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# A cross-sectoral analysis of energy shortages in Pakistan: based on supply-driven input-output model

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**ABSTRACT**

The impacts of energy shortages characterized by regular blackouts, natural gas, and electricity load shedding in Pakistan affected each economic sector, causing an energy-induced crisis and ecological sustainability issues. This study was conducted to reveal the benefits of renewable energy and describe the economic losses associated with electricity unavailability using supply-driven input-output as a price model across 34 sectors. The results revealed that exogenous shocks in electricity prices are responsible for bringing significant fluctuations across the business cycle in the country. Similarly, the overall output of Pakistan's economy will decrease by 24.89 rupees due to a 1-kilowatt-hour reduction in electricity supply. Moreover, both forward and backward linkages of Pakistan's economy revealed that higher electricity allocation coefficients pose significant output impacts on most sectors. We conclude that indirect output impacts require due consideration to avoid the underestimation problem due to total electricity shortages. It is recommended that the government provide a social and legal framework to boost the environmental sustainability and economic activities in the textile, oil refining, production of cement, and fertilizer sectors for sustainable economic growth.

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## 1. Introduction

Energy is essential for running daily life activities, especially in the modern era with a wide range of applications. To date, most of the energy needs are fulfilled using non-renewable energy resources (NREs), e.g., coal, natural gas, oil and peat across the globe. NREs are mostly used in the household, agriculture, industries, and transportation sectors. Developing countries, particularly Pakistan, Bangladesh, India, and Afghanistan, heavily rely upon NREs, i.e., diesel, coal, compressed natural gas (CNG), and liquefied petroleum gas (LPG), which destroy the environmental quality but also cause many diseases. Since NREs are limited in quantities and cannot be replenished,

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an ever-increasing demand for these resources is causing energy shortages (Raza et al., 2022). For instance, the energy-induced crisis has become a chronic issue in Pakistan due to electricity and natural gas unavailability forcing the government towards a planned-load shedding policy across rural and urban areas (Yaseen et al., 2020). The electricity shortfall in particular, started in 2007 and reached its peak in 2018 when the demand-supply gap surpassed 9000 MW (Luo et al., 2020). Under the electricity load-shedding policy, urban areas faced 10-12 hours of load-shedding (Butt et al., 2021). Rural regions suffer 14 to 20 hours of daily electricity shortage, causing massive economic damage (Uddin et al., 2019).

Countries rely upon the import of fossil fuels due to the scarcity of indigenously available energy resources. During the financial year 2019, Pakistan imported oil from the international market worth 34.2 trillion Pakistani rupees (PKR) (Yaqoob et al., 2021). Therefore, fluctuation in the prices of energy commodities is one source of uncertainty regarding the amount of revenue spent on importing fossil fuels in the country (Li et al., 2021). Hence, with this uncertainty, an increasing trend in global oil prices causes an extra burden on the economy, followed by increased power generation costs (Khan et al., 2019; Sohoo et al., 2021). Consequently, the circular debt incurred by the power sector reached 2.306 PKR alongside depreciation in the value of the rupee (Awan & Mukhtar, 2019). Poor Infrastructure, overconsumption of imported petroleum and oil, unexplored renewable energy options, poor distribution system, and wastage of energy are major causes of energy crisis (Chien et al., 2021; Wang et al., 2020; Jakstas, 2020). The energy dissipated in transmission lines, sub-transmission line, and transformers are also technical losses. The transmission loss is approximately 22% and distribution loss is approximately 50% of all generated electricity in 2018 (Hosseini-Motlagh et al., 2020). The current power crisis is due to outdated and inefficient power plants that cannot produce electricity, operate the plants at optimum capacity, and institutional distortions (Grainger & Zhang, 2019).

According to Pakistan economic survey 2019-2020, thermal power generation shared the highest fraction among various technologies used for electricity production, i.e., 58.5%(coal-fired: 25%, LNG-fired: 28.5%, and oil-fired: 5%), followed by hydroelectric power 30.9%, nuclear 8.2% and renewables 2.4%. However, the government has planned to increase the share of electricity from renewable energy resources (RERs), i.e., raising it from the current 2.4% to 13.5% by 2030 (Shahid et al., 2021; Wescoat et al., 2018). The future sources of RERs are expected to consist of wind power (6%), solar photovoltaic (4.5%), and other RERs (3.0%) (Aized et al., 2018). Similarly, some of the outdated thermal power plants will defective in future and will not be contributing electricity to the national grid (Kamran et al., 2019). It has driven up power tariffs that made electricity unaffordable for commercial, industrial and domestic consumers over time (Lowitzsch, 2019). Furthermore, inadequate grid networks, and subsidized end-consumer prices are the key challenges of energy transitions (Hrnčić et al., 2021). As a result, assessing the economic effect of scarcity of electricity on Pakistani sectors is crucial (Kamran et al., 2020).

The government of Pakistan revised the nuclear power policy for the country after the Fukushima incident in Japan in 2011(Kanwal et al., 2020). Consequently, the government decided to limit its activities targeting nuclear power generation before the

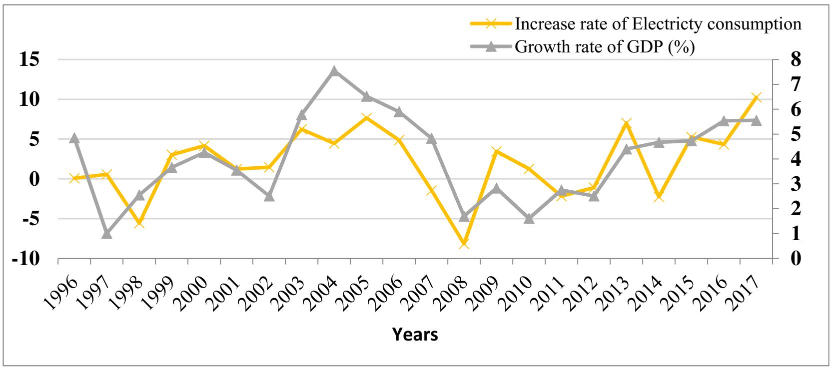


**Figure 1.** Nexus between electricity consumption rate and GDP growth rate.
Source: https://www.worlddata.info/asia/pakistan/energy-consumption.php; https://data.worldbank.org/indicator/NY.GDP.MKTP.KD.ZG?locations=PK

maturation of renewable energy technologies (York & Bell, 2019). Pakistan is still pursuing economic development related to electricity consumption (see Figure 1).

