponding share in total energy consumption decreased from 97.22% to 81.38%. In the case of diesel traction also, while its index of GTK increased to 452.59 the index of energy consumption increased to 499.59 (1964-65 = 100). In other words, while the share of GTK of diesel traction increased from 19.82% in 1964-65 to 57.41% by 1982-83, the corresponding increase in percentage share of diesel consumption in total energy was from 2.32% to 16.27%. This indicates that in steam and diesel tractions, energy requirement per unit of output has increased over time. The Graph 3.a, 3.b and 3.c illustrate this trend, which showsthe relationship between energy-mix pattern and traction-mix patern of steam, diesel and electric tractions respectively. In contrast, in electric traction energy consumption is increasing less than proportionately compared to GTK. That is, while index of GTK increased to 479.14 index of energy consumption increased only to 363.79 (1964-65 = 100).

Thus, it can be observed that there are differences in the direction of change and magnitude of change in the energy consumption per unit of output among different tractions. The 'energy intensity' is the objective yard stick for the assessment of this difference. A detailed analysis of energy intensities of each traction is carried out in the succeeding chapter.

97.22 96.55 96.01 95.29 94.49 93.97 93.38 92.76 92.75 91.41 91.09 90.57 88.95 87.96 87.33 86.76 85.23 82.53 81.38

71.39 65.43 61.6 57.76 53.1 50.11 47.62 44.83 42.36 39.29 37.42 35.09 30.87 28.93 25.63 23.33 20.77 16.7 15.6

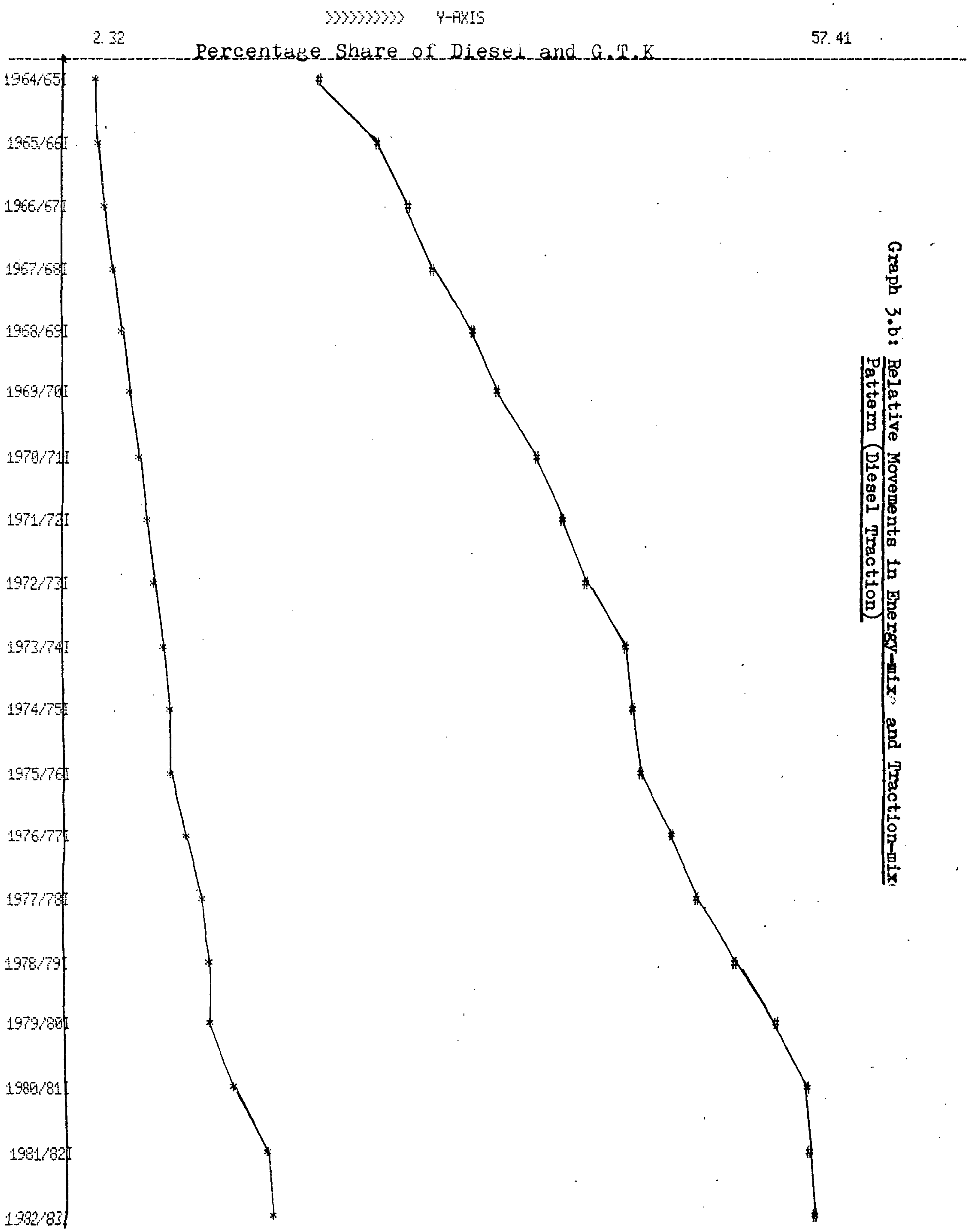


Graph 3.a: Relative movements in Energy-mix and Traction-mix Pattern (Steam Traction)

GRAPH NO 1 DATA

2.32 2.9 3.42 4.01 4.66 5.1 5.7 6.28 6.89 7.58 7.84 8.38 9.52 10.44 11.02 11.5 12.94 15.25 16.27

19.82 23.8 26.25 28.53 31.66 33.43 36.01 38.31 39.91 43.09 43.57 44.12 46.67 48.65 51.87 54.7 56.89 57.4 57.4

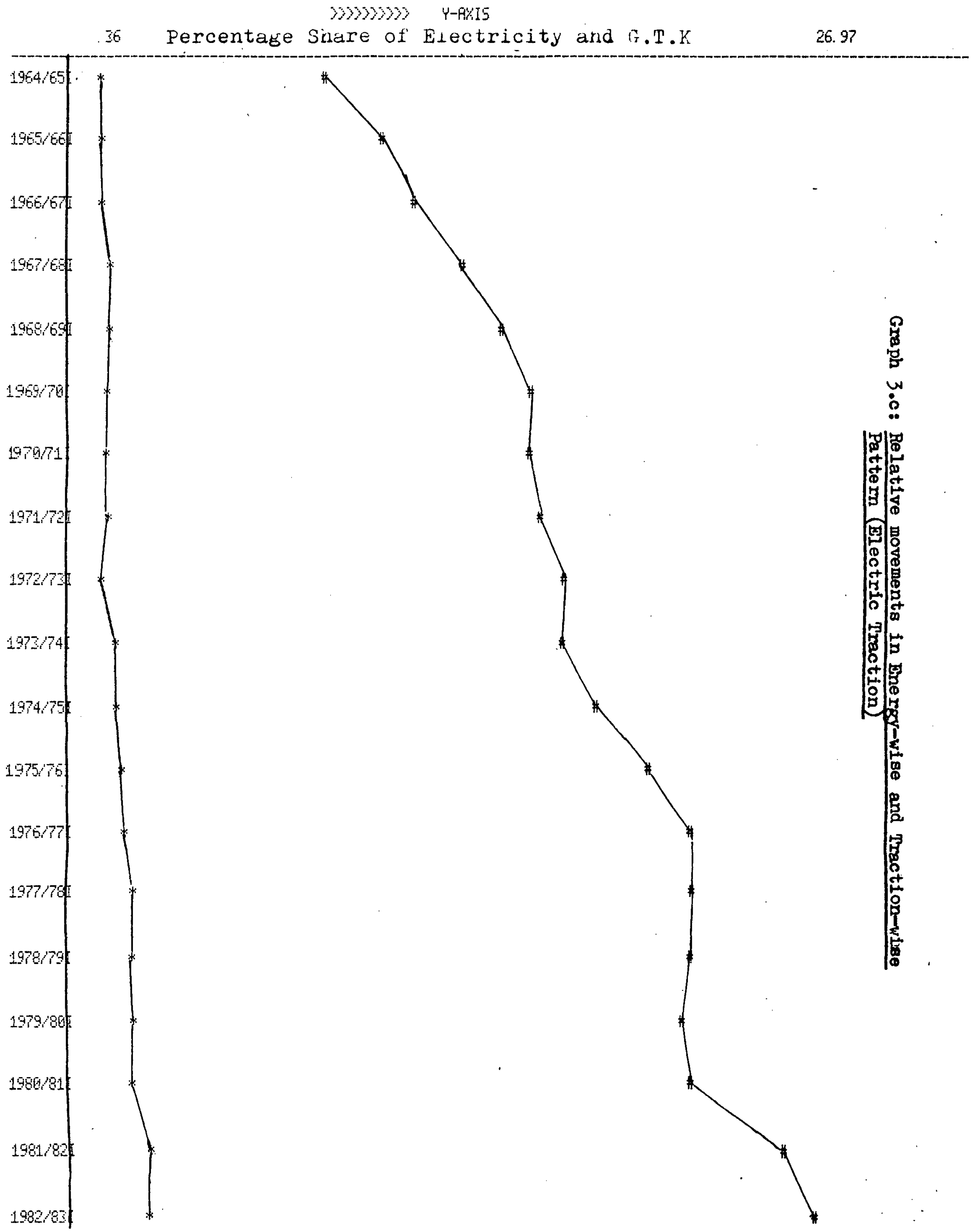


Graph 3.b: Relative Movements in Energy-mix and Traction-mix Pattern (Diesel Traction)

GRAPH NO 1 DATA

.46 .54 .57 .7 .86 .93 .93 .95 .36 1.01 1.07 1.29 1.53 1.6 1.65 1.74 1.83 .2.21 2.34

8.79 10.77 12.15 13.71 15.24 16.46 16.37 16.86 17.73 17.64 18.92 20.79 22.46 22.42 22.5 21.97 22.34 25.89 26.



Graph 3.c: Relative movements in Energy-wise and Traction-wise Pattern (Electric Traction)

Turning over to the financial aspect of energy from the physical aspect, we see that share of energy cost in the total working expenses of Indian Railways has been increasing since 1964-65, the share has increased from 15.82% of total working expenses in 1964-65 to 24.00% in 1982-83.[11/] This means that in the wake of general price hike, energy costs have been increasing relatively faster than other components of working expense.

While total cost of all the three energy forms registered increase, the cost of steam traction was increasing relatively slower compared to the cost of diesel and electricity. As a result of this the relative shares of the cost of each form of energy in total energy cost, have under gone changes. In 1964-65 about 82.67% of total energy cost was accounted by coal, 15.11% by diesel and 2.22% by electricity. But this pattern changed by 1982-83, to 32.14% by coal, 52.08% by diesel and 15.77% by electricity (Table 3.7 and Fig. 3.3). That is, at present consumption of diesel accounts for more than half of the total cost of energy. Though in physical terms share of diesel in total energy consumption is only 16.27% in 1982-83 its share in terms of cost is 52.08%. This reflects the fact that diesel is relatively a very costly form of energy and from the point of view of railways financial economy it is important to economise its consumption.

In order to get a more clear picture of financial economy we have to examine the relationship overtime between energy cost and GTK of each traction. For this the yard stick used is energy cost per unit of output, which we termed as energy cost index (ECI). Table 3.8 sets out the ECI[12/]

Fig.3.3: Energy Cost indifferent tractions as percentage of Total Energy Cost

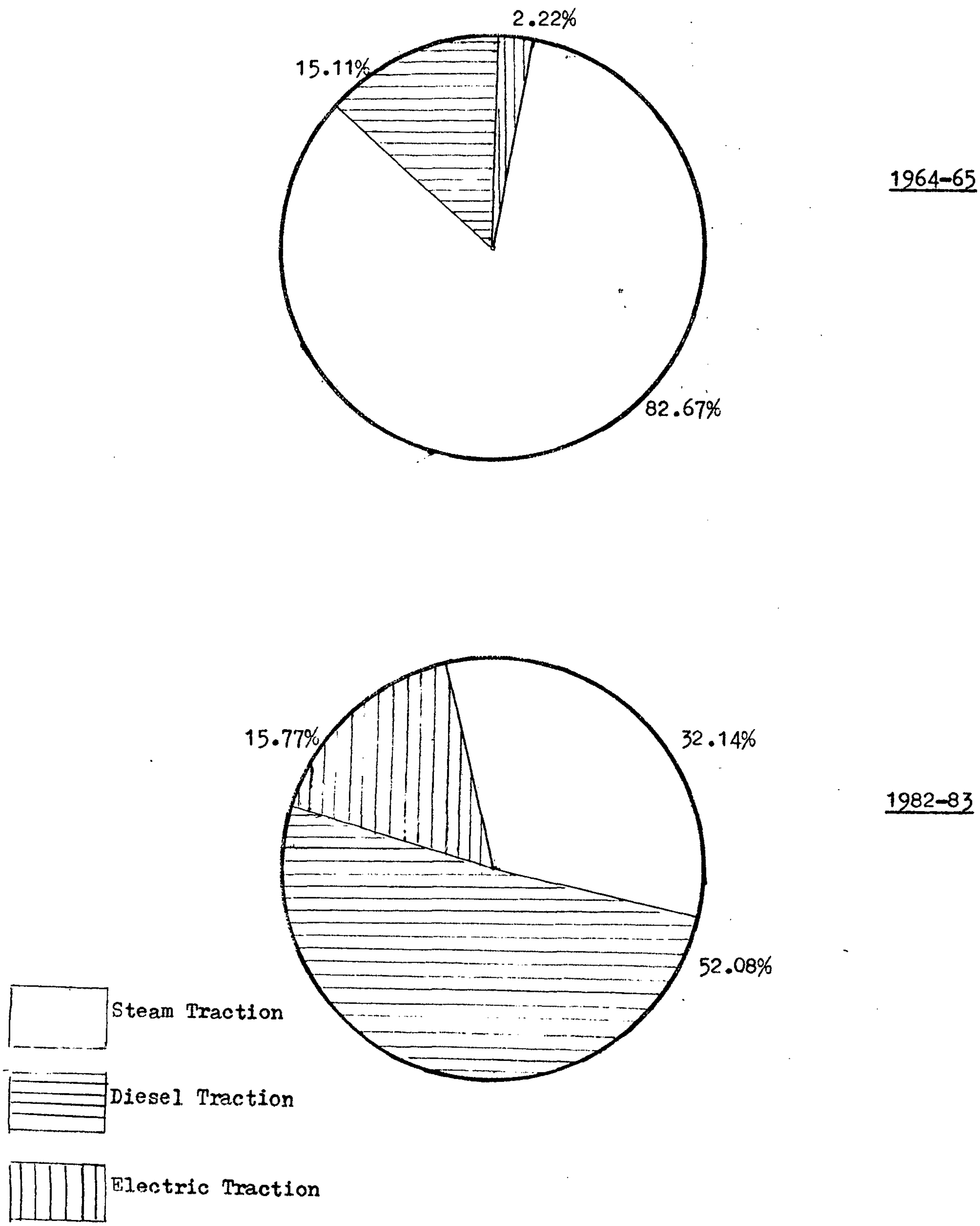


Table 3.7: Percentage of Energy Cost by Types of Traction

Year	Steam	Diesel	Electric
1964-65	82.67	15.11	2.22
1965-66	74.10	20.72	5.18
1966-67	71.14	23.98	4.88
1967-68	68.39	25.63	5.98
1968-69	66.52	26.65	6.83
1969-70	64.76	28.46	6.78
1970-71	63.72	29.16	7.12
1971-72	60.93	31.09	7.98
1972-73	57.95	33.12	8.93
1973-74	56.19	33.36	8.45
1974-75	54.39	36.02	9.59
1975-76	53.14	36.20	10.66
1976-77	49.56	38.47	11.97
1977-78	46.87	40.68	12.45
1978-79	45.35	40.69	13.96
1979-80	47.14	38.97	13.89
1980-81	40.54	46.35	13.11
1981-82	33.07	53.09	13.85
1982-83	32.14	52.08	15.77