Input-output (I/O) analysis is suitable for studying the impact of major blackouts (as the 10-14 hrs/day that seem to occur quite frequently in Pakistan because it estimates the positive or negative economic shocks that ripple the various sectors of the whole economy, e.g., business cycle effect on an industry, prolonged war, and strike repercussions. In addition, this analysis can evaluate the direct labour, capital, imports, and indirect requirements of an industry. Input-output methodology address different issues, for example, related to the demand, supply, prices and distribution of energy. This analysis quantifies the economy's supply chain, of not only centrally planned economies but also national accounting operations of almost all western regions. Different international organisations (OECD, Eurostat, among many others) publish and use input-output tables (national and multiregional) for the elaboration of very different types of indicators associated with the development and impacts of global value chains

Previous studies have analyzed the impact of electricity shortage from a single industry perspective. Focusing on one industry can neglect association with other sectors because all sectors have inter-industry characteristics and interdependent linkages. Therefore, the current research focused on the producers' perspective and applied the supply-driven input-output (I/O) model to check the direct and indirect impacts of electricity shortages in Pakistan across 34 sectors. This is the national-scale study in a real-world setting whereby the economic impacts of energy shortages have been reported exampling the most notorious case of energy failure. Both direct and indirect economic impacts of shortages in power supply have been estimated in an ex-post-facto manner exampling Pakistan. Similarly, the impact of fluctuations in electricity prices has been evaluated on all sectors of the economy.

The upcoming sections of this paper consist of a literature review related to energy shortage (Section 2), Supply-driven Input-Output analysis of energy systems, (section 3), Theoretical and Methodological Framework (Section 4), Sectorial classifications and data sources (Section 5) results and interpretation (Section 6) and conclusions and policy recommendation (Section 7).

## 2. Literature review

Pakistan is a developing country with limited supplies of indigenously available energy resources in the country. Consequently, the country heavily relies upon the import of primary energy resources from other countries, e.g., oil, coal and natural gas. These resources are used to produce the only form of final energy (secondary energy) in the country, i.e., electricity. It can observe that scientific literature abundantly contains research articles describing energy crisis, electricity shortages, electricity load shedding, natural gas load shedding, and energy insecurity of Pakistan especially from 2007 onwards which has been termed as energy crisis and or energy failure. Some of these studies are (Valasai et al., 2017; Shabbir et al., 2020; Abbasi et al., 2021; Abdullah et al., 2020) among others. Similarly, there are studies whereby the economic impacts of this so called energy crisis has been established based on individual sectors e.g., Xie et al. (2018) (transportation sector), Rochlin (2021) (heating of house sector), Ouyang et al. (2021) (industrial sector), and Syed et al. (2021) (household sector). There are various causes of the energy crisis as mentioned in scientific literature with regards to Pakistan; however, most of them consider lack of energy planning and bad government policies of the past to be responsible for today's energy insecurity. There are three main sectors who really need the energy like buildings, transport and industries (Song et al., 2017). Energy efficient buildings (residential and commercial) used to achieve healthy, comfortable, and environmentally friendly life (Huo et al., 2018; Hasanuzzaman et al., 2020). While Industrial sector depends on energy demand for processing the material with cost cutting theme, whereas travel industry use it where, why and how they travel (Shaik & Yeboah, 2018).

Developed countries are trying to accomplished sustainable energy resources management by adapting state-of-the-art energy modeling and planning tools (Hemmati et al., 2017). On the other hand, some of the developing countries such as China, Nigeria, Malaysia, and others are using similar tools for policy formulation and planning (Lin and Zhu, 2020; Nong et al., 2020; Xingang et al., 2013). Wang and Wu (2023) explored that mostly energy is consumed on non-energy products. However, Cairns (2014) found that power production and its distribution are essential for socio-economic growth. But energy production resources are limited over time, and the energy demand is increasing. Many people have not got the electricity facility. Gul et al. (2018) reported that Pakistan's Northern areas have yet not linked with grid stations.

Some of the leading causes and factors responsible for electricity shortages in the country are increased industrialization and population growth Rehman et al. (2018), electricity theft (Jamil, 2013), inefficiencies in electricity generation and distribution, outdated plants, reliance on imported fuels Khan and Abbas (2016) and political instability, poor fiscal management, massive institutional failure, and imprudent energy policies (Shah et al., 2019). Commercial activities, transport, and telecommunication were disrupted due to this power outrage (Davidov & Pantoš, 2018). Business suspended their operation for not having electricity which disturbed 210 million people. It led to considerable industrial and economic damages, and all the cities plunged into darkness (Jamil, 2013).

The impacts of electricity shortages on firm-level have been studied across the world following different approaches and techniques. Fisher-Vanden et al. (2015)

investigated electricity shortage impact on Chinese small-and medium-sized enterprises and concluded that energy shortage is the core bottleneck in business development which causes high transaction costs. Similarly, (Kamran et al., 2019 & Kanwal et al., 2020; Santika et al., 2020) investigated the effects of electricity shortages on small and medium firms in India; and found that, productivity losses and revenue reduction are due to energy shortages. Kessides (2013) reported the adoption of technology by firms as impacts of electricity shortages. They concluded that, firstly, the lack of energy exerts pressure on the firms to invest in expensive diesel generators. Secondly, due to lack of suitable alternate energy supply source, the industries shut down their activities causing wastage of semi and non-flexible inputs e.g., material and labor (Allcott et al., 2016). Thirdly, firms prefer purchases instead of making electricity-intensive intermediate information, this implies that, the production cost goes high due to energy shortages (Fisher-Vanden et al., 2015). Lastly, power shortage becomes the reason for companies to replace electricity-intensive technology. According to Grainger and Zhang (2019), electricity shortages are the leading cause of increasing production costs.