Source: Computed from various Annual Statistical Statements of Indian Railways,

Table 3.8: Energy Cost Index

Rs. per 1000 GTK

Year	Steam	Diesel	Electric	Total
1964-65	3.73	2.48	1.44	3.28
1965-66	3.56	2.69	1.49	3.10
1966-67	3.87	3.06	1.35	3.35
1967-68	4.42	3.36	1.63	3.74
1968-69	4.93	3.31	1.76	3.93
1969-70	5.35	3.53	1.71	4.14
1970-71	5.42	3.28	1.76	4.05
1971-72	5.68	3.39	1.98	4.18
1972-73	5.68	3.45	2.09	4.16
1973-74	6.43	3.69	2.15	4.49
1974-75	7.56	4.29	2.63	5.20
1975-76	8.85	4.80	2.99	5.85
1976-77	9.73	4.99	3.23	6.06
1977-78	10.04	5.18	3.44	6.20
1978-79	11.53	5.11	4.04	6.52
1979-80	15.95	5.62	4.99	7.89
1980-81	19.78	8.26	5.95	10.13
1981-82	25.65	11.98	6.93	12.96
1982-83	28.90	12.75	8.85	14.21

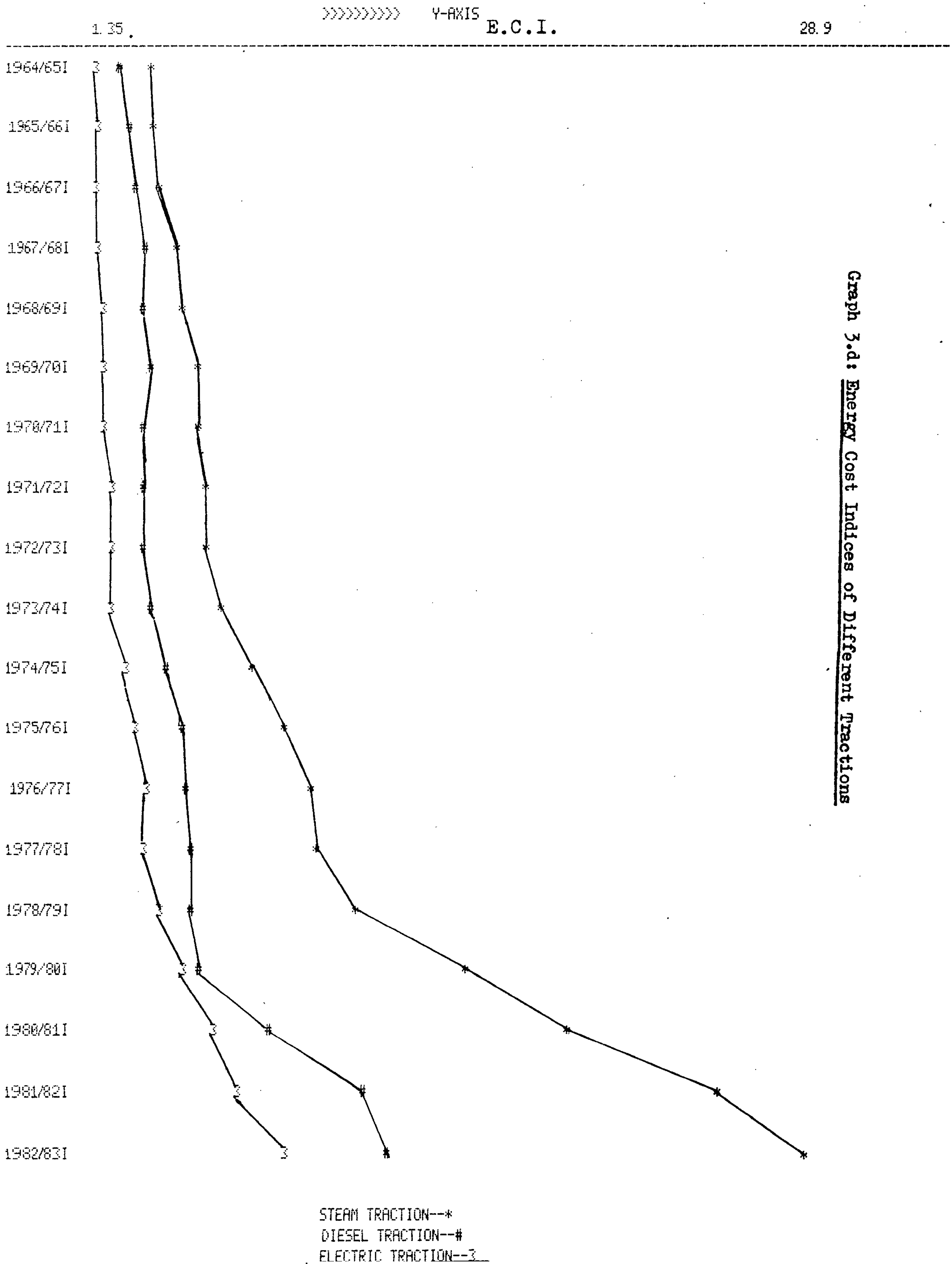
Source: Computed from various Annual Statistical Statements of Indian Railways.

for the period 1964-65 to 1982-83. A perusel of the Table shows that there are significant differences in the ECI of different tractions. ECI is highest for steam traction compared to diesel and electric tractions and second highest ranking is for diesel traction. The lowest ECI is for electric traction. This is true throughout the period under consideration. This differences in the ECI between different tractions is the result of mainly two factors, unit prices of different energy resources and second, differences in energy intensities.

Another aspect of ECI is the changes in indices of each traction over time. ECI of all the three tractions registered an increase. But different tractions registered different rates of growth. It is Diesel traction which marked the highest growth in ECI - even though, in absolute terms magnitude is still lower than steam tractions -- followed by electric and steam tractions respectively in that order. Over time, from 1964-65, to 1982-83, ECI of electric, steam and diesel tractions increased by 514.58%, 674.8% and 414.1% respectively. (Graph 3.d illustrates increase in ECI of each traction).

At this juncture it is important to examine what are the factors which lead ECI to move in the above seen fashion. At first let us try to identify the factors which are likely to have a bearing on Total ECI.

One of the factors which is likely to influence ECI is the



Graph 3.d: Energy Cost Indices of Different Tractions

magnitude and behaviour in energy intensities.[13] Obviously, even if energy prices remain same, energy cost index will increase if the energy input per unit of GTK increases over time.

The second main factor which is likely to influence ECI is change in the unit prices of energy sources. Thus the oil price hike of 1973 and 1978-79 have influenced the ECI adversely. The sharp increase in the ECI after 1979-80 for example may be due to the very sharp increase in the oil price which influenced the prices of other energy sources as well, due to close linkage between them. Table 3.9 shows the unit prices of different energy sources.

The third factor which is likely to influence ECI is the change in traction-mix pattern. That is, even if unit prices and energy intensities of each traction remain the same, a shift in the traction-mix pattern would lead to a change in the ECI. This can be explained by assuming a hypothetical situation where traction-mix pattern is shifting in favour of electric traction. Therefore, electricity consumption will increase due to increase in the movement of traffic in this traction. But the magnitude and direction of change in the ECI will depend on the relative energy intensities of electric traction compared to the energy intensities of the traction from which traction-mix pattern moved away. If energy intensities and unit costs are relatively lower for electric traction then total ECI will decline as a result of this shift in traction-mix.

The above discussion identifies unit costs, energy intensities, and traction-mix pattern as key factors which have a bearing on the total ECI.

Table 3.9: Unit Prices of different energy resources

Rs./Kcal x 10^6

Year	Coal	Diesel	Electricity
1964-65	9.19	71.19	92.72
1965-66	8.47	78.63	104.77
1966-67	8.89	78.14	103.14
1967-68	9.85	85.81	117.09
1968-69	10.78	87.77	122.33
1969-70	11.36	92.15	120.12
1970-71	11.66	86.69	132.21
1971-72	11.87	89.23	151.86
1972-73	11.82	90.43	162.91
1973-74	12.27	93.26	166.86
1974-75	14.18	110.69	212.33
1975-76	17.09	125.86	239.65
1976-77	18.95	137.64	265.00
1977-78	18.74	137.23	273.26
1978-79	19.46	138.49	316.74
1979-80	25.07	156.34	368.95
1980-81	28.52	214.83	429.88
1981-82	35.95	308.89	561.63
1982-83	40.84	331.33	696.28

Source: Calculated from Annual Statistical Statements of Indian Railways, Various Issues

Therefore, it is pertinent to examine how these variables behaved over time and to what extent each of these are responsible for the observed increase in ECI. This shall be attempted in the next chapter.

Notes and References

1. Tractive effort of locomotives has registered a marked increase during 1950-51 to 1982-83. The index of this increased to 192 by 1982-83 (1950-51 = 100). For details see; Indian Railways Year Book 1982-83, Government of India, Ministry of Railways.

2. Although the first electric train was introduced in the Bombay suburban section in 1925, till 1958 electric train was mainly confined to suburban sections such as Madras, Bombay etc., Only 388 route-kilometres out of a total of 55,011 in 1958 were electrified. The use of diesel trains were confined to shunting activity, that too on a few sections only.

3. Generally, the life span of the steam locomotives is 40 years and after that it is supposed to be taken off from the line.

4. The actual figures of GTK are presented in the Appendix I.

5. Steam traction was not at all an alternative due to its inherent drawbacks of low speed and carrying capacity. Thus the problem was to choose either diesel or electric traction.

6. The 'break-even level' for electrification varies between 28.0 anf 31.25 million GTK per route kilometres, per annum. For details see: Study of Relative Economies of Diesel and Electric Traction on Indian Railways, Government of India, Ministry of Railways (1978).

7. NCAER, Economies of Diesel and Electric Traction, (1970). New Delhi.

8. To find out 'break-even' point, first, a comparison of total cost per million G.T.K corresponding to different levels of traffic density for electric and diesel tractions is made. Then, the traffic density at which the cost per million GTK for electric traction is found chap will be considered as 'break-even' point.

9. Report of the National Transport Policy Committee, Government of India, (1980).

10. The conversion procedure is presented in the second chapter of this study.

11. It can be seen from the following Table that in 1982-83 the single largest component in the working expense is expense for fuel.

Item	Expenses (Rs. crores)
General Superintendence and Service	182.72 (5.75)
Repairs and Maintenance of Permanent Way Works	355.20 (11.17)
Repairs and Maintenance of Motive Power	289.03 (9.09)
Repairs and Maintenance of Carriages and Wagons	413.50 (13.01)
Repairs and Maintenance of Plant and Equipment	183.90 (5.79)
Operating Expenses-Rolling Stock and Equipment	326.07 (10.26)
Operating Expenses-Traffic	366.61 (11.53)
Operating Expenses-Fuel	763.61 (24.00)
Staff Welfare and Amenities	127.99 (4.03)
Miscellaneous Working Expenses	163.09 (5.13)
Provident Fund, Pension and other retirement benefits	12.99 (0.41)
Gross Expenditure	3184.77

Source: Indian Railways, Annual Report and Accounts 1982-83, Ministry of Railways, Government of India.

Note : Figures in the brackets are the percentage of total expenditure

12. These figures are calculated on the basis of method discussed in the second chapter of this study.

13. Methodology of estimation of energy intensities is presented in the Chapter II.

Appendix 1

GTK in different tractions

in thousands

Year	Stream Traction	Diesel Traction	Electric Traction
1964–65	231815504	64345584	28555310
1965–66	228211514	83010042	37565157
1966–67	215529651	91844534	42524915
1967–68	206734525	102097164	49076305
1968–69	197541970	117767359	56677954
1969–70	191835278	128005025	63020139
1970–71	181629687	137363901	62436104
1971–72	176791836	151069948	66479402
1972–73	169594251	159788342	70992258
1973–74	143833327	157830322	64622374
1974–75	142751651	166597218	72163577
1975–76	150500980	189209359	89148776
1976–77	140906607	213039830	102551126
1977–78	135913856	222853985	105329110
1978–79	116442448	235631641	102225481
1979–80	106155591	248931527	99985297
1980–81	94806279	259697003	102002646
1981–82	81744054	280895191	126715688
1982–83	79188671	291223480	136819282

Source: Various Annual Statistical Statements of Indian Railways.

Chapter 4

SOURCES OF VARIATION IN THE GROWTH OF ENERGY COST

From the preceding discussion it is evident that the energy cost to generate a unit of transport output in Indian Railways has registered significant increase overtime. Further, it is seen that these changes are the result of the independent and interactive influences of factors like energy intensities, unit prices of energy resources, and the traction-mix pattern. It is the objective of this chapter to examine to what extent and now these factors have changed overtime, during the period 1964-65 to 1982-83, and to analyse how and to what extent the changes in these factors influenced the increase in energy cost index (ECI).

We have already seen how exactly each of the factors which we have identified, influence ECI. Therefore, as the second step of our investigation let us examine how they have behaved over time. One of the important factors which influence ECI is energy intensities. Energy intensities of the railway system and for each traction are presented in the Table 4.1. It can be observed from the Table that energy intensities of different tractions behaved differently both in terms of magnitude and direction of change. While energy intensities of steam and diesel tractions showed an increasing trend, registering

Table 4.1: Energy intensities of different tractions

K.Cal x 10^6/1,000,000 GTK

Year	Steam	Diesel	Electric
1964-65	405.98	34.86	15.53
1965-66	413.88	34.19	14.21
1966-67	434.33	36.34	13.06
1967-68	448.45	38.19	13.92
1968-69	455.81	37.68	14.41
1969-70	470.53	38.25	14.21
1970-71	468.18	37.82	13.31
1971-72	477.92	37.89	13.02
1972-73	480.06	38.14	12.85
1973-74	523.02	39.52	12.89
1974-75	532.68	39.26	12.43
1975-76	517.63	38.10	12.50
1976-77	512.73	36.28	12.14
1977-78	535.23	37.78	12.59
1978-79	592.09	36.91	12.73
1979-80	636.27	35.97	13.54
1980-81	693.41	38.44	13.83
1981-82	713.04	38.34	12.33
1982-83	707.60	38.38	11.79

Source: Computed from Annual Statistical Statements of Indian Railways, Various Issues.

average annual compound growth rate of 2.99% and 0.28% respectively. Energy intensities of electric traction, however registered a decreasing trend accounting for an average annual compound growth rate of -0.85%. Another important point to note is that energy intensities of the electric traction is the lowest among the three tractions and steam traction has the highest position (Table 4.1). It can also be seen that this order was maintained through out the time period under consideration. In other words, in relative terms, steam traction is the least energy efficient and electric traction is most efficient traction. The trend in the growth of energy intensities further indicates that differences in energy intensities among different tractions have become more pronounced. The ratio between energy intensities of steam traction and electric traction is about sixty in 1982-83 and the ratio between diesel and electric traction is little more than three. This shows that purely in terms of energy efficiency, coal has never been an efficient source of energy for railways and its use efficiency has been decreasing over time. This is true from the point of view of its cost also.[1/]

Energy intensities of tractions depend on the operating and engineering conditions such as average speed, average load, condition of locomotives etc. Differences and changes in these factors will get reflected in the energy intensities of each traction. From the energy conservation point of view this issue is very important, and hence in the next chapter it will be discussed in detail how changes in engineering and operating conditions influence energy intensities.

Unit price of energy is another factor influencing ECI. For the purpose of comparison unit prices of energy sources are expressed in terms of price per unit of K.Calorie. Energy prices have been rising very fast especially, since the second energy crisis of 1978 (Table 4.2). It is not often recognized that it was not after 1973-74, but after the second oil price shock of 1979-80, that the energy price indices in India showed sharpest increase (Graph 4.a). It is interesting to note that this is true for all the three energy sources.[2/] It is also striking to observe that though there have been oil price hikes, it is the price of electricity which has showed the highest percentage growth. In other words, the index of unit price of electricity increased to 750.42 by 1982-83 while the index of diesel and coal increased only to 465.42 and 444.40 respectively (Table 4.2). As we said above all the three unit prices of energy forms show the sharpest increase after 1979-80. In the case of oil it is due to the unprecedented increase in oil prices by OPEC. But the fact that unit prices of electricity and coal also registered the same trend is worth noting.[3/]

The third principal factor influencing energy cost index is change in the traction-mix pattern. As has been observed in the previous chapter, the traction-mix pattern has shifted away from steam to diesel and electric tractions. This shift has naturally its bearing on ECI.[4/]

Graph 4.a: Price Indices of Different Energy Resources 1963-64 to 1982-83

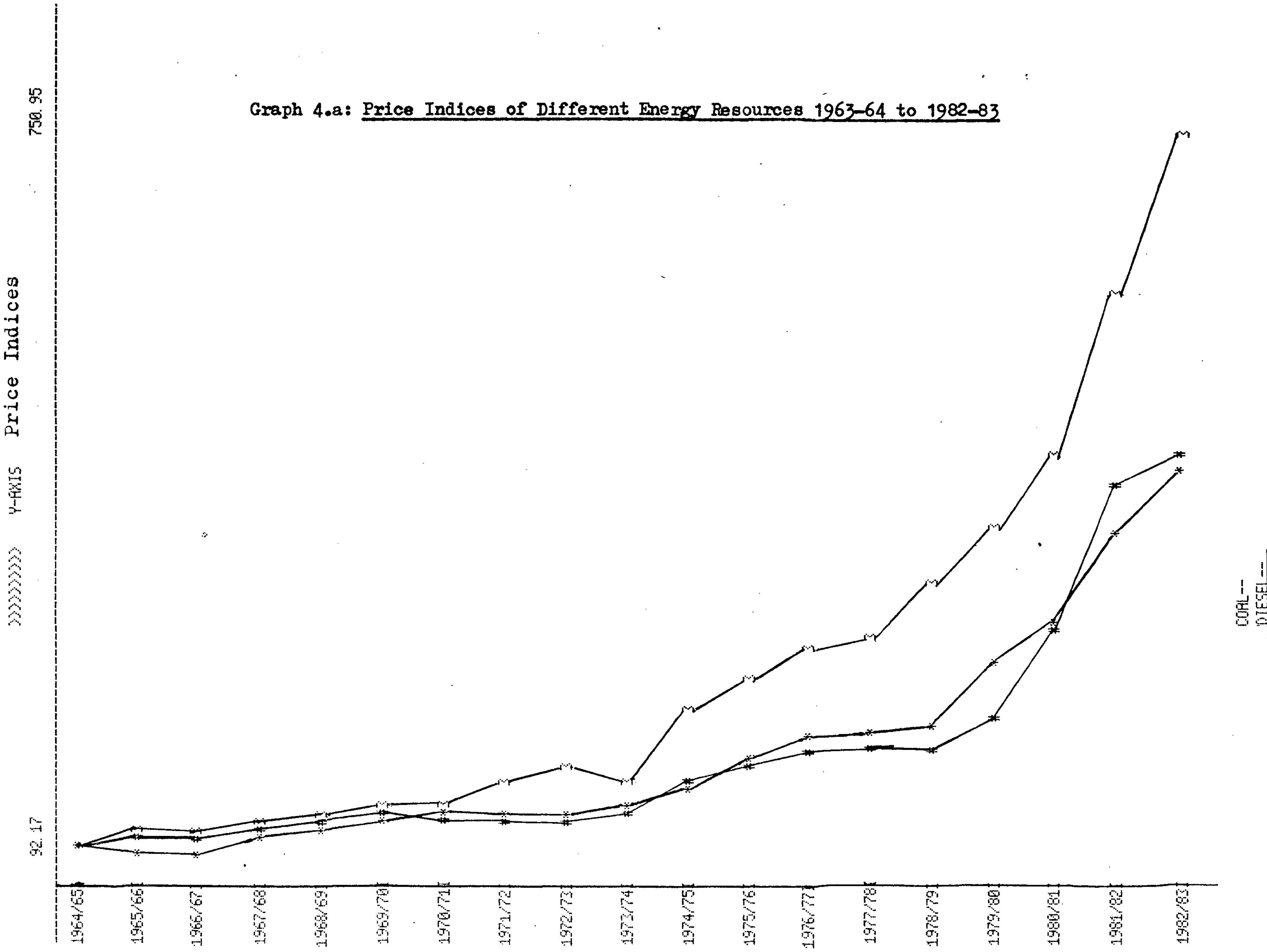


Table 4.2: <u>Index of Prices of Energy Forms</u> (Per K.Cal x 10^6)

Year	Coal	Diesel	Electricity
1964-65	100.00	100.00	100.00
1965-66	92.17	110.45	113.00
1966-67	96.74	109.76	111.24
1967-68	107.29	120.54	126.28
1968-69	117.30	123.29	131.93
1969-70	123.61	129.44	129.55
1970-71	126.88	121.77	142.59
1971-72	129.16	125.34	163.78
1972-73	128.62	127.03	175.70
1973-74	133.51	131.00	164.31
1974-75	154.30	155.49	229.00
1975-76	185.96	176.79	258.47
1976-77	206.20	193.34	285.81
1977-78	203.92	192.77	294.72
1978-79	211.75	194.54	341.61
1979-80	272.80	219.61	397.92
1980-81	310.34	301.77	463.63
1981-82	391.19	433.90	605.73
1982-83	444.40	465.42	750.95

Source: Calculated from Annual Statistical Statements of Indian Railways, Various Issues.

Decomposition Model

In this section an attempt is made to decompose the variation in the ECI into seven components consisting of three independent and four interaction components, each reflecting the contribution of (a) changes in price of energy (b) changes in energy intensities (c) changes in traction-mix (d) interaction effect of price and traction-mix, (e) interaction effect of price and energy intensities, (f)interaction effect of energy intensities and traction-mix and (g) interaction effect of price change, energy intensities and traction-mix. The principal components price, energy intensities and traction-mix are independent influences which determine the overall ECI, and these are in-turn determined by more or less independent set of factors.

The price structure of energy resources during the period has been determined considerably by exogenous factors, mainly government policy. Traction-mix and energy intensities are determined to a large extent by Railway policy. However, traction-mix shift is a matter of long term policy since it involves considerable investment. Whereas, energy intensity is found to be determined partly by a set of short term factors such as operating and traffic conditions (speed, load, quality of fuel, efficiency of locomotive crewetc)

We employ an additive form of decomposition scheme which can provide a useful framework to evaluate the relative contribution of each one of the above specified components in the total variation in ECI. The additive form of decomposition model[5/] employed runs as follows:

The variables and notations used in this model are:

P_i : Price of i^{th} energy source

E_i : Quantity of energy consumed from i^{th} source.

G_i : Transport output (GTK) of i^{th} traction.

C_i : Proportion of output of i^{th} traction in total output.

I : Energy cost index (ECI)

S_i : Energy intensities of i^{th} traction.

By definition,

$$C_{it} = \frac{G_{it}}{\Sigma G_{it}} \qquad \ldots\ldots\ldots \qquad (1)$$

$$I_t = \frac{\Sigma P_{it} E_{it}}{\Sigma G_{it}} \qquad \ldots\ldots\ldots \qquad (2)$$

$$S_{it} = \frac{E_{it}}{G_{it}} \qquad \ldots\ldots\ldots \qquad (3)$$

The subscripts 0 and T refer respectively to the base year and terminal years

Therefore, for t^{th} period ($t = 0, T$)

We can write from (2) above,

$$I_t = \sum P_{it} \; C_{it} \; S_{it}$$

The change in the ECI between the terminal and initial periods can be written as

$$I_T - I_0 = \sum P_{iT} \, C_{iT} \, S_{iT} - \sum P_{io} \, C_{io} \, S_{io}$$

which can be decomposed as:

$$I_T - I_0 = \sum (P_{iT} - P_{i0}) \, S_{i0} \, C_{i0} \quad \text{(Pure price component)}$$

$$+ \sum (C_{iT} - C_{i0}) \, P_{i0} \, S_{i0} \quad \text{(Pure traction-mix pattern)}$$

$$+ \sum (S_{IT} - S_{i0}) \, P_{i0} \, C_{i0} \quad \text{(Pure energy intensity)}$$

$$+ \sum (P_{iT} - P_{i0}) \, (C_{iT} - C_{i0}) \, S_{i0} \quad \text{(Interaction component due to price and traction-mix)}$$

$$+ \sum (P_{iT} - P_{i0})(S_{iT} - S_{i0}) \, C_{i0} \quad \text{(Interaction Component due to price and energy intensities)}$$

$$+ \sum (C_{iT} - C_{i0}) \, (S_{iT} - S_{i0}) P_{i0} \quad \text{(Interaction component due to traction-mix and energy intensities)}$$

$$+ \sum (P_{iT} - P_{i0}) \, (C_{iT} - C_{i0}) \, (S_{iT} - S_{i0}) \quad \text{(Second order interaction)} \ldots\ldots (4)$$

The above scheme of decomposition model consists of seven components with three pure effect components, two first order interaction components and one second order interaction component. Pure effect components show the contribution of the changes in any one of the factors responsible for changes in ECI, while assuming that other factors remain constant. The first three components show pure effects of price, traction-mix and energy intensity respectively. The pure price component shows, in the absence of any change in the other two factors namely traction-mix and energy intensities, the contribution of price change in the movement of ECI. In other words, this component indicates, in a hypothetical situation, what would have been the effect of price change on the ECI if the other two variables had remained at the same level as in the base year. The second component, similarly measures the changes in ECI that would have occurred as a result of changes in traction-mix pattern in the absence of changes in the other influences such as price and energy intensities. Likewise, the third term is pure energy intensities effect, which measures the change in the ECI, that would have occurred as a result of changes in the energy intensities in the absence of any change in price and traction-mix pattern.

The fourth, fifth and sixth terms are first order interaction components which indicate the impact of joint movements in any of the two contributing factors on the growth in ECI, while the value of third factor is considered same as the base year value. A positive interaction between traction-mix and energy intensities for instance, would mean that traction-mix has shifted in favour of those tractions which show higher growth of energy intensities and which would obviously result in any increase in ECI. Thus, if only two factors changed, their total impact would be the sum of the two 'pure' effects plus the first order joint interaction effect comprising the two variables. Similarly, a positive interaction between traction-mix and price may imply a shift in traction-mix in favour of the tractions observing higher increase in its energy prices. In our equation, the fourth component shows the interaction between price and traction-mix pattern and fifth and sixth components are respectively first order interactions between price and energy intensities, and traction-mix and energy intensities. The last term in the right hand side of the equation is the second order interaction term between all the three principle variables considered. This gives the mutual interdependence between the three, if any.

In the above decomposition scheme, the difference between terminal and base period in the magnitude of the variables can be represented either in terms of growth rate of the concerned variables, or absolute differences between terminal and base period of the variables. In the present analysis we use absolute changes in the variables which is more suited to the linear additive variant. Moreover, in order to reduce the problems arising from possible year to year variations in the variables, three and two year averages have been used for the base and terminal periods.

The empirical analysis is carried out for three different time durations (a) for the entire period, i.e.; 1964-67 to 1980-83 (b) for the sub period 1964-66 to 1976-78 and (c) for the period 1976-78 to 1981-82 in order to understand the impact of so called second energy crisis.[6/] The results of the decomposition exercise for the entire period and for the subperiods are presented in Tables 4.3 and 4.4 respectively.

<u>Interpretation and implications of the results</u>

It can be observed from the Table 4.3 that over the period from 1964-67 to 1980-83, ECI increased from 3.2 to 12.43 that is, it increased

Table 4.3: Results of Decomposition Exercise (1964-67 to 1980-83)

Components	Absolute Values (Rs/1000 GTK)	% Share*
ECI (1964-67)	3.243	..
ECI (1980-83)	12.433	..
Variation in ECI	9.20	
Pure Effects		
Traction-mix	-0.68	-7.38
Price	9.66	104.99
Energy Intensities	1.72	18.67
First Order Interaction		
Traction-mix and Energy Intensities	-1.17	-12.68
Traction-mix and Price	-1.87	-20.29
Price and Energy Intensities	5.06	54.93
Second Order Interaction		
Price, Energy Intensities and Traction-mix	-3.52	-38.24

* Percentage shares are calculated taking absolute value of total variation in energy cost index (ECI) as the denominator.

by 283.64% over time. It can also be seen from the Table that among the principal components of ECI both price and energy intensities were moving in such a way as to push up ECI, while traction-mix pattern has been shifting in a direction to counteract the rise in ECI. This is reflected in the negative sign of pure traction-mix pattern and positive signs of the pure price and pure energy intensities components.

The positive components, i.e., those due to pure price, pure energy intensities and, interaction due to price and energy intensities together add up to 178.59% of total variation in ECI. This implies that in the absence of any change in traction-mix pattern, ECI would have increased by 178.59% of the total variation in ECI. (In otherwords the variation in ECI would have been 16.43 Rs/1000 GTK instead of the actual observed variation of 9.20 Rs/1000 GTk). That is instead of 12.43 K.Cal x 10^6/1000 GTK during 1980-83, ECI would have increased to 19.68 K.Cal x 10^6/ 1000 GTK. The single major factor accounting for such an increase is the price component, the direct or pure contribution of which was 104.99% of total variation in ECI. The second major factor among positive components is the interaction effect due to price and energy intensities (54.93%). This implies that apart from the pure effects of price and energy intensities separately, (in the absence of changes in the traction mix pattern) the joint effect of price and energy intensities would have increased the ECI by an additional 54.93% of the total variation in ECI. It is significant to observe that both the pure effects, namely pure price and pure energy intensities components showed positive signs. The value of the latter was 18.67% of total change in ECI. The adverse effect of the interaction between price and energy intensities has the highest percentage contribution among the first order interaction components. It clearly shows the importance of controlling energy intensities because, even though its direct or pure effect is 18.67% of total variation of ECI, its cumulative effect together with price is quite high.