## 3. Supply-driven input-output analysis of energy systems

Input-output applications for energy concerns have mostly focused on demand linkages which are employed to check the high economic effect from exogenous shocks (Schreiner & Madlener, 2021). Supply-driven I/O model is suitable in a monopolistic market, when firms allocate products according to their historical sales patterns and maintain the existing markets in sudden disruption of production. This model also suggests that output coefficients are more stable than input coefficients due to shortage of resources. Furthermore, government will have a tendency to allocate funds and stabilize the output patterns among their clients Giarratani (1981). Therefore, reduced form of linear system represents its solved economy structure that ties each sector's total (gross) output demand to its final (net) use in all sectors. Inter-industry flows are free to fluctuate as the vector of ultimate output changes, subject only to technical variables of production (Kuswardana et al., 2021). Leontief (1936) developed a model by assuming unlimited resource in an economy. He hypothesized that each sector has interdependent with other sectors, which leads to two independent solutions, one for prices and the other for quantities, by using production function as a final demand. The aim of this I/O model is to analyze the final demand change impact on each sector's production. He also assumed that producers bought all inputs in the fixed proportion, which means multiple inputs and single homogenous output. All information is in physical terms. Therefore, it quantifies as 'demand-driven model'. He was awarded Nobel Prize due to the Input-Output model's formulation in the year 1937. However, an alternative approach is needed that relates the input change of each sector when resources are limited. So, Ghosh (1958) formulated an alternative model to address these conditions for centrally planned economies and Augustinovics (1970) was made its first application in economic structure. In which he assumed that fixed output coefficients to link changes in value added, such as sectoral primary input in one sector to production in other sectors, it quantifies as 'supply-driven' (Miller & Blair, 2009).

Ghosh also added the value-added vector in the output value. Since coefficients were based on each sector's revenues from selling goods to its intermediate and final customers, this version can link to a supply-side economy. According to Walters (1965), the model can analyze centrally planned economies and systems controlled by monopolistic market forces and general economies with limited resources. Although the Ghosh model did not receive any familiarity until (Hewings & Jensen, 1987) presented this model's empirical application. Later, forward linkages measure from the output allocation perspective and the supply side of the I/O model (Bulmer-Thomas, 1983). However, (Hazari & Krishnamurty, 1970) used the coefficients matrix to define the backward and forward linkages. When McGillivray, in the year 1977 posted a controversial statement against Ghosh's formulation (Rose & Miernyk, 1989). This received much attention in energy models and regional analysis (Bon, 1986). Giarratani (1976) evaluated the supply linkages relating to the energy sector's gross output and other American industries by taking energy output as an exogenous variable.

Umar et al. (2018) investigated the impacts of power shortages on of downstream sectors and explored the inter-industry links of the resources. Wu and Chen (2017) analyzed the energy system by applying the supply-driven I/O model in developing countries. Similarly,(Kerschner and Hubacek (2009) investigated the impacts of shortages in the supply of crude petroleum due to increased cost across Chile, the United Kingdom, and Japan in 2008. Their results show that, a 10% output decrease in the crude petroleum area has a terrible impact on financial activities, trade service, and electricity production in these three countries. However, instead of input coefficients, they set fixed production coefficients for the supply-driven I/O model. Bon (1986) applied I/O model using the data from 1947 to 1977, and reported that both I/O coefficients were stable. Wu et al. (2016) examined Taiwan's direct and indirect effects by applying Ghosh model. They concluded that, a high indirect product is more reliable than an immediate impact for downstream producers. Zeshan and Nasir (2019) checked the economic effect of electricity by applying I/O (2010-11) data in Pakistan and found that if the government facilitates the economic activities then economic growth would be sustainable

The supply-based I/O model has been used in the literature review to analyze the lack of supply. Though, few studies have applied this model to explore the cost-effective implications of power shortages for various sectors. Current research tried to fill the gap of needs impact of electricity by employing a supply-driven I/O model on each economic sector of Pakistan.

## 4. Theoretical and methodological framework

To analyze electricity shortages' impact on each sector, the researcher has applied the supply-driven I/O model developed by (Ghosh, 1958) and the price model developed by (Leontief, 1937). The theoretical basis defines as the following sub-categories. The I/O model is applied to find the interdependencies and their economic impact among each sector. Commonly the input-output model is divided into two types: (1) demand-driven I/O model and (2) the supply-driven I/O model.

### 4.1. Demand-driven input-output model

Demand-driven economic linkages were developed by Leontief (1936), which represents per unit output at the end of the process' While alternatively Ghosh (1964) developed the supply-driven I/O model, in which starting of the process and per unit input were used (Miller & Lahr, 2001). Both models apply for analysis and planning according to the suggestion of Gosh. The economy of a country can be categorized into n sectors. In the input-output table, many sectors have an inter-industry relationship that can be expressed as follows:

$$X_i = \sum_{j=1}^{n} Z_{ij} + f_i \tag{1}$$

$$X_j = \sum_{i=1}^{n} Z_{ij} + v_i \tag{2}$$

$X_i$= Represents the total output of sector $i$
$Z_{ij}$= input from sector i by sector j to produce amount $X_j$
$f_i$= the final demand for the product in sector $i$
$X_j$= total input used in sector $j$
$v_i$= the primary input (it contains government taxes, operating surpluses, depreciation, and employee compensation required by sector $j$

$$X = AX + Y \tag{3}$$

$$\mathrm{A} = \begin{bmatrix} a_{11} & \cdots & a_{1n} \\ \vdots & \ddots & \vdots \\ a_{n1} & \cdots & a_{nn} \end{bmatrix} \tag{4}$$

The structural equation is used for various industries' input coefficients. Values of coefficients in a table are called technology matrix. Assuming that the electricity input coefficient in sector $j$ is $a_{ej}$, an electricity input is denoted as $Z_{ej}$, while $X_j$ shows that sector $j$ has gross output values, i.e., $a_{ij} = Z_{ej}/X_j$. By transposing the equation (3) gives equations (6) and (7)

$$\mathrm{X - A\,X = Y} \tag{5}$$

$$\mathrm{(I - A)X = Y} \tag{6}$$

$$\mathrm{X} = (\mathrm{I} - \mathrm{A})^{-1}\, Y = LY \tag{7}$$

Leontief presented a standard demand function and quantity functions (Miller & Lahr, 2001) such as $X = (I - A)^{-1}Y$, I is the identity matrix, $L = (I - A)^{-1}$ shows the Leontief inverse matrix with $L = [l_{ij}]$, Y is the final demand, and A denotes an intermediate matrix without imports.