Moving over to negative components, it can be observed that all the negative components add up to -78.59% of the total variation in the ECI. This measures the total counterbalancing effect which may be ascribed to mainly the change in the traction-mix pattern. This includes the pure traction-mix component, components due to interaction between traction-mix and price, traction-mix and energy intensities and second order interaction component. This shows that although the traction-mix alone (as measured by its pure effect) is not a major factor to counteract the increase in ECI (it contributed only -7.38% of total variation in ECI), traction-mix together with other two factors could counteract large part of the joint and mutually reinforcing effect of price and energy intensities on ECI. In other words, it is precisely in the context of the adverse movement of price of energy and energy intensities that the impact of traction-mix change has assumed considerable significance. For instance, if traction-mix pattern had not changed then during 1980-83, about Rs.350.6 crores per year would have to be spent for incremental energy consumption than actually consumed. This can be explained mainly by tracing the behaviour of the traction-mix pattern. It has been shifting in favour of those tractions which show lower growth or decrease in energy intensities. For example, this can be observed in the negative sign of interaction due to changes in traction-mix and energy intensity. That is, the traction-mix pattern has been reallocated in favour of diesel and electric tractions away from steam traction, thus saving an amount equal to 12.68% of total variation in ECI or Rs.1.17 per 1000 GTK. (That is, even though energy intensities of steam and diesel traction increased due to shift in traction-mix pattern the interactive influence of these factors brought down ECI. Due to this ECI declined by Rs.1.17 per 1000 GTK or saving of Rs.56.7 crores per year during 1980-83 period)

We have already seen that energy intensities of diesel traction increased at much lower rate compared to steam traction, and in electric traction it is actually decreasing. The pure traction-mix effect is negative because even in the base period energy intensities and prices of energy was much lower for diesel and electric tractions. Therefore, it can be said that although energy efficiency of steam and diesel tractions in the Indian Railways deteriorated, its adverse effect has been counteracted by reallocation of traction-mix pattern.

The other negative component is price and traction-mix interaction. This component acted to neutralise the positive effect of rise in prices. The quantitative magnitude of this effect was -20.29% of total variation in ECI. This counteracting behaviour occured due to the fact that traction-mix pattern has been shifting in favour of tractions which use less costly energy resources or which show lower increase in energy cost (that is, price per unit of output). It is worth noting that though unit prices of electricity and diesel show faster growth rates than in the case of coal, due to lower energy intensities in those two tractions, even in the base period, the energy cost per unit of GTK has been growing at lower rate and its magnitude is also lower, compared to steam traction. Thus, the interaction term of traction-mix and price show negative sign.

The findings of decomposition analysis carried out for the two sub periods, 1964-66 to 1981-83, show broadly similar pattern as in the overall decomposition analysis, with respect to direction of movement in the component variables and their impact on ECI. However, it is of some interest to compare the relative contribution of the components in the total ECI change between the two sub-periods.

The Table 4.4 shows that the variation in ECI during the second sub period is greater than the first period. While the variation in ECI during the first sub period shows 92.22% increase over the base year the same for second sub period shows 121.21% increase. A close examination of the movements in the determinant factors, price, traction-mix and energy intensity indicate that during the second sub period the magnitude of variation in these determinant factors were much lower except in the case of energy price.

In both the sub periods traction-mix pattern has been moving to counteract the reinforcing effect of price and energy intensities on the

Table 4.4: Results of Decomposition Analysis, From 1964-66 to 1976-78 and 1976-78 to 1981-82

Components	1964-66 to 1976-78		1976-78 to 1981-82	
	Absolute Value (Rs./1000 GTK)	% Share*	Absolute Value (Rs./1000 GTK)	% share*
1	2	3	4	5
Pure Effect				
Price	3.53	110.63	7.29	118.86
Traction-mix	-0.54	-16.90	-0.73	-11.88
Energy Intensities	0.71	22.13	1.12	18.30
First Order Interaction				
Traction-mix and Energy Intensities	-0.37	-11.63	-0.47	-7.62
Traction-mix and Price	-0.70	-22.04	-0.57	-9.30
Price and Energy Intensities	0.77	24.26	1.18	19.31
Second Order Interaction				
Price, Traction-mix and Energy Intensity	-0.45	-14.23	-0.48	-7.83
Total	2.95		7.35	

* Percentage shares are calculated taking absolute value of ECI of the respective base years as the denominator.

increase in ECI. But in the second sub period the percentage change in the share of GTK of each traction in total GTK showed lower magnitudes i.e. 3.99, 9.75 and -13.74 percentage points respectively for electric, diesel and steam tractions, as compared to 12.66, 28.88 and -38.51 percentage points respectively for the first sub period. On the contrary, the increase in unit prices shows much higher increase in the second sub period. That is index of price increase showed 360.18, 256.00 and 209.96 percentage points for the second sub-period respectively for electric, diesel and steam traction, and 21..67, 88.43 and 111.75 percentage points for the first sub-period respectively for electricity, diesel and coal. In the case of energy intensities the change is more pronounced in the first sub period compared to second sub period (The energy intensities of electric, diesel and steam tractions showed -4.06%, 2.84% and 26.02% variation during the second sub-period as compared to -15.33%, 8.18% and 37.50% respectively for the first sub-period.) This pattern of the movement in determinant factors suggest that in the second sub period although the adverse effect of energy intensities show lesser increase compared to first sub period, the faster increase in the unit prices of energy resources, in the second sub period, led to a faster increase in ECI. Further, the traction-mix pattern in the second period could not counteract as effectively as in the case of first sub period.

The contribution of each component represented as percentage of respective base year ECI (base year of respective sub periods) is given in the Table 4.4 (column 3 and 5). The Table indicate that, relative to the base year ECI in the two sub periods, there is a difference in the percentage contribution of each of the components, except in the case of pure price component. These are higher in terms of their magnitudes (i.e. ignoring the +/- signs) in the first sub period. (For example, the pure component of traction-mix shows 16.90% and 11.88% respectively for the first and second sub periods. Similarly the interaction term of price and traction-mix shows 22.04 and 9.30% respectively for first and second sub periods). This implies that mutually counteracting forces in the first period were much stronger compared to second sub period. Essentially it suggests that traction-mix switch took place to a greater extent in the first sub period leading to greater counteractive influence of increasing ECI. Similarly, the reinforcing effect of energy intensities on the increase in ECI, also shows lower magnitude during the second sub period. That is, while the pure effect of energy intensities in the first period shows 16.9% of base year ECI, in the second sub period it is only 11.88% of its base year ECI. Further, the independent and interactive influence of energy intensities and traction-mix together (i.e; pure energy intensities, pure traction-mix and interaction component due to price and traction-mix) add up to -6.4% of the base year ECI and -1.2% of base year ECI respectively for first and second sub periods. This implies that the total counteractive influence of energy intensities and traction-mix together is lower in the second sub period. It is important to observe that price remains the most important contributory factor for the increase in ECI in both sub periods. But the adverse effect of inflationary movement is found greater during the second sub period. The contribution of pure price shows 110.63% of the base year ECI for the first period and 118.86%

of its base year ECI for the second sub period.

This shows that the reinforcing effect of changes in price on increase in ECI has been more than counteractive influence of changes in traction-mix pattern, and this influence took place to a greater extent during the second sub period. The unit prices of energy sources being an exogenous variable to Railways, the option before the railway authorities in order to reduce ECI are either to reallocate the traction-mix pattern towards more energy efficient tractions or to improve energy efficiency within each traction or to combine both strategies. It seems from the above analysis that Indian Railways have followed mostly the first strategy, giving little importance to the improvement of energy use efficiency. For example, even diesel traction, which hauls more than 57% of the total volume of traffic, has registered an increase of 10.38% in its energy intensities over time. This would undoubtedly get reflected in the total ECI. This we have already seen in the above analysis. This can be better illustrated with the help of the following hypothetical exercise. Let us assume a situation where the energy intensities of electric traction alone had changed, keeping the energy intensities of the other two tractions, namely steam and diesel constant. Now if we allow changes in the traction-mix pattern and prices as observed in the Indian Railways, the total energy cost index would have worked out to be only Rs.11.47 per 1000 GTK,[7] in 1982-83 as compared to the actual ECI of Rs.14.21 per 1000 GTK. This arithmetical exercise establishes the need and importance of reducing the energy intensities. Thus one important conclusion arising from the above analysis is that Indian Railway authorities appear to have concentrated only in reallocating the traction-mix pattern, that even only up to 1976-78, neglecting the energy use efficiency. Our conclusion indicates that, in fact a comprehensive policy integrating reallocation of the composition of traffic (traction-mix) with improvements in energy efficiency would be more helpful in reducing energy cost index and energy conservation.

To sum up, the above analysis suggest that the independent and joint influence of energy prices and energy intensity were the reason for the increase in ECI. But traction-mix pattern changed in such a way as to counteract the increase in ECI by shifting away from steam traction (whose energy intensities and ECI were highest, relatively, and increasing very fast over time) to diesel and electric tractions whose ECI and energy intensities are lower. Due to this structural change in traction-mix pattern the ECI increased only by 283.38% over time, otherwise it would have increased by 506.85% over time, (i.e.; from 1964-67 to 1980-83). It was also observed that traction-mix pattern, after the mid seventies did not change much especially away from diesel traction whose ECI is higher than electric traction. It suggests that there is further scope to change traction-mix pattern as a means to bring down ECI further by reallocating more traffic in the electric traction and minimising traffic in steam and diesel tractions whose energy intensities and energy cost index are higher than electric traction. But the problem with this policy is that it requires a huge amount of finance for investment on overheads required for electrification of lines. The fixed traction installations for electrification requires heavy initial investment, though its recurring operating costs are lower. Therefore reallocation of traction-mix pattern can be used only as a long term policy instrument. But in the short run what is more important is to improve energy use efficiency, especially of diesel traction which hauls about more than half of the total volume of traffic of the Indian Railways. Therefore, to summarise a long run energy planning in railways should aim at a comprehensive policy integrating reallocation of the traction-mix pattern and improvement in energy use efficiency.

An attempt is made in the next chapter to examine the determinents of the energy intensities or energy use efficiency of each traction.

Notes and References

1. We have seen in the previous chapter that energy cost index of steam traction is the highest among the three tractions. Thus it can be observed that the trend in the growth of energy intensities of steam traction might have influenced ECI adversely. But since its share in the total volume has been decreasing, to what extent this influenced ECI is a question which we shall examine later in this chapter.

2. The unit prices of all the three energy sources measured in its original units of measure is presented in the Appendix I.

3. Price being an exogenous variable to Railways detailed discussion regarding the reasons for this observed trend, though worth examining, is not done here.

4. Detailed discussion on traction-mix pattern is already given in the previous chapter, so we do not repeat it here.

5. This model is developed along the lines of Minhas and Vaidyanathan model to decompose agricultural growth. B.S. Minhas and A. Vaidyanathan, "Growth of crop output in India 1952-54 to 1958-61", Journal of the Indian Society of Agricultural Statistics, Vol.XVII, No.2, 1965. A detailed discussion regarding the original model is presented in the Appendix II.

6. The reason for selecting 1976-78 as the cut off period for the decomposition of sub-periods is to analyse the impact of 'second energy crisis'. The movement of price shows the fastest increase after this period.

7. The worksheet of the calculation procedure is presented in the Appendix III.

Appendix I

Average Price* of Energy Forms

Year	Coal Rs/Tonne	Diesel Rs/Kilolitre	Electricity Paise/kwh
1964-65	54.47	649.95	8.49
1965-66	50.22	717.91	9.01
1966-67	52.73	713.47	8.87
1967-68	58.38	783.37	10.07
1968-69	63.94	801.40	10.52
1969-70	67.37	841.35	10.33
1970-71	69.12	791.53	11.37
1971-72	70.41	814.73	13.06
1972-73	70.09	825.65	14.01
1973-74	72.76	851.48	14.35
1974-75	84.06	1010.63	18.26
1975-76	101.34	1149.19	20.61
1976-77	112.36	1256.68	22.99
1977-78	111.14	1253.00	23.50
1978-79	115.41	1264.51	27.24
1979-80	148.65	1427.48	31.73
1980-81	169.13	1961.51	36.97
1981-82	213.17	2820.27	48.30
1982-83	242.14	3025.20	59.88

* Overall average price of fuel per Tonne/Kilolitre including handling, incidental charges and all freight both rail and sea from pits mouth or station of supply to engine sheds etc., from where issued to locomotive purpose.

Appendix II

Component Analysis for Analysing Sources of Growth

To analyse the sources of growth, generally used statistical methods are multiple regression and component analysis. But the explanatory power of multiple regression is low. It is worth quoting A. Vaidyanathan on this.[1/]

> "There is the ubiquitous problem of multi-collinearity between input variables arising from the fact that almost all of them tend to grow over time. This functional forms cannot accommodate varying degrees of complementarity and substitution relation between inputs".

Therefore, generally component analysis is preferred which is free from this type of problems.

In India component analysis was used to analyse sources of growth by Minhas and Vaidyanathan.[2/] They, for the first time used an additive scheme of decomposition to analyse growth of crop output. They describe their analytical design as "...... component elements are so chosen that their contributions to output growth are determined by more or less

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1. A. Vaidyanathan, "On Analysing Agricultural Growth" Journal of the Indian Society of Agricultural Statistics, Vol.XXXIII, No.1, April, 1980.

2. B.S. Minhas and A. Vaidyanathan, "Growth of Crop Output in India: 1951-54 to 1958-61 — An Analysis by Component Elements". Journal of the Indian Society of Agricultural Statistics, April, Vol.XVII, No.2, 1965.

independent set of factors. Each of these sets of factors can be separately analysed ......". And this analysis would, "provide the building blocks for constructing output projections".[1] The model they employed is presented below

They define crop output in year 0 (P_0) as:

$P_0 = A_o \sum W_{io} C_{io} Y_{io}$ and in the terminal year (P_t) as:

$P_t = A_t \sum W_{it} C_{it} Y_{it}$

where,

A = Gross crop area

W_i = Constant price weights assigned to different crops

C_i = Proportion of area occupied by different crops

Y_i = Crop yield

They split up the increase in crop production over time period (1951-54 to 1958-61) into their component elements in the following manner:

$$P_t - P_o = (A_t - A_o) \sum W_i C_{io} Y_{io} + A_t \sum W_i C_{io} (Y_{it} - Y_{io}) + A_t \sum W_i Y_{io} (C_{it} - C_{io}) + A_t \sum W_i (Y_{it} - Y_{io}) (C_{it} - C_{io})$$

In this additive scheme, the first component in the right hand side of the equation is the "area effect" reflecting an increase in output of this magnitude would have taken place solely due to change in area in the absence of any change in per acre yield and cropping pattern. Second component shows the effect of changes in yield for a constant area and crop composition pattern and the third component portrays the effect of

1. B.S. Minhas and A. Vaidyanathan; ibid

changes in cropping pattern in absence of any change in area and crop yield. The last component measures the effect on output which could be attributed to interaction between per acre yield change and the changes in cropping pattern.