### 4.2. Supply driven (Ghosh model)

The supply-driven and demand-driven models are opposite to each other. Primary input varies; allocation coefficient is used to examine other industries' direct and indirect effects as a sector. The Supply-driven $I/O$ model is appropriate where markets with shortages or supply restrictions. Ghosh price model presented as:

$$X' = BX' + V' \tag{8}$$

$$B = \begin{bmatrix} b_{11} & \cdots & b_{1n} \\ \vdots & \ddots & \vdots \\ b_{n1} & \cdots & b_{nn} \end{bmatrix} \tag{9}$$

The matrix is representing allocation coefficients or (output coefficient) becomes $B = [b_{ij}]$ (Rose & Miernyk, 1989). The current study has included the import value $(M_i)$ to find the sectorial economic impact because the difference between the technical and allocation coefficient is the import value represented by,

$$X' = (I - B)^{-1}V' \tag{10}$$

Where $X'$ represents the transpose of (nx1) output vector, $V'$ is value-added, and it becomes $G = (I - B)^{-1}$ with $G = [g_{ij}]$, Gosh inverse output matrix (Miller & Blair, 2009). Sales of production from a particular industry allocate to other sectors, such as $b_{ij} = (\frac{z_{ij}}{X_i})$. Similarly, in the electricity supply sector (S17), of allocation coefficient is shown here.

$$Ce = \frac{z_{ej}}{X_e}$$

$C_e$ represents the electricity allocation coefficient, $Z_{ej}$ allocated electricity, $X_e$ is the power supply sector's gross production value. Furthermore, Different industries use various inputs, and these inputs are purchased from multiple other industries. Production depends on inter-industry relationships, which is measured by linkage analysis. Linkages have two types, backward links, and forward connections. Backward linkage ($BL$) is the interconnection of an upstream sector with a given industry from which it buys its inputs.

In contrast, an interconnection of a downstream sector with a given industry sells its outputs named forward linkage ($FL$). Chenery (1958) first time proposed the backward links and forward connections shown in equations (11) and (12), normalizing of these measures; empirical studies presented.

$$\overline{BL}(t)_j = \frac{\sum_{i=1}^{n} b_{ij}}{\left(\frac{1}{n}\right)\sum_{i=1}^{n}\sum_{j=1}^{n} b_{ij}} \tag{11}$$

Column sum of the sector $j$

$$\overline{FL}(t)_j = \frac{\sum_{i=1}^{n} b_{ij}}{\left(\frac{1}{n}\right)\sum_{i=1}^{n}\sum_{j=1}^{n} b_{ij}} \tag{12}$$

Column sum of the sector $j$

### *4.3. Supply-driven I/O model application and electricity shortages output impact*

When researchers include the imports in the supply-driven $I/O$ model, the ratio between the total productions and imports $(M_i)$ in sector $i$ is fixed $m_i = M_i/X_j$, but the total demand of industry $i$ will change to $d_i = X_i + M$, and the new allocation coefficient is stated in matrix form $D = X + M$. Now Sector $j$'s input quantity can be rewritten as $K_{ij}{=}\frac{z_{ej}}{di}$,

$$X_j = \sum_{j=1}^{n} Z_{ij} + v_j \tag{13}$$

$$X_j = \sum_{j=1}^{n} k_{ij} d_i + v_j \tag{14}$$

Equation (14) in an abbreviated matrix form, it is possible to rewrite as

$$X = K'D + V \tag{15}$$

Equation M = mX and D = X + M is incorporated into Eq. (17):

$$X(I - K'(I + m)) = V \tag{16}$$

$$X = (I - K'(I + m))^{-1} V = GV \tag{17}$$

$$K = \begin{bmatrix} k_{11} & \cdots & k_{1n} \\ \vdots & \ddots & \vdots \\ k_{n1} & \cdots & k_{nn} \end{bmatrix},\ M = \begin{bmatrix} m_{11} & \cdots & m_{1n} \\ \vdots & \ddots & \vdots \\ m_{n1} & \cdots & m_{nn} \end{bmatrix},\ D = \begin{bmatrix} d_1 \\ \vdots \\ d_n \end{bmatrix}$$

Where imports $(M_i)$; domestic output $(X_i)$; the aggregated demand matrix $(D)$ equal to $(d_i)$ the total demand of the industry $i$. $K$ is the allocation coefficient matrix, including imports; it transposes the $K$ matrix; import ratio is a diagonal matrix of m; that reflects the imports direct and indirect specifications for sector $j$. This research pays particular consideration to explore the economic impact by taking the electricity supply sector as an exogenous. Here electricity supply sector converts transaction value into numerical values (million PKR) to the electricity of physical quantities (million $kWh$). The equation signifies the electric supply sector as an exogenous factor.

$$X = \left(I - K'(I+m)\right)^{-1}_{n-1}[(V + C_e X_e)] = G_{n-1}(V + C_e X_e) \tag{18}$$

Where subscript $e$ represents the electricity supply sector, and $n-1$ means all sectors of the economy excluding the electricity supply sector. After treating the electricity supply sector as exogenous, the new allocation inverse matrix $G_{n-1}$, abbreviated to $\left(I - K'(I+m)\right)^{-1}_{n-1}$ equation (19) can be used to analyze the effect on the output values of each field.