Later Minhas[1], Vidya Sagar[2], Dharam Naryan[3] etc. extended and modified the above mentioned additive model incorporating additional variables. Further, Ashok Parikh[4] employed multiplicative scheme which decompose, unlike additive schemes which decompose absolute increase and hence linear growth rates of output, the multiplicative scheme that explains its compound rate of growth in terms of the component growth rates.

These arbitrary schemes of decomposition models help us in "establishing certain general hypotheses on growth pattern vis-a-vis its components and their interaction. Besides providing estimates of growth contributed by these components this analysis may also help in deducting hypotheses on causes and effects of a specific growth pattern[5]

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1. B.S. Minhas, "Rapporter's Report on Measurement of Agricultural Growth", Indian Journal of Agricultural Economics, Vol.XXI, 1966.

2. Vidya Sagar, "Decomposition of Growth Trends and Certain Related Issues", Indian Journal of Agricultural Economics, Vol.35, No.1, 1980

3. Dharam Narayan, "Growth of productivity in Indian Agriculture" Indian Journal of Agricultural Economics, Vol.VIII, 1966.

4. Ashok Parikh, "Statewise Growth Rates in Agricultural Output — An Econometric Analysis", Artha Vijnana, Vol.VIII, 1966.

5. Vidya Sagar, (1980), op.cit.

"But this should be backed by rigorous research to provide sufficient evidence to support or to contend these hypotheses".[1]

Thus it means that this type of decomposition exercise serve mainly to help in 'organising data systematically' for analysis of casual factors in the growth process. However, being essentially an accounting exercise, this method does not attempt to establish by statistical methods the strength or weakness of the casual relationships between the variables. Thus the studies aiming at this purpose should consider decomposition analysis only as a starting point of the analysis. In the text, we have adopted this method (in its additive decomposition variant) to study a problem which is analytically analogous.

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1. Vidya Sagar, "A Component Analysis of the Growth of Agricultural Productivity in Rajasthan: 1956-61 to 1969-74," Indian Journal of Agricultural Economics, Vol.XXXII, No.1, 1977.

Appendix III

Work Sheet

Energy cost index at time t is defined as the product of energy intensities and the respective unit prices of time point t.

$$E.C.I = \frac{(\text{Energy intensities at } t)(\text{Unit prices at } t)}{1000 \text{ Gtk}}$$

To find out what would have been the energy cost index in 1982-83, if energy intensities of diesel and steam tractions did not change, we have to employ base year 1964-65 energy intensities of these tractions instead of t^{th} year values, while allowing all other variables to change as observed. Energy cost indexes thus calculated are presented below:

Energy Cost Index

Steam	Diesel	Electric	Average (total)
16.58	11.61	8.21	11.47

Chapter 5

DETERMINENTS OF ENERGY INTENSITIES

In the last chapter, we analysed inter alia the quantitative significance of declining energy efficiency in raising the overall energy cost index of the Indian Railway system. Our analysis showed that a fairly large proportion of the increased energy cost can be attributed to direct and indirect influences of worsening energy efficiency or energy intensities. Hence, it is important from the policy viewpoint, to identify the factors underlying this decline in energy intensities. This chapter attempts to identify various service characteristics and operating conditions which are likely to have a bearing on energy intensities. It also tries to examine how and to what extent the changes in these factors have influenced the energy intensities of each traction. As seen in the preceding chapter, the movement of energy intensities over time have been as follows: while energy intensities of steam and diesel tractions showed an increasing trend, registering average annual compound growth rate of 2.997% and 0.281% respectively, the energy intensities of electric traction, however, marked a decreasing trend accounting for an average annual compound growth rate of -0.853%.

There are wide variations in operating/service conditions between regions, gauges, freight and passenger services etc. Therefore, a disaggregated analysis based on the above categories would be most appropriate, for it would furnish us with more insights into the factors, determining energy intensities. But due to serious data limitations we are constrained to limit our analysis to the national data disaggregated by the traction level alone. Nevertheless, we may make use of the available information to explain the determinents of energy intensities of the All India level for each traction. Since very little systematic analysis has been done, even at this level of aggregation, it is hoped that this will be a useful contribution to the literature.

Factors Influencing Energy Intensities

The objective of railway operation is to transport freight and passengers. For this purpose, first, the energy resources have to be converted to the mechanical energy and made available at the wheels of the locomotive. This in turn is converted into traffic output in the form of gross tonne kilometres (GTK), which measures the volume of passenger and freight transport as the product of weight times distance travelled. The amount of energy needed for this process depends on various traffic, operating and technical factors as mentioned in official documents.[1/] Thus, the major determinants of energy intensities are the following:

a. Average load

b. Average speed

c. Efficiency of locomotives and rolling stock

d. Grade and quality of basic energy resource used

e. Efficiency of locomotive crew and

f. Technological developments etc.

Let us examine how each one of the determinants influences energy consumption and in turn energy intensities.

a. Average load:

It has been well recognised that the best energy efficiency is achieved only when the ratio of the technologically specified, maximum feasible load to actual average load of the train is as close to unity as possible. Poor load leads to under-utilisation of locomotive capacity and consequently higher fuel consumption per unit of GTK than otherwise possible. It is mentioned in the Operating Manual of Railways[2] that each type of locomotive has its optimal load to achieve the maximum output with minimum energy input. Thus it is necessary that each locomotive should be given that specified load to attain energy efficiency.

For operational convenience average load is defined as traffic output per distance travelled by locomotive. That is, it is the ratio between gross tonne kilometre per year and engine kilometres of that year.

$$\text{Average Load (L)} = \frac{\text{Gross tonne kilometres (GTK)}}{\text{Engine kilometres (EK)}}$$

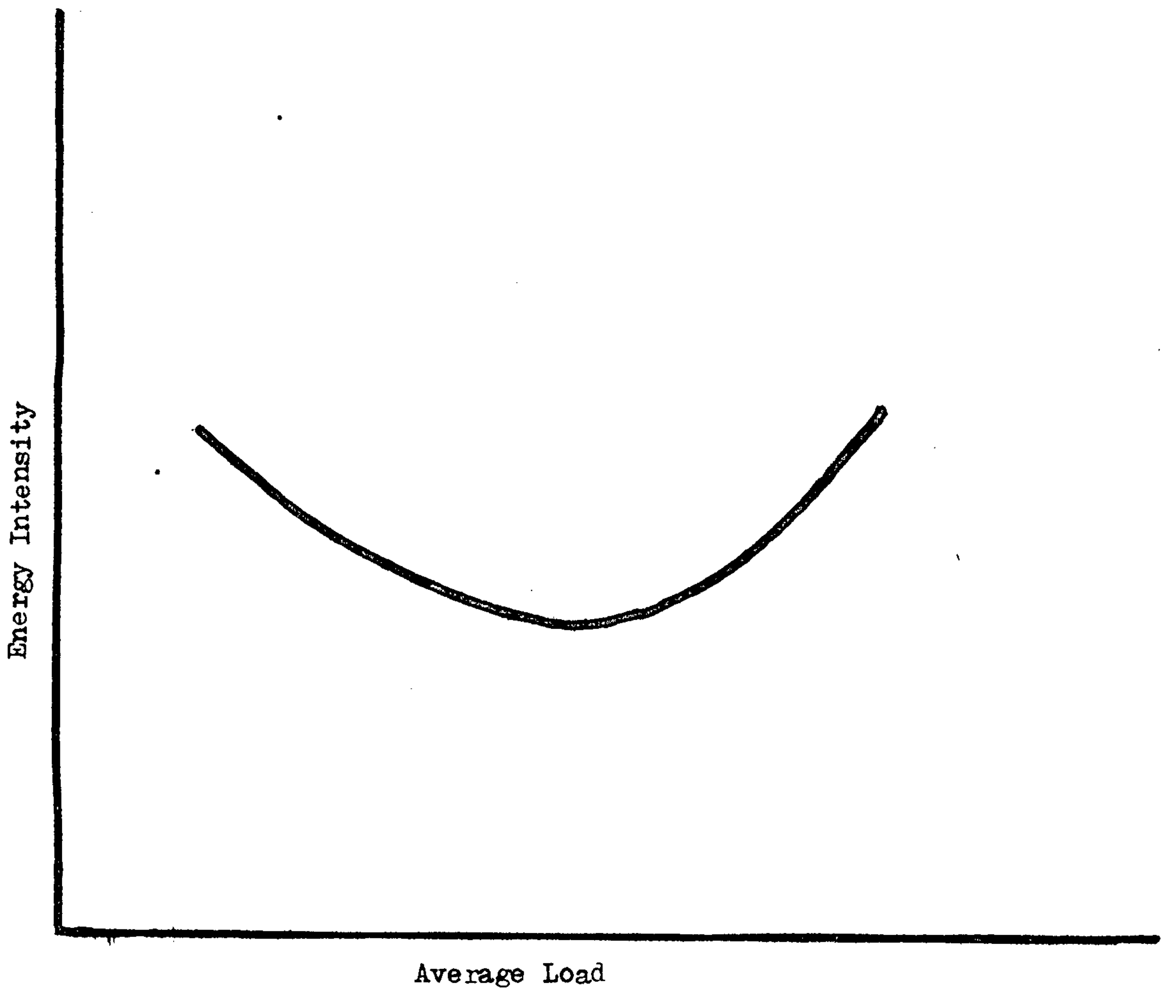
This shows that if engine kilometres increase without corresponding increase in GTK it will lead to deterioration in average load and hence capacity utilisation. This is because there is a minimum quantum of energy required for the engine or locomotive to travel a specified distance. Increase in average load upto an optimum level will necessitate only marginal increase in energy consumption. Therefore, it is always economical from the point of view of energy conservation and cost reduction to haul upto this optimum level of load. But above the optimum level, the incremental energy consumption will be much higher and it will become uneconomical. The Figure 5.1 clearly illustrates the technological relationship between average load and energy intensity.

Disproportionate increase in engine kilometres compared to GTK occurs when engines are used for auxiliary services such as shunting and siding which are not directly productive but a necessary service for the main traffic.[3/] As the share of engine kilometres used for auxiliary services increase in total engine kilometres it will adversely influence energy intensity because it increases energy consumption without producing transport output-GTK.

b. Average Speed:

Another factor which influences energy intensities is average speed, that is, average distance of train moved per engine hour. Poor speed results in longer hours on rail, which in turn result in extra fuel consumption without corresponding increase in GTK. In the literature dealing with estimation of energy intensities, increase in transit time is generally associated with an increased use of energy,[4/] independent of distance hauled. This increase in transit time (reflected in decrease in average speed) can be due to increased stoppages or to speed restrictions. Even if the engine is stationary, it requires energy particularly in the case of diesel and steam locomotives which cannot be put off for short time periods due to difficulties in restarting the engine.[5/]

Fig.5.1: Technical Relations Between Energy Intensity and Average Load



In operational terms, average speed is the ratio between engine kilometres of an year and engine hours of that year. In other words, it shows the distance locomotive travelled per hour.

$$\text{Average Speed (S)} = \frac{\text{Total engine kilometres (EK)}}{\text{Total engine hours (EH)}}$$

Transit time which is the main determinent of speed depends on mainly two factors namely, extent of unproductive engine hours and type of service.

Unproductive engine hours occur due to increased detentions enroute for crossing, precedence, detachment of hot boxes, incidence of speed restrictions, problems of signalling etc. These are the activities for which trains have to be stopped or slowed down, which in turn increase energy consumption and energy intensities. It is also well established that acceleration and decelaration of the trains are more energy intensive activities compared to normal running at constant speed. Thus a decrease in unproductive engine hours can contribute to an increase in the average speed and energy efficiency.

The second factor which influences speed is type of service. As we said above, the auxiliary work which is more energy intensive due to more frequent accelerations and decelerations and stoppages, also increases the transit time without corresponding increase in engine kilometres. Apart from auxiliary services there are other services namely the 'local passenger' services which are generally slow trains with frequent stoppages. This also increases transit time. Therefore, if the share of these auxiliary and other slow services increase in total engine hours, then the average speed will decrease and which in turn influence energy intensities.

But if the average speed is higher than optimum speed, which is determined by technology, then it will result in excess consumption of energy.[6] Therefore, from the point of view of energy consumption it is advisable to run at the technologically specified optimal speed of the type of locomotive, without increasing the unproductive engine hours.

c. Efficiency of locomotive and rolling stock:

Locomotive is a means of conversion of latent heat present in the fuel to mechanical energy. The conversion ratio would depend primarily on design parameters but even for the same design, the ratio can vary within a range as much as 5% to 10% depending on the quality of maintenance.[7] Generally a steam locomotive is designed to put in service for 40 years and diesel and electric locomotives for only 15 years. Therefore, if locomotives are used after its economical life span, then it will adversely influence energy consumption.[8]

Maintenance of 'rolling stock' also influences the energy intensity. If the rolling stocks and tracks are not in proper condition, then this may lead to unnecessary imposition of speed restrictions. This will influence the transit time,[9] which in turn influences energy intensities.

d. Grade and quality of basic energy form used:

Quality of fuel refers primarily to the heat value of the fuel. The final output will, then, be dependent on the heat value of the fuel, if all other determinants remain same. In the case of diesel and electricity this factor is not important because their heat values per unit of energy are fixed.

For instance, railways use only 'high speed diesel oil' (HSD), for traction purpose, for which the heat value is fixed. But various grades of coal are mined in India, and their heat value, ash content and size of the coal vary widely. India Railway Service locomotives are designed to use coal of specific grade ranging between 7,225 kilo calories per kilogram to 6,835 K.cal/Kg. Further the consumption of coal has been found to increase by 2 to 2.5 per cent in locomotive boilers for every one per cent rise in ash content. This is mainly because, the steam locomotive boiler is restricted in size and shape due to the restrictions of moving dimensions, unlike stationary boilers, as a result locomotive boiler has to be worked very intensively to get the necessary output of steam. It is therefore, evident that whenever correct grade and size of coal is not available much more coal is used than otherwise.[10/] Therefore, it is important to use the specified grade of coal inorder to curtail the waste of energy and to reduce energy intensities.

e. Efficiency of the locomotive crew:

There is a close correlation between efficiency of locomotive crew and energy use efficiency. It is generally held by experienced locomotive foremen and inspectors that on a rough estimate, the difference between the quantity of coal consumed by a well trained and motivated crew and an untrained and indifferent crew is at least 10% and may be as high as 25%.[11/] Thus, if well trained and motivated engine drivers are employed the energy efficiency will be higher than otherwise.

f. Technological development and other factors:

Technological development aiming at energy saving techniques can influence energy intensities. For instance, in Britain, thermal efficiency of steam locomotive has improved to the level of 12%[12] compared to the Indian maximum of 6 - 7% by technological improvements. Japan Railways (J.N.R) have adopted the 'regenerative breaking system' in electric and diesel tractions in a large scale[13] and found that it is much more economical compared to the 'dynamic braking system' which have been used before. These examples show that technological factors can influence energy intensities and any improvement at this side will have an effect on energy efficiency.