$$\Delta X = G_{n-1}(\Delta V + C_e X \Delta_e) \tag{19}$$

$X$ is the output matrix. Its changes in each sector denote as $\Delta X$; $R_e$ is the power supply matrix's allocation coefficient; the output or production matrix is $X_e$, whereas $\Delta X_e$ is changing in the power sector's output matrix, $\Delta V$ is the value-added matrix change. Assuming ($\Delta V = 0$), and now rewrite equation (19), as follows:

$$\Delta X = G_{n-1} C_e X \Delta_e = \left(I - K'(I+m)\right)^{-1}_{n-1} C_e X \Delta_e \tag{20}$$

$$\Delta X = G_{n-1} C_e \Delta X_e = G_{n-1} C_e \left(\frac{\Delta X_e}{p^b}\right) p^b = G_{n-1} C_e p^b (\Delta E_e) \tag{21}$$

Where the average electricity price and change of power supply in the supply sector are $p^b$ and $\Delta E_e$ respectively, to conclude, the entire Production effect (direct and indirect) $\Delta X$ depends on the allocation inverse matrix $G_{n-1}$ allocation coefficient of power supply sector is $C_e$ and average price of electricity is $p^b$. The direct output effect is the original output effect, while the indirect output effect is the subsequent output effect induced by inter-industry linkages. Also, it is possible to represent the direct. $\Delta X_D$ and indirect $\Delta X_I$ output influence as equations (22) and (23), respectively:

$$\Delta X_D = C_e \Delta X_e = C_e p^b (\Delta E_e) \tag{22}$$

$$\Delta X_I = \Delta X - \Delta X_D \tag{23}$$

### 4.4. Price model application to change the electricity prices

Normally, input-output equations do not consider the input cost change and the output price because of fixed input-output assumption around coefficients. Therefore, the Ghosh model is interpreting as a price model because it is equivalent to the Leontief price model (Dietzenbacher, 1997). The cost structure of each sector's development activities considers in the input-output framework. Hence, the balance of monetary values can represent as follows:

$$X_j = p_j^0 \times Q_j^0 \quad (24)$$

$X_j$ is the output, whereas $p_j^0$ and $Q_j^0$ is unit price and quantity respectively in the base year. If \$1 is assumed base year unit price, $X_j^0 = Q_j^0$. Including a reasonable profit, the price of the commodity relies on overall costs. It is possible to represent the Leontief price model as an equation.

$$p_j = \sum\nolimits_i a_{ij} p_i + v_j + m_j \quad (25)$$

The unit price of sector $i$ is $(p_i)$ multiplied with input coefficient $(a_{ij})$ is equal to sector $j$ unit price $(p_j)$, value-added plus, and unit rates of imports in Sector j. Every sector has a unit price of the base year which is one PKR $(p = 1)$ and can be written as

$$(I - A')p = v + m \quad (26)$$

A. transposes the input coefficient matrix. Thus $p$ is the unit price of each sector and $v$ is the value-added price of each sector $(vj = \frac{Vj}{X_j})$ when imports and value-added price changes of industry $j$, change in unit price denotes $(\triangle p)$

$$\Delta p = (I - A')\Delta(v + m) \quad (27)$$

Leontief's model considers that $(I - A')$ is an inter-industry transpose matrix that can analyze the actual and indirect effect of shifts in unit price for each sector in intermediate inputs and value-added. This research, however, examines the price-change impact of the electricity sector by the assuming $\triangle V = \triangle M = 0$ and the electricity supply sector treated as an exogenous variable.

$$\Delta P_j = (I - A')_{n-1}^{-1}[\Delta(V + M) + A_e \Delta P_e] \quad (28)$$

$$\Delta P_j = (I - A')_{n-1}^{-1} A_e \Delta P_e \quad (29)$$

Where $\Delta P_j$ is changing in the price of sector j; $(I - A')_{n-1}^{-1}$ the Leontief inverse matrix of electricity supply sector $(n - 1)$ by taking it as an exogenous? The electricity supply sector's input coefficients represented $A_e$; $\Delta V$ and $\Delta M$ show change in value-added and imports; $\Delta P_e$ changes in the electricity supply industry's price. The electricity supply sector's input coefficients represented $A_e$; $\Delta V$ and $\Delta M$ show change in value-added and imports; $\Delta P_e$ changes in the electricity supply industry's price. With the restructuring of the power generation market in equation (29), the $\Delta P_e$ is a price shift in the production of electricity; it is possible to transform the sector to average price change per kilowatt-hour $(kWh)$ by way of display in Eq. (30). In the power supply market, where $\triangle P_{\mathrm{kWh}}$ is the average price change per $kWh$.

$$\Delta P_j = (I - A')^{-1}_{n-1}\left(\frac{X_e}{p^b}\right)\left[{}^{\Delta P_j}\Big/_{\frac{X_e}{p^b}}\right] = (I - A')^{-1}_{n-1}\left(\frac{X_e}{p^b}\right)\Delta P_{kWh} \tag{30}$$

## 5. Sectorial classification and data source

The Asian Development Bank (ADB) data library published Pakistan's Input-Output tables from 2010 to 2017, showing a comprehensive picture of the entire economy, Pakistani manufacturers, and customers' interrelationships. Therefore, taking the up-to-date $I/O$ table of 2017 for vital information sources and analysis. And the initial input-output table was aggregated into 34 sectors to evaluate power shortages, covering two energy and 32 non-energy sectors—these aggregate sectors are listed in Table 1. Moreover, an exogenous variable for subsequent analysis is in the electricity supply sector.

## 6. Results and interpretation

Seven sectors have the highest direct output coefficients shown in Table 2. Textile and textile products (S4), Agriculture, hunting, forestry (S1), Food, beverages, Real estate activities (S3), Renting of Machinery (S30), Electricity (S17), Post and Telecomm (S27), and other community (S34). The absolute percentage differential in input coefficients on a sectoral average was 4.28%, 3.14%, 3.10%, 2.39%, 1.74%, 1.585and 0.88%, respectively.

**Table 1.** Sectorial division of Pakistan's economy.

| Sector name | ID | Sector name | ID |
|---|---|---|---|
| Agriculture & forestry | S1 | Construction | S18 |
| Mining and quarrying | S2 | Sale and maintenance | S19 |
| Food & beverage | S3 | Wholesale trade | S20 |
| Textiles and its products | S4 | Retail trade | S21 |
| Leather and its products | S5 | Hotels and restaurants | S22 |
| Wood and its products | S6 | Inland transport | S23 |
| Paper and printing | S7 | Water transport | S24 |
| Coke and refine petroleum | S8 | Air transport | S25 |
| Chemicals and their products | S9 | Auxiliary transport | S26 |
| Rubber and plastics | S10 | Post and telecom | S27 |
| Non-metallic minerals | S11 | Financial intermediation | S28 |
| Fabricated metal | S12 | Real estate activities | S29 |
| Machinery | S13 | Renting of Machinery | S30 |
| Electrical and optical equipment | S14 | Public administration | S31 |
| Transport equipment | S15 | Education | S32 |
| Manufacturing and recycling | S16 | Health and social work | S33 |
| Electricity | S17 | Other community | S34 |

Source: https://data.adb.org/.

**Table 2.** Seven highest difference input-output sectors in intermediate input coefficients.

| Sector i | | Sector j | | $\Delta a_{ij}$ |
|---|---|---|---|---|
| S4 | Textile and its products | S13 | Machinery | 4.28% |
| S1 | Agriculture and forestry | S3 | Food and beverages | 3.14% |
| S8 | Coke and refined petroleum | S2 | Mining and quarrying | 3.10% |
| S22 | Hotels and restaurants | S30 | Renting of Machinery | 2.39% |
| S5 | Leather and its products | S16 | Manufacturing and recycling | 1.74% |
| S13 | Machinery | S21 | Retail trade | 1.58% |
| S25 | Air transport | S20 | Wholesale trade | 1.33% |

Source: Author's calculation.

In the range of numerical values of seven intermediate input coefficients, the largest variations were between 4.28% and 1.33%. To sum up, for 33 industries, the Average percentage difference excluding (electricity sector) in input productivity coefficients ($\Delta a_{ij}$) was 0.11% observed. The findings revealed that the improvement in coefficients of output had a minor impact on coefficients of input, decreasing output coefficients in the supply of energy by 50 percent.

### 6.1. Inter-industry linkage effect

All the output of one industry depends upon the input of other interlinked sectors. Therefore backward and forward linkages have a strong relationship in an economy. Suppose an enterprise wants to increase its output. In that case, it demands to increase the input such as (energy, gas, and water supply) and additional food supplies, clothes, defense from other industries. This relation is called backward linkages (BL). It also encompasses partnerships of input service and dealer contracts to build jobs for enhancing domestic manufacturing capability. It usually shows in the demand-side model. The industry keeps its relationship with clients. Therefore it offers its output for selling purposes because it becomes the input of other industries for production. It also means adding the value of manufacturing and refining to the materials extracted by the sector to manufacture finished products domestically instead of selling them in their raw form. It usually shows as a supply-side model. This relation is called forward linkages (FL). Backward, forward, and overall links of all sectors showed in Table 3

Results show that the overall value of the electricity supply sector (S17) is 3.77, which means that this sector hit the 1st rank of the economy with a robust inter industry relationship. Agriculture, hunting (S1), and Textile industries (S4) have an overall second and third rank with overall values of 3.49 and 2.47. The bottom three sectors which have the lower impact of electricity shortage found in health and social work (S33), other community (S34) and education (S32) with the value of 1.51, 1.61 and 1.38 respectively. Forward linkage shows that the electricity shortage harms industrial activities and the overall economic growth of Pakistan.

### 6.2. Electricity shortages output impact on the individual sector and the economy

According to the results, Pakistan's entire economy declined by 24.89 PKR when the 1 *kWh* power supply was reduced due to economic activity's slowdown. Thus, the power shortage price was 24.89 PKR/*kWh*. The energy shortage cost was 18.71 PKR/*kWh* in the other 33 sectors, while the supply sector of electricity (S17) did not include. The electricity demand is determined based on their production levels and the electricity sector (S17) final product is supplied to other industries. Therefore, power supply has a direct and indirect effect on manufacturing industries.

It is possible to further divide the sectoral production effect into direct (immediate) and indirect output impacts—the impact of natural products is closely linked to the coefficient of electricity allocation in Figure 2. During energy shortages, industries allotted lower (higher) electricity portions reported minor production impacts. The