Empirical Analysis

i. Behaviour of Explanatory Variables Over Time:

Among the above discussed variables which are likely to have a bearing on energy intensities, all the variables need not have actually influenced changes in energy intensities in India during the period considered. Depending upon the magnitude and direction of changes in each of these factors it will have different effect on energy intensities. Apart from that, for each traction each of these factors may influence energy intensities differently. At this stage, we shall examine how each one of these factors behaved and influenced energy intensities of each traction of Indian Railways.

a. Average load:

Significant differences in the magnitude and direction of changes in the average load among the three tractions can be observed during the period under consideration in Indian Railways (Table 5.1). The steam and diesel tractions show decreasing trend registering an average annual compound growth rate of -2.36% and -0.97% respectively. On the contrary, electric traction showed an increasing trend accounting 0.55%. Regarding the magnitude of the load, average load of the steam traction is the lowest and much below the average load of electric traction which has the highest average load.[14]

The main factor influencing average load of a traction is composition of traffic of the traction or type of service,[15] carried out in that traction as mentioned earlier. For a traction there are mainly two types of operations, namely main traffic service and auxiliary service.[16] Even in main traffic service there are differences in average load between passenger and freight traffic services. Freight traffic services are much heavier or average load will be much higher, compared to passenger services, obviously, because of the differences in the nature of content. Therefore, as the share of freight traffic in total volume of traffic changes, the average load of the traction will also change.

During 1964-65 about 57.98% of the total traffic of steam traction was constituted by freight traffic but by 1982-83 this share decreased sharply to 23.83% accounting for about 34.15 percentage points decrease over the entire period (See Figure 5.2). In the case of diesel traction the share of freight traffic in total traffic of diesel traction was 77.26%

Fig.5.2: Percentage Share of Passenger and Freight Services in Total Service

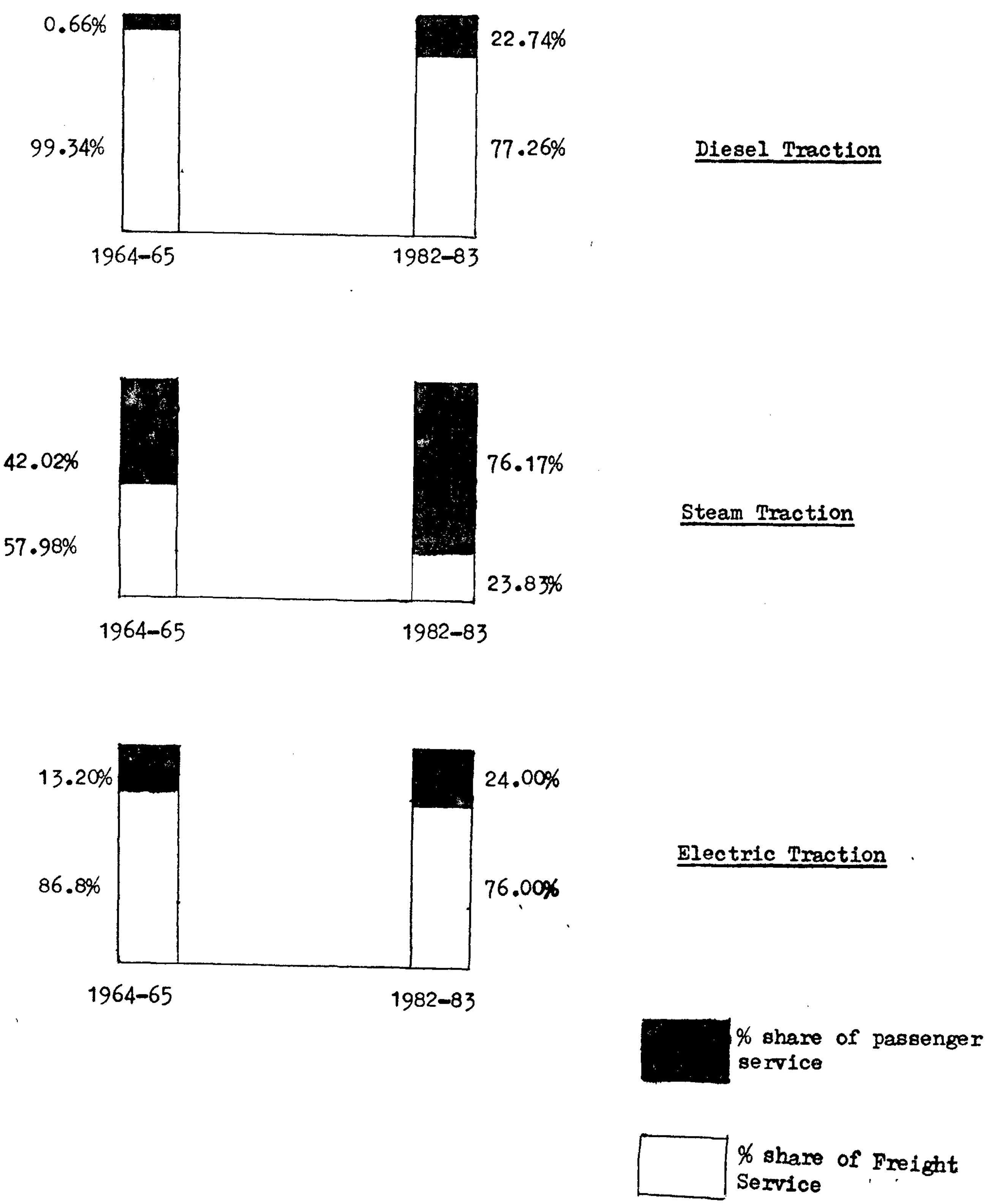


Table 5.1: Average Load of the Tractions

GTK/Engine Kilometres

Year	Steam Traction	Diesel Traction	Electric Traction
1964-65	532.18	1289.36	1114.22
1965-66	523.97	1231.80	1159.74
1966-67	507.69	1209.37	836.86
1967-68	498.71	1180.46	1154.57
1968-69	487.84	1189.25	1144.57
1969-70	467.62	1150.01	1135.97
1970-71	467.67	1148.27	1124.23
1971-72	462.11	1154.97	1111.79
1972-73	460.97	1145.62	1163.75
1973-74	441.52	1092.52	1140.47
1974-75	457.22	1086.46	1173.51
1975-76	446.66	1094.17	1149.22
1976-77	431.09	1096.40	1139.51
1977-78	419.04	1103.10	1716.49
1978-79	393.82	1083.97	1090.77
1979-80	375.19	1092.06	1081.42
1980-81	352.38	1076.09	1088.98
1981-82	340.16	1063.47	1137.27
1982-83	343.99	1019.59	1151.44

Source: Calculated from Annual Statistical Statements of the Indian Railways (Various years)

Table 5.2: Percentage Share of Auxiliary Services in Total Services of the Traction

Year	Steam	Diesel	Electric
1964-65	18.86	3.95	1.76
1965-66	19.49	3.53	1.68
1966-67	19.94	3.39	1.05
1967-68	20.09	3.46	1.33
1968-69	20.55	4.96	1.19
1969-70	20.97	5.66	1.08
1970-71	21.69	5.52	1.05
1971-72	22.08	5.57	1.05
1972-73	22.54	6.29	1.12
1973-74	24.64	7.17	1.76
1974-75	24.88	8.47	1.77
1975-76	23.96	8.54	1.51
1976-77	24.26	7.54	1.36
1977-78	24.99	7.32	1.29
1978-79	26.70	7.81	1.20
1979-80	27.17	8.11	1.30
1980-81	27.53	8.80	1.45
1981-82	28.28	9.35	1.77
1982-83	26.71	10.34	1.17

Source: Calculated from Annual Statistical Statements of Indian Railways (Various Issues) in 1982-83 compared to 99.34% in 1964-65. That is, relatively the decrease in the share of freight traffic in total traffic is lower in diesel traction compared to steam traction, it is only 22.08 percentage points decrease over time compared to 34.15 for steam traction (See Figure 5.2). But this trend is still lesser in the case of electric traction compared to other two tractions. It showed a decline of only 10.80 percentage points over the entire period (86.8% in 1964-65 and 76.00% in 1982-83).

Therefore, it appears that this decrease in the share of freight traffic in total traffic of the respective tractions has influenced the behaviour of load adversely, especially in the case of steam and diesel tractions.

The behaviour of auxiliary services also shows adverse trends from the point of view of average load and thus energy intensities. As its share in total engine kilometres increases the average load decreases, since such an increase does not create any additional GTK. Besides this indirect effect, it has a direct bearing on energy use. The auxiliary activities are more energy intensive compared to main traffic services due to their peculiar nature of operation such as frequent deceleration, acceleration and stoppages.

The share of auxiliary service in total service increased over time in all the three tractions, but with differing magnitudes. The most striking increase is in the diesel traction. The annual average compound growth rate of the auxiliary service in total service of diesel traction is 5.9%, while the corresponding growth rates for steam and electric tractionsare 2.24% and 1.48% respectively. Regarding the magnitude of percentage share of auxiliary service in total service of the tractions, it is highest in steam traction compared to diesel or electric tractions (See Table 5.2)

It appears from the above discussion that the increase in the auxiliary service compared to total services has contributed to a decrease in the average load of diesel and steam tractions. What is more important from the point of view of energy conservation is the direct relationship between auxiliary activity of steam traction and its energy intensities. The Table 5.3 shows that energy requirement of auxiliary activity of steam traction has increased considerably. Energy requirement per 1000 Km. auxiliary activity was 178.67 Kcal x 10^6 in 1964-65 which increased to 240.07 K.Cal x 10^6 in 1982-83. By contrast, diesel traction shows a reverse trend. Its energy requirement decreased from 18.27 K.Cal x 10^6 in 1964-65 to 15.47 K.Cal x 10^6 by 1982-83. In the case of electric traction we do not have the data of electricity consumption for auxiliary works prior to 1974-75, hence we calculated energy requirement per Km. of auxiliary service only from that time onwards, and it shows that its value is moving around 2.1 K.Cal x 10^6.

Therefore, it may be said that an increasing share of auxiliary service in the total service of the respective tractions along with an increasing energy requirement for auxiliary service is very serious from the point of view of energy conservation and cost reduction.[17/] The auxiliary work done by steam traction is most uneconomical from the energy utilisation view point and this work should be shifted away from

Table 5.3: Energy Requirement for Auxiliary Activity

(K.Cal x 10^6)

Year	Steam Traction	Diesel Traction	Electric Traction
1964-65	14678942(178.67)	36046.692(18.27)	- -
1965-66	15420001(181.61)	46619.659(19.60)	- -
1966-67	16121579(190.46)	48637.470(18.87)	- -
1974-75	- -	- -	2210.59(2.03)
1975-76	- -	- -	2577.06(2.20)
1976-77	- -	- -	2300.01(1.88)
1980-81	17354595(234.34)	333870.15(15.72)	3175.37(2.34)
1981-82	15562429(229.12)	387191.51(15.68)	4711.94(2.39)
1982-83	14759106(240.07)	456828.83(15.47)	4797.94(1.92)

Note: Figures in the brackets are the energy intensities of auxiliary service, defined as the energy required to do 1000 Kms of auxiliary work That is K.Cal x 10^6/ 1000 Kms

Source: Calculated from Annual Statistical Statements of Indian Railways (Various Years) this traction to either electric or diesel traction. The auxiliary work done by steam locomotives is more energy intensive because it is more sensitive to acceleration and deceleration and stopping. Neverthless, we have observed that the share of this service in total service of this traction has been increasing.[18] An important observation worth special mention is that, in all the three tractions the share of auxiliary services were on the increase. This indicates that, there is ample scope to curtail energy consumption by reducing this service as much as possible. Moreover, since all the three tractions show the same trend, it can not be said that this trend is due to substitution of this work from one traction to other.[19]

The second major factor influencing average load is planning of railway schedules, especially of the freight traffic. For a goods train to work at optimum average load, it is essential that advance planning done at the time of train ordering should actually be implemented, which again is linked to working to a pre-set time schedule.[20] The railway authorities themselves are not fully satisfied with present performance of working to time schedules and they feel that further improvements can be made.[21]

To what extent changes in the average load of each traction has influenced its energy intensities may be examined in the next section of this chapter.

b. Average Speed:

Average distance travelled per engine hours is another factor which has a bearing on the energy intensities. This determinant is termed as average speed. Poor average speed results in longer hours on rail, which in turn leads to extra fuel consumption.

In Indian Railways except for diesel traction, the average speed of the other two tractions show a decreasing trend. The annual average compound growth rate of average speed of diesel traction is 0.83% while the corresponding growth rates of steam and electric tractions are -0.07% and -0.46% respectively. Table 5.4 shows the average speed of each tractions and it can be seen that the absolute magnitude of average speed is highest in the case of electric traction followed by diesel and steam tractions respectively.[22]

The main factors influencing the average speed are unproductive engine hours and type of service.[23] The share of unproductive engine hours as a percentage of total engine hours have been decreasing in steam and diesel tractions while it showed an increasing trend in electric traction, over the period under consideration, Table 5.5. Over time, while percentage of unproductive engine hours decreased by -17.56% in steam traction and -24.46% in diesel traction, it registered an increase in electric traction accounting for an increase of 5.87%. Therefore, one of the main reasons for the increase in average speed of diesel traction may be the decrease in unproductive engine hours compared to total engine hours. The same reasoning can be applied to the opposite trend in the average speed of electric traction. But in the case of steam traction it seems that even though, unproductive engine hours moved in favourable

Table 5.4: Average Speed of the Tractions

(10 Kms/Hour)

Year	Steam Traction	Diesel Traction	Electric Traction
1964-65	1.167	1.583	1.759
1965-66	1.169	1.648	1.749
1966-67	1.161	1.765	2.565
1967-68	1.166	1.769	1.893
1968-69	1.171	1.785	1.868
1969-70	1.166	1.800	1.906
1970-71	1.173	1.818	1.902
1971-72	1.180	1.800	1.877
1972-73	1.183	1.770	1.894
1973-74	1.166	1.778	1.805
1974-75	1.161	1.739	1.808
1975-76	1.176	1.761	1.908
1976-77	1.187	1.896	2.056
1977-78	1.179	1.907	
1978-79	1.157	1.880	1.860
1979-80	1.153	1.869	1.816
1980-81	1.151	1.883	1.820
1981-82	1.136	1.963	1.871
1982-83	1.162	1.975	1.964

Source: Computed from Various Annual Statistical Statements of Indian Railways

Table 5.5: Percentage of Unproductive Engine Hours in Total Engine Hours

Year	Steam Traction	Diesel Traction	Electric Traction
1964-65	17.74	26.24	37.21
1965-66	17.84	27.32	38.02
1966-67	17.98	25.47	37.75
1967-68	18.28	25.84	35.99
1968-69	18.75	24.38	39.71
1969-70	19.09	24.74	38.42
1970-71	18.81	24.90	38.81
1971-72	18.61	25.21	38.07
1972-73	18.32	25.22	35.43
1973-74	18.29	25.88	37.05
1974-75	18.08	25.39	36.22
1975-76	17.22	24.74	37.54
1976-77	16.58	23.31	37.63
1977-78	16.43	22.81	40.94
1978-79	16.10	23.04	43.21
1979-80	15.80	22.72	44.57
1980-81	15.29	22.26	42.43
1981-82	15.02	20.77	41.01
1982-83	14.31	20.23	38.65

Source: Calculated from Various Annual Statistical Statements of Indian Railways direction the average speed showed a decrease. It can be due to the influence of other variables such as changes in the type of service etc.