**Table 3.** Input share (backward), Output share (Forward), and overall linkages effect.

| | | Backward linkages affect | | Forward linkages affect | | Overall affect. | |
|---|---|---|---|---|---|---|---|
| Total Sectors | ID | Value | Rank | Value | Rank | Value | Rank |
| Agriculture & forestry | S1 | 0.84 | 26 | 2.65 | 01 | 3.49 | 02 |
| Mining and quarrying | S2 | 0.75 | 30 | 1.13 | 10 | 1.88 | 17 |
| Food & beverage | S3 | 1.24 | 04 | 0.84 | 19 | 2.08 | 07 |
| Textiles and its products | S4 | 1.26 | 02 | 1.21 | 09 | 2.47 | 04 |
| Leather and its products | S5 | 1.2 | 05 | 0.7 | 24 | 1.9 | 15 |
| Wood and its products | S6 | 1.12 | 09 | 0.69 | 26 | 1.81 | 24 |
| Paper and printing | S7 | 1.07 | 14 | 0.96 | 13 | 2.03 | 09 |
| Coke and refine petroleum | S8 | 1.04 | 15 | 0.9 | 14 | 1.94 | 11 |
| Chemicals and their products | S9 | 1.12 | 10 | 1.24 | 08 | 2.36 | 05 |
| Rubber and plastics | S10 | 1.13 | 08 | 0.73 | 22 | 1.86 | 21 |
| Non-metallic minerals | S11 | 01 | 20 | 0.87 | 16 | 1.87 | 20 |
| Fabricated metal | S12 | 1.08 | 13 | 0.79 | 21 | 1.87 | 19 |
| Machinery | S13 | 1.2 | 06 | 0.68 | 27 | 1.88 | 18 |
| Electrical and optical equipment | S14 | 1.04 | 16 | 0.71 | 23 | 1.75 | 27 |
| Transport equipment | S15 | 1.03 | 17 | 0.89 | 15 | 1.92 | 13 |
| Manufacturing and recycling | S16 | 0.98 | 21 | 0.87 | 17 | 1.85 | 22 |
| Electricity | S17 | 1.57 | 01 | 2.2 | 02 | 3.77 | 01 |
| Construction | S18 | 1.1 | 11 | 0.65 | 30 | 1.75 | 26 |
| Sale and maintenance | S19 | 0.88 | 23 | 0.7 | 25 | 1.58 | 32 |
| Wholesale trade | S20 | 0.71 | 33 | 1.31 | 05 | 2.02 | 10 |
| Retail trade | S21 | 0.79 | 27 | 1.79 | 03 | 2.58 | 03 |
| Hotels and restaurants | S22 | 1.24 | 03 | 0.68 | 28 | 1.92 | 14 |
| Inland transport | S23 | 01 | 19 | 1.34 | 04 | 2.34 | 06 |
| Water transport | S24 | 1.09 | 12 | 0.62 | 33 | 1.71 | 29 |
| Air transport | S25 | 1.14 | 07 | 0.66 | 29 | 1.8 | 25 |
| Auxiliary transport activities | S26 | 0.88 | 24 | 1.02 | 11 | 1.9 | 16 |
| Post and telecommunications | S27 | 0.95 | 22 | 0.87 | 18 | 1.82 | 23 |
| Financial intermediation | S28 | 0.76 | 29 | 0.97 | 12 | 1.73 | 28 |
| Real estate activities | S29 | 0.64 | 34 | 1.3 | 06 | 1.94 | 12 |
| Renting of Machinery | S30 | 0.74 | 31 | 1.29 | 07 | 2.03 | 08 |
| Public administration | S31 | 1.02 | 18 | 0.62 | 34 | 1.64 | 30 |
| Education | S32 | 0.73 | 32 | 0.65 | 31 | 1.38 | 34 |
| Health and social work | S33 | 0.87 | 25 | 0.64 | 32 | 1.51 | 33 |
| Other community | S34 | 0.77 | 28 | 0.84 | 20 | 1.61 | 31 |

Source: Author's calculation.

direct production effect is smaller than the indirect output impact in most industries except (e.g., S4, S9, S21, and S23) in the sectors of operation. The service industry, for instance, sells finished goods or downstream customers' utilities. Therefore, these industries would suffer a more considerable indirect impact. The results are matched with the findings of (Wang et al., 2021).

Total production impacts drive-by indirect output impacts resulting from inter-industry relationship (see Figure 3). It has significantly positive relationship between indirect production and downstream purchasers.

Figure 4 shows that higher indirect production sectors such as Agriculture & forestry (S1), Textiles and textile products (S4), Retail trade (S21), and Inland Transport (S23) sold their main output to the intermediate commodity manufacturing and capital goods industry (S10) (Khan et al., 2021). Sectors sell their semi-finished goods to other manufacturing sectors in this industrial chain. However, lower indirect output sectors sold their products to Machinery (S13), Electrical and optical equipment (S14), Construction (S18), and Hotels and restaurants (S22) sold their primary production to consumers. These industries sold their products directly to end-users. Energy is consumed mostly non energy products (Wang & Wu, 2023).

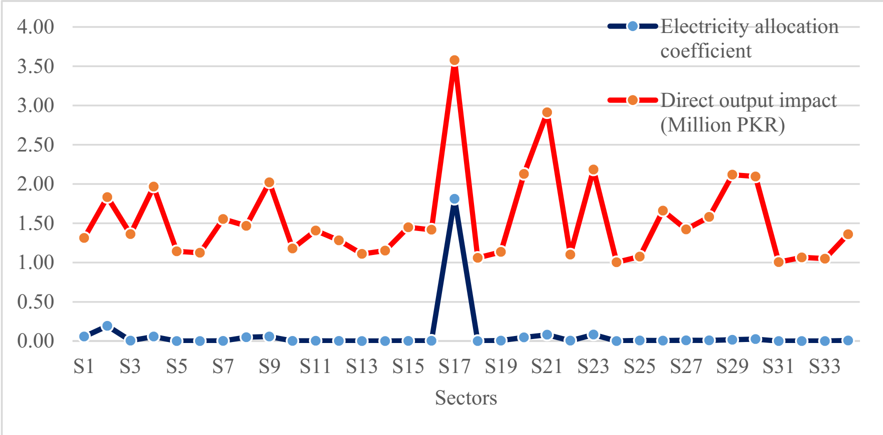


**Figure 2.** Electricity allocation and direct output impact.
Source: https://www-pub.iaea.org/MTCD/Publications/PDF/CNPP2021/countryprofiles/Pakistan/Pakistan.htm.

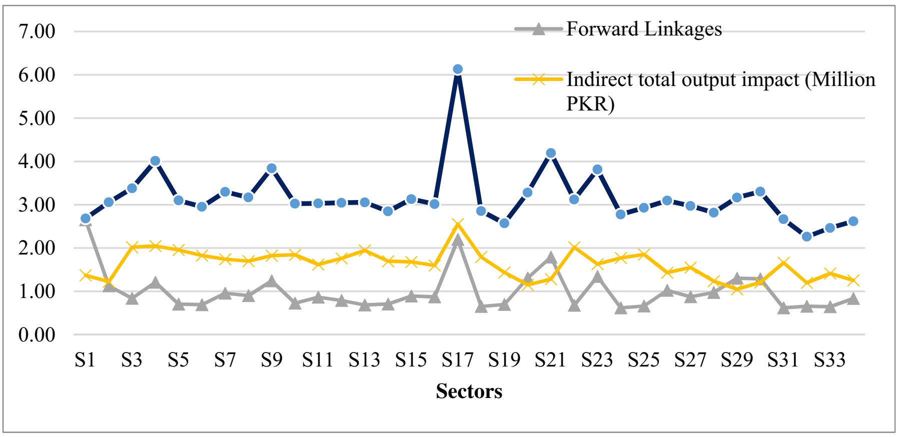


**Figure 3.** Forward linkages and indirect output impact.
Source: https://data.adb.org/dataset/pakistan-input-output-economic-indicators.