It was observed above that percentage share of auxiliary service in steam traction showed sharp increase. This increase can be the major reason for the decrease in average speed in this traction. The change in type of service might have outweighed the favourable impact of changes in unproductive engine hours. In the case of diesel traction, although the highest increase in auxiliary service as a percentage of total engine hours was registered, it does not seem to have influenced the average speed adversely. This can be due to the reason that there may not be much wastage of time in doing auxiliary services since the diesel locomotive has the advantage of faster acceleration and deceleration compared to steam locomotives. Therefore, even if the auxiliary service increases relative to total service of the traction it will not adversely influence average speed or transit time quite as much as in the case of steam traction. However, in the case of electric traction also it does not affect average speed or energy efficiency as much as in the case of steam traction.

In the next section of this chapter we will try to examine the causal relationship between the average speed of each traction and the energy intensities of respective tractions.

c. Efficiency of locomotive and rolling stock:

It has been generally accepted that provision for depreciation fund by the Indian Railways has been less than at the desired level, specially after the financial position of Indian Railways started deteriorating after the late sixties. This resulted in heavy maintenance arrears of locomotives, other rolling stock and tracks, mainly due to shortage of workshop capacity and shortage of certain critical items.[24/] As a result, arrears in the replacement of overaged locomotives, rolling stock and track renewals started accumulating. This resulted in the deterioration of efficiency of the rolling stock, track and locomotives, leading to higher energy consumption. Naturally this might have caused for the increase in energy intensities of each of the tractions in differing degrees.

The highest number of over-aged and inefficient locomotives are in the steam traction,[25/] especially since the early seventies when Railways decided to stop production of steam engines and as a result. Research, Designs and standards Organisation (R.D.S.O) of the Indian Railways stopped further research and testing of steam locomotives. This was undertaken as a part of progressive dieselisation and electrification programme of Indian Railways. This resulted in the negligence of steam traction, and increasingly this traction was used mainly for auxiliary and inferior services such as 'local trips'. The percentage of "over aged" and "inefficient" stock to the total stock on lines for steam locomotives in 1982-83 was about 16.47% in Broad Gauge and 15.43% in Metre Gauge. However, field observations conducted by the Study Group on Economy in Energy Consumption[26/]

found that actual share of inefficient stock is more than what is indicated in these figures.[27] Therefore, it can be inferred that the Indian Railways' dieselisation and electrification strategies might have affected the willingness for proper maintenance of steam locomotives resulting in the deterioration in the efficiency of these locomotives.

By contrast, in diesel traction, although there are arrears in the maintenance of locomotives, the situation has improved over time. During 1972-73 there were about 4.42% Broad Gauge locomotives and 2.86% Metre Gauge locomotives which were overdue for regular servicing or overhaul. But by 1982-83 the figure came down to 3.27% and 2.01% respectively. In the case of electric locomotives we do not have information regarding the change over time in the level of maintenance or efficieincy of locomtives. The available information (from Annual Report, 1982-83) about the percentage of electric locomotives overdue for overhaul shows that it was between 6.80% and 7.00% during 1981-83 period. Thus, there is some evidence suggesting the existence of inefficient locomotives in electric traction also. But there is no concrete evidence to believe that their incidence has increased over time. Finally, in the case of diesel locomotives, the situation has been moving in a favourable direction, from the point of view of energy conservation.

The extent of maintenance arrears of other rolling stock such as wagon, passenger carriages etc. are increasing over time. In Table

5.6 the percentages of the stock of passenger carriages and wagons overdue for overhaul are given for 1972-73 and 1982-83. This shows that over time these have accumulated. This increase will have a direct bearing on energy intensities as it leads to speed restrictions enroute and increase in unproductive engine hours resulting in wastage of energy. This will also influence the capacity utilisation, since wagons and coaches cannot be fully utilised, resulting in lower average load.

Thus we can conclude by stating that over time due to shortage of workshop capacity and inadequate equipments and spare parts, maintenance arrears have been generally increasing for steam locomotives. However, the opposite is true in the case of diesel locomotives and in the case of electric locomotives we are not in a position to conclude anything regarding changes over time. This observed increase in maintenance arrears of steam traction can be partly responsible for the deteriorating efficiency of steam locomotives and other rolling stocks. In the case of diesel traction the increase in energy intensities cannot be explained in terms of increasing inefficiency of locomotives rather it is possibly be due to decrease in efficiency of other rolling stock. No such conclusions can be reached in the case of electric traction.

d. Grade and quality of energy resources used:

Grade and quality of energy form is relevant only in the case of coal. In India coal supplied from different mines are of different quality and grade. We have information regarding the amount of coal consumed by

Table 5.6: Percentage Stock Over-Due for Overhaul

Item	Broad Gauge		Metre Gauge	
	1972-73	1982-83	1972-73	1982-83
Passenger Carriages	7.10	10.57	4.69	5.65
Wagons	18.73	23.62	10.97	17.22

Source: Annual Report and Accounts, Various Issues

steam locomotives below the technically specified level of grade and is presented in the Table 5.7. The figures indicate that the percentage of

Table 5.7: Coal Consumed Below the Specified Grade as a Percentage of Total Consumption

Year	Percentage consumed
1977-78	42.1
1978-79	45.1
1979-80	42.0
1980-81	39.6
1981-82	48.0
1982-83	48.8

Source: Report sent by Chief Mining Officer to Railway Ministry, Various reports since 1977.

coal consumed below the specified level has been on an increase. In fact, this deterioration in the quality of coal supplied to Indian Railways started since the nationalisation of coal mines and its distribution,[28] during 1972-73. (Government nationalised the cocking coal mines in 1972 and the non-coking coal mines in the following year). It was estimated that in 1978-79 the amount of coal consumed was higher than the normal requirement due to non-availability of coal of proper quality, the excess amounting to about 0.3 million tonnes. Therefore, quality deterioration or non-availability of specified grade coal is one of the reasons for the increase in energy intensities in the steam traction.

e. Efficiency of locomotive crew:

The relation between energy intensities and the operating efficiency with which locomotive crew utilise energy has been mentioned in the previous discussion. In Indian Railways, with the progress of dieselisation and electrification the bulk of the educated and professionally competent locomotive staff have apparently diverted to drive diesel and electrical locomotives.[29] As a result there has been a steady dilution of the skill level among the steam locomotive staff. Apart from this, with the administration concentrating on training and educating diesel and electric locomotive crew, the steam locomotive crew have suffered relative neglect in this respect. This led to a situation where, "a large majority of the running staff are not even aware of the proper method of firing driving which is essential for achieving optimal fuel consumption".[30] Therefore, in the case of steam traction, this is one of the reasons for the observed increase in energy intensities over time.

In the case of diesel and electric locomotive crew, we do not have much information, but for the Review of the Performance of the Indian Government Railways, by the Railway Ministry. This indicates that the training programmes for these locomotive crew have been conducted properly and the refresher courses are also given to the crew. Therefore, we can conclude on this basis that there may not have been any deterioration in the efficiency of the locomotive crew in electric and diesel tractions, and energy efficiency due to this.

f. Technology and other factors:

Generally almost all the developed railway systems in the world, have adopted new energy saving techniques, especially after the energy crisis.[31/] But Indian Railways have shown only little progress in this respect. The Committee on Motive Power Plan indicated that[32/] "The diesel locomotive designs currently in use in Indian Railways are out-dated and 20 years old. There are deficiencies in the electric locomotive designs also". In the case of steam locomotives, not only is the basic design out dated, but no major attempt at improvement has been made since the beginning of 1970's because of the proposed electrification programme. As mentioned earlier Research, Designs and Standards Organisation of Indian Railways has also stopped attempts at innovating new energy saving techniques. The only exception to this stagnation in technological change is the innovation of 'regenerative braking system' in the electric traction after 1976-77. Regenerative braking system can save energy by returning the electric energy generated by the 'dynamic brak'[33] to the overhead wiring as electric power for the supply to other trains. Since the coasting and deceleration period is about 40% of the running period, a good amount of energy can be saved by using regerative braking system while coasting and decelerating. Diesel engine can also use regenerative braking system and it has been observed that about 5000 kilo litres of diesel can be saved per day for a working fleet of 1500 locomotives.[34] Therefore, it is high time that in Indian Railways diesel locomotives should also use it.

Apart from regenerative braking system in electric locomotives there is no information available regarding innovations leading to decrease in energy intensities. There might have occurred technological changes which have indirect influence on energy efficiency. For instance, there are changes in the design and material used for the manufacturing of wagons, passenger carriages and other rolling stock. This might have influenced the weight of the trains which in turn influence energy use efficiency. Thus, we can only say that in electric traction one of the reasons for the decrease in energy intensities is technical improvement in braking system. It can also be said that there are ample scope to introduce or innovate energy saving techniques which are already introduced and found economical in other railways.

ii. Empirical Results:

An attempt may be made here to examine the impact of movements in the above discussed deterninents on the energy intensities of each traction.

For this purpose multiple regression models were fitted for each traction. Due to serious data limitations, for variables other than average speed and average load other determinents of energy intensities were not included in the model. But inorder to capture the influence of other variables we tried separate regression model where time trend variable along with average load and average speed variables are considered as an additional independent variable. Thus for each traction we have two types of model specifications. The multiple regression models used are the following:

$$Y = \alpha + \beta_1 X_1 + \beta_2 X_2 + \varepsilon \qquad \text{(I)}$$

and the regression model with time trend as an additional independent variable is

$$Y = \alpha + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + \varepsilon \qquad \text{(II)}$$

where,

X_1 = Average load

X_2 = Average speed

X_3 = Time trend variable

α = Intercept term

Y = Energy intensities

The estimated parameters are presented in the Table 5.8. From the Table it can be observed that, in the case of equation without time trend variable R^2 is high only for the equation for steam traction. This implies that unlike diesel and electric traction in the case of steam traction explanatory variables speed and load alone, are capable of explaining almost all of the variation in the energy intensities. But the introduction of the time trend variables improves the R^2 of all the three tractions significantly and give the second regresion model much greater explanatory power for explaining the variations in the energy intensities. This indicates that other variables apart from average load and average speed are also important in explaining the variations in energy intensities especially for diesel and electric tractions. Thus, we will mainly depend on the model specification with the time trend variable to explain the relative importance of the determinents of energy intensities.

Turning over to the role of individual explanatory variables, it is observed that in all the three tractions the coefficients associated with average load are negative and are significantly different from zero at 5% level of significance. The negative sign of the coefficients associated with average load in the equation for all the three tractions indicate presence of inverse relationship between average load and energy intensities, as expected. But the degree of its influence on energy intensities varies between tractions. Diesel traction is more responsive to changes in load factor and the least responsive is electric traction as is evident from the calculated values of elasticities at the margin.[35/] This implies that there is considerable scope to bring down energy intensities by increasing average load. In the case of diesel and steam traction it is very important to reverse the present declining

Table 5.8: Estimated regression Equations

Dependent Variable: Energy Intensities (y)

Regression equation	Traction	Constant	Explanatory Variables X_1	X_2	X_3	$\bar{R}^2$
1	Steam	2772.64 (8.16)	-1.4764 (23.28)	-1364.60 (4.51)	-	0.9815
2	Steam	2879.21 (8.16)	-1.1376 (3.50)	-1610.39 (4.24)	3.3591 (1.06)	0.9902
3	Diesel	66.20 (3.97)	-0.0154 (2.49)	-4.34 (0.867)	-	0.3748
4	Diesel	84.88 (5.44)	-0.0392 (4.01)	0.3285 (0.0724)	-0.3403 (2.76)	0.5595
5	Electric	19.79 (5.34)	-0.0062 (2.37)	-4.07 (2.30)	-	0.2242
6	Electric	28.50 (7.53)	-0.0055 (3.35)	-4.23 (3.88)	-0.1175 (5.20)	0.7057

Note: Figures in parentheses are the computed student's t values. $\bar{R}^2$ refers to corrected ordinary R^2 in view of the degree of freedom.

X_1 = Average load

X_2 = Average Speed

X_3 = Time trend variable

trend in average load so as to improve energy intensities.

The coefficients associated with the average speed for steam and electric tractions are significantly different from zero at 5% level of significance. But the coefficient in the case of diesel traction is not, significant i.e. average speed has a statistically insignificant impact on energy intensities of diesel traction.

The negative coefficients associated with the average speed in the equation for both steam and electric tractions are consistant with the argument made above, it clearly shows the inverse relationship between energy intensities and average speed. Estimated Elasticities at the margin calculated for steam and electric tractions (-2.6946 for steam and -0.6157 for electric traction) clearly show that steam traction is more responsive to changes in average speed compared to electric traction. This is mainly due to the reason that a steam locomotive requires relatively more energy even if the engine is stationary and further, it consumes more energy if the train is accelerated or stopped more frequently, as is happening in this traction. Exceptional behaviour in the diesel traction may be due to the comparatively wide speed range, from nearly 20% to 90% of the maximum rated speed of its locomotives. In the case of electric locomotives also the speed range is quite wide but because of the presence of very high percentage of unproductive engine hours, the average speed appears relatively more important determinent in influencing energy intensities compared to diesel traction. Therefore, apart from minimising unproductive engine hours in all the three tractions, it is very important to reverse the increasing trend of it in the electric traction. Considering the role of time trend in influencing energy intensities, it appears that it is significant in the case of diesel and electric tractions. In the case of steam traction, coefficient associated with time trend is not significantly different from zero at 5% level of significance. Thus, it can be said that, though over variables apart from average load and average speed are important, average load and averaged speed together explains major part of the variation in energy intensities of the steam traction. In the case of diesel and electric tractions time trend is important because other variables apart from average load and average speed are also important in explaining the variation in energy intensities. This can be seen from the Table 5.8 that introduction of time trend improves the R^2 considerably. In the electric traction introduction of time trend variable improves the R^2 from 22% to 70%. In the diesel traction also it improves R^2 quite considerably. Further the sign of the coefficient associated with time trend variable shows negative sign, in the equations for diesel and electric tractions. This implies that, there is an inverse relationship between the energy intensities and the movement of other variables.

In general, the reported regression coefficients cannot be directly used to compare the relative importance of the determinants of the energy intensities from different regression equations. This is because the regression coefficient varies with the units in which each variable is measured. Thus, the regression coefficients "may be made more comparable by stating each of the variables in units of its own individual standard deviation".[36] Thus this adjusted coefficients are termed beta coefficients.[37]

The beta coefficients calculated area presented in the Table 5.9. It suggests that changes in average load is most important variable in determining changes in energy intensities of steam traction and average speed relatively less important. This ranking in order of importance is the same for diesel traction also. However, in the case of electric traction it is average speed which seems to be the most important determinent of energy intensities. Therefore, from energy conservation point of view, railway authorities should give more priority to increase average load in the case of steam and diesel tractions while in the electric traction it is average speed. Ranking beta coefficients of time trend variable, we see that it is more important in the case of diesel and then in the electric traction.

To sum up, it appears from the above discussion that average load has influenced energy intensities in all the three tractions. Average speed, however, was found to be significant only in the case of steam and electric tractions. In the case of steam traction average load and speed together explains major part of the variation in energy intensities i.e.; about 99%. But in the case of other two tractions, we found that time trend variable is also important in explaining the variations in energy intensities. Due to serious data limitations we could not examine the influence of each one of the factors going into the "time trend" variable seperately. The policy implications of the regression exercise are: To bring down the energy intensities it is advisable to increase the average load in all the three tractions and to improve average speed in steam and electric tractions. In the case of electric traction it is high time to reverse the increasing trend in unproductive engine hours to increase average speed and thereby energy use efficiency. In the case of diesel traction, average load seems to be the most crucial deteminent of energy intensities. Thus, increase in average load in diesel traction would improve energy intensities of this traction considerably. The crucial determinant in the case of electric traction is average speed. Apart from reallocating auxiliary activities from steam traction to electric and diesel tractions, railway

Table 5.9: Estimated beta Coefficients

Traction	For load	For Speed	For Time trend
Steam	0.6883	0.1724	0.2030
Diesel	1.8787	*	1.4265
Electric	0.9139	1.0420	0.7372

*Since regression coefficient was not statistically significant we did not calculate beta coefficient for it.

authorities should try to check the increasing trend in the auxiliary services as a percentage of total services of each traction. Further, it was also noted that the efficiency of locomotives, and rolling stock also suffered set backs from lack of proper maintenance. There are also ample scope for innovating new technology inorder to improve energy use efficiency.

Notes and References

1. Report of the Study Group on Economy in Energy Consumption: Coal Government of India, Ministry of Railways, 1980.

2. Manual of Statistical Instructions, Vol.II, Government of India, Ministry of Railways, 1979.

3. For our purpose, we can divide the total railway service into two viz., main traffic service and auxiliary service. The latter constitutes important services required before and after any main traffic operation. Auxiliary service include mainly two activities, namely shunting and siding. Shunting refer to the operation of moving a vehicle or vehicles inside a station, marshalling yard or other railway installations (depot, workshop etc.) which are not considered as a train movement. Siding refer to the crossings, loops at stations, relief sidings, sidings in the coal fields etc.

4. A.F. Daughety et al, 'A New Approach to Railroad Cost Estimation,' Transport Research Forum, 1978, pp.93-96. R.K. Mittal, Energy Intensity of Various Transportation Modes, Transportation Research Record, 689, 1978, pp.25-31.

5. For instance, if the steam engine is working while the train is stationary, it consumes about 150 Kg. of coal per hour. Thus, even if train is not moving under these circumstances it will involve substantial energy consumption.

6. A.F. Daughety et al, *op.cit.*

7. Government of India (1984) *op.cit.*

8. For example, if an over aged steam locomotive is used, then its thermal efficiency can be lower than 4% instead of five to seven percentage.

9. We have already seen above how excess transit time or average speed influence energy intensities. Therefore, here, efficiency of operation indirectly influences energy intensities through transit time.

10. Excess 'small and dust' — small pieces and dust of coal — mixed with coal causes considerable loss of partly burnt coal from the locomotive due to its less than specified size. The results of trials carried out by Research, Designs and Standards Organisation show that if there is 25% 'smalls and dust' instead of 5%, then coal consumption increases by 5.6% and calorific value decreases from more than 7500 K.Cal to 6000 K.Cal. (Note given to National Transport Policy Committee (1980) by the Railway Ministry).

11. Government of India (1980) op.cit.

12. <u>Progressive Rail Roading</u>, Vol.26, No.2, Feb. 1983.

13. T. Shima,'Measures Taken by Railways to Cope with Energy Problem', <u>Rail International</u>, Vol.4, April 1977.

14. The average load of electric traction is 3.35 times higher than steam traction and 1.13 times higher than diesel traction. The average load of diesel traction is 2.96 times higher than average load of steam traction.

15. General rail service can be divided into mainly two types, namely main service and auxiliary service. Main service constitutes the rail movements of freight and passenger from one station to other. The auxiliary service constitute the services needed for the main service such as, shunting, siding etc.

16. See note 3 above.

17. We have calculated the cost of energy for auxiliary service (per 1000 Kms of auxiliary work) and found that steam traction costs about Rs.9804.46 and the corresponding cost for diesel and electric traction are Rs.5125.68 and Rs.1336.80 respectively.

18. Since Railway authorities decided to eliminate steam locomotives from its main line operation, the 'old aged' locomotives are now used for auxiliary services. Since, the stock of steam locomotives is quite high it is not possible to keep it idle. Thus they employ it for auxiliary service which do not require fast movement. This is the main reason for the sharp increase in its share in auxiliary service.

19. At present we do not have any evidence to explain the reason for this adverse trend, but it will be useful to examine it in detail.

20. Government of India (1980) op.cit.

21. This is based on the author's personal discussion with the officials of Railway Ministry.

22. The calculated values of mean speed of each traction is as follows:

(10 Kms/Hour)

Steam	Diesel	Electric
1.16655	1.8099895	1.87216

23. We have already discussed how these factors influence energy intensities, therefore, we do not repeat the discussion here.

24. Summary of the Main Report of Rail Traffic Enquiry Committee, Government of India, Ministry of Railways, 1980, April.

25. This information was obtained from a discussion with the officials of Railway Ministry.

26. Government of India (1980) op.cit.

27. For example, it was found that 2% increase in fuel consumption can be accounted due to the absence of or partial presence of 'arch brick', along, which amounts to coal worth of Rs.5 crores at 1980 price. (Arch brick is an equipment in the locomotive which helps to protect half burned coal from going waste and the absence of it can lead to 5 to 12% increase in energy consumption compared to with arch brick locomotives. And it was found that about 10% of the steam locomotives on line do not have this).

28. This impression was supported by information obtained from the officials of Railway Ministry during a personal discussion with them.

29. Government of India (1980) op.cit.

30. Government of India (1980) op.cit.

31. T. Shima, op.cit. and K. Esveld, 'Consumption of Energy in Transport', Rail International, Vol.12, December, 1979.

32. Report of the Committee on Motive Power Plan, Government of India, Ministry of Railways, 1978, December

33. In dynamic braking system electric energy becomes heat energy and then it is released into the air while it applies brake. For details see T. Shima (1977) op.cit.

34. K.B. Ramalingam, 'Energy Economy in Rail Transportation', Urja, Vol.XIV, No.5, November, 1983.

35. We have calculated elasticities at the margin by taking values of average laid and average energy intensities from 1979-80 to 1982-83. The elasticities at the margin thus arrived at are 0.5839, 1.1160 and 0.4763 respectively for steam, diesel and electric traction.

36. Ezekiel,M. and Fox, K.A., Methods of Correlation and Regression Analysis: Linear and Curvilinear, 1965.

37. The formula given in Ezekiel, M and Fox, K.A.(1965) to calculate beta coefficient is

$$\text{Beta coefficient} = \frac{\text{Standard Deviation of Independent Variable}}{\text{Standard Deviation of Dependent Variable}}$$

For details see Ezekiel M and Fox, K.A(1965).

Chapter 6

SUMMARY AND CONCLUSION

Ever since the 'energy crisis' this subject, energy, has aroused great interest and concern among technologists, economists, scientists and common man. The reasons for this concern are clear and needs no elaboration. The problems stemming from use of commercial and non-commercial energy resources are relatively well documented. Emphasis on improved energy use efficiency has been the most important outcome of this concern followed by the search for newer and non-conventional energy sources.

As seen in the introductory chapter, the links between transport, energy and economic development place the transport sector at the fore-front of policy discussion in India and other developing countries. Further, railways assumes greater importance in India, from the point of view of energy substitution and conservation. This is not only because of its higher share in the traffic service but also it is the only mode where energy substitution is possible in the short run. Though there are few isolated attempts to examine energy consumption pattern and energy use efficiency in Indian Railways, none of these studies analyse changes in the energy efficiency of diesel and electric traction. Further unlike other studies this study treats financial and physical efficiency as inter-related aspects of energy efficiency.

This study tried to analyse changing pattern of energy consumption with a view to explain the physical and financial energy efficiency trends in Indian Railways. Financial energy efficiency of the railway system (ECI) was looked at as a function of price of energy resources, energy intensities of each traction and traction-mix pattern. Physical energy efficiency of the system (Total energy intensity) is determined by energy intensities of each traction and traction-mix pattern. Thus, financial energy efficiency of the system is directly influenced by both physical and financial factors. Physical energy efficiency is influenced by physical factors along with indirect influences of financial factors through the reallocation of traction-mix pattern. Therefore, this study conceived the two aspects of energy efficiency viz., physical and financial efficiency, as interrelated though they are relatively independent. In a capital scarce economy like India, it is all the more important to examine both the aspects of energy efficiency. But one major dimension of financial economy namely overhead installation expenditure for energy substitution from diesel to electricity is not considered. This aspect although beyond the scope of our study is an important consideration in the energy in planning Indian Railways and considerable attention is required.

One crucial observation confimed by the study is that from both the points of view — physical and financial — the most efficient traction is electric and least efficient steam traction. Further, we find that this ranking holds true for the entire period under consideration (from 1964-65 to 1982-83), but the differences in the energy efficiency among different tractions became wider over time.

It was found in the Chapter III that the ECI of Indian Railways increased over time registering 7.65% annual average compound growth rate. It is steam traction which registered the highest increase followed by electric traction. Even though ECI of electric traction registered high growth, its magnitude was found well below the other tractions.

In the IVth chapter we decomposed the observed variation in ECI into components using an additive form of decomposition scheme. This helped to evaluate the relative contribution of independent and interactive influences of the determinents of ECI. It suggested that while independent and interactive influence of rise in energy price and energy intensities pushed up ECI, traction-mix pattern moved in such a way as to counteract the increase in ECI. But changes in traction-mix pattern could not fully counteract the adverse effects of price and energy intensities, although this shift significantly checked the ECI from rising higher. For instance, it was seen that ECI would have increased to 19.68 K.cal/1000 GTK instead of the actually observed 12.43 K.Cal/1000 GTK during 1980-83 if the traction-mix had remained same as during 1964-65.

It appears from the foregoing analysis that among the variables which may be influenced by policy, energy intensities and traction-mix pattern, Indian Railway authorities have concentrated only in reallocating the traction-mix pattern, neglecting energy intensities, to reduce energy cost index and energy use efficiency. It was found from the decomposition analysis carried out for the two sub-periods that the reinforcing effect of changes in price and energy intensities on increase in ECI took place relatively to a greater extent during 1976-78 to 1981-83 This was mainly because traction-mix pattern did not change much after mid-seventies, especially away from diesel to electric traction whose ECI is much lower than diesel's.

Therefore, the main policy implication emerging out of the analysis of financial energy economy is that in the short run, given pervasive capital shortage, it is important to improve physical energy efficiency, especially of diesel traction which hauls more than half of the total volume of traffic of the railway system. However, in the long-run energy planning in the Railways should aim at a comprehensive policy integrating reallocation of the traction-mix pattern and improvement in energy use efficiency.

The above considerations combine to produce what is often cited as a dilemma by policy makers and planners. It is important from the financial and physical energy efficiency point of view to reallocate traffic away from diesel traction to electric traction. However, electrification of tracks require heavy fixed investment for the over head equipments, which is a burden to the Railways because of capital scarcity. This high fixed cost involved in electrification can yield sufficient returns only above a high level of traffic. It is not possible however from our analysis to fully resolve this dilemma since we have concentrated only on the "variable cost" picture. It is important to mention that the issue of energy substitution, from diesel to electricity, should be considered from the view point of the wider economic perspective of social investment allocation rather than simply financial profitability and financial costs directly affecting the Railways. Although this issue is very important from the point of view of energy conservation policy, it is beyond the purview of our present enquiry and is left for future research. However, this study suggests that capital scarcity should not be a barrier in railway electrification, the main consideration for it should be conservation of non-renewable, high cost energy resources like diesel.

Moving over to physical energy efficiency, apart from the impact of changes in it on financial energy economy of Indian Railways, it has also a bearing on the question of depletion of non-renewable energy resources, especially fossil fuels. In the fourth chapter we found that energy intensities (physical energy efficiency) except in the case of electric traction, have been on an increase. Further as in the case of ECI, steam traction is the least efficient and electric traction most efficient traction, from the point of view of physical energy efficiency. This holds true for the entire period under study. This make more acute the need to improve energy use efficiency in the Railways.

In the Vth chapter, we concentrated in identifying various factors underlying the changes in energy intensities and tried to examine how and to what extent these factors influenced energy intensities of each traction. This was done through regression analysis. Among explanatory variables included in the analysis were average load and average speed in each traction. Due to data limitations, the impact of some of the other relevant variables, could only be captured by the time trend variable.

In the case of steam traction among the determinents of energy intensities average load and average speed are found to explain major part of the increase in the energy intensities. We found that other operating conditions also have bearing on energy intensities, but was not important. From the analysis it was also found that auxiliary activities done in this traction is highly uneconomical, relatively, and this should be stopped as early as possible. Even the main line operation in this traction should eventually be terminated with a view to conserve energy.

In the case of diesel traction average load and other operating conditions were found influencing the energy intensities adversely. Average speed, however, was not found to be an important variable. It may be because, the diesel engines have a very wide speed range from nearly 20% to 90% of the maximum rated speed.

In the case of electric traction though average load, average speed and other operating conditions were found to influence the energy intensities average speed was found to be the most important determinent of energy intensities.

The main policy implications derived from the analysis of physical energy efficiency are the following: Energy use efficiency can be improved if the auxiliary activities can be reallocated from steam traction to electric and diesel tractions. Apart from this, the present increasing trend in the auxiliary activities should be reversed. Further, the presence of very high share of unproductive engine hours in total engine hours of the tractions is also found to affect energy intensities adversely. This should be decreased, especially in the electric traction where it is highest and show increasing trend. These two activities together would improve the average speed and average load.

With regard to other operating conditions of Railways it was found that the efficiency of locomotives and other rolling stock should be improved. They suffered set backs from lack of proper maintenance. Further the outdated designs and technology used for the manufacture of diesel and electric locomotives should also be improved old and inefficient locomotives should be replaced, and energy saving techniques should be innovated in Indian Railway locomotives. More specific policy recommendations to improve energy use efficiency can be derived only from more detailed analysis for different regions for passenger and freight traffic seperately. Therefore, we feel that more disaggregated analysis is needed.

Though energy economy is not the sole criterion for transport policy, we feel that capital scarcity should not be a barrier in electrifying the lines. We would support the view expressed by National Transport Policy Committee (1980), Government of India, to minimise the traffic in diesel traction and would also suggest termination of the operation of steam locomotives. Further, a long-run energy conservation policy should aim at a comprehensive policy integrating reallocation of the traction-mix and improvement in energy use efficiency.

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