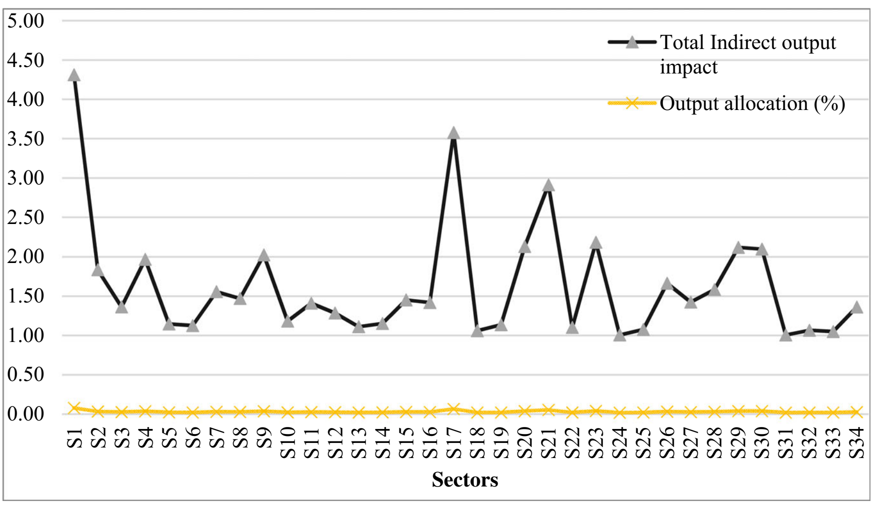


**Figure 4.** The interconnection between output allocations impact and indirect output.
Source: https://data.adb.org/dataset/pakistan-input-output-economic-indicators.

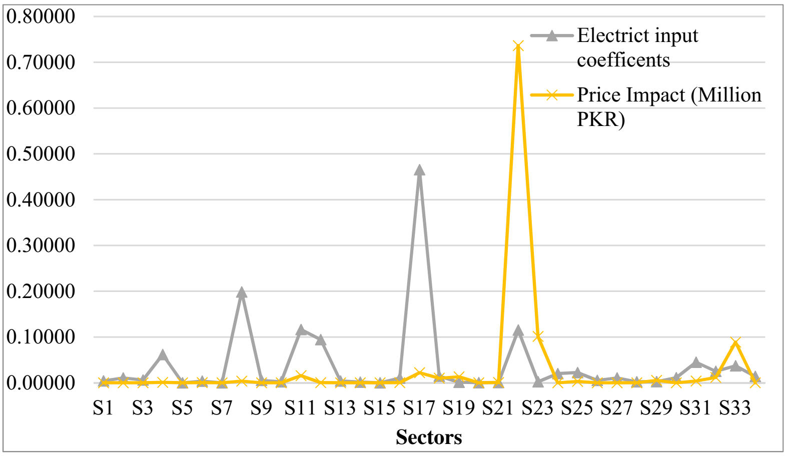


**Figure 5.** The nexus between electricity input coefficient and price impact.
Source: https://data.adb.org/.

### *6.3. Electricity price change impact on economy and the individual sector*

The electricity price rose by 20% per kWh based on Pakistan's average electricity price in 2017 (Rs.14.96/kWh). The findings showed that the average cost of the 33 sectors, except the electricity supply sector (S17), would increase by 201.36 billion PKR. The increase would represent 20.8% of the total value of the output of these 33 sectors. Hotels & restaurants (S22), health & social work (S33) sectors are experiencing high price impact (see Figure 5.) These sectors have annual rises in electricity prices, 74.5 billion PKR and 9.59 billion PKR, respectively. In contrast, the sectors food & beverages (S3), wood & products (S6), Paper and printing (S7), and Chemicals and chemical goods (S9) have the lowest price impacts. The electricity input coefficient on each sector influences the impact level of the price impact mechanism. The input coefficient of electricity is higher than in Textile and textile products (S4), coke and refined petroleum (S8), Non-metallic minerals (S11) industries and other sectors like Agriculture & forestry (S1) and Mining & quarrying (S2) (Abbas et al., 2020). As a result, the manufacturing industry has suffered a high price impact.

## 7. Conclusion and policy implication

The current study examined the economic losses associated with electricity unavailability using supply-driven input-output as a price model across 34 sectors of the Pakistan economy. The results revealed that exogenous electric price shocks are responsible for bringing significant fluctuation across the business cycle in the country. Similarly, an overall output of Pakistan's economy will decrease by 24.89 rupee due to a 1 kilowatt-hour reduction in electricity supply. Moreover, both forward and backward linkages of Pakistan's economy revealed that higher electricity allocation coefficients pose significant output impacts on most sectors. High forward linkages industries had high indirect output impacts for indirect production effects. The results of forwarding linkages suggest that indirect production impacts in all sectors were more significant than direct output impacts. Based on the year 2017, the average price of electricity was 5.13 PKR/kWh, and supposing a 5 percent rise in prices per kWh (5.39 PKR/kWh), the average expense of the economy as a whole, The total cost will increase by 401.36 billion PKR 20.8 percent of these 33 sectors' combined production values. Concerning the Price effects process, the electricity input coefficient significantly influences each industry. Electricity, thus, in the electricity sector, all input coefficients were more effective as compared with the sectors of agriculture and utilities, higher price effects have been faced by the manufacturing industry, e.g., Fabricated metals (S12), construction (S18), and Electrical equipment's (S14). We conclude that, in order to avoid the underestimation problem as a result of total electricity shortages, indirect output impacts require due consideration.

The following policy recommendations are given below:

1. Pakistan mostly relies on imported fossil fuels which are huge burden on its economy and government has no much finance to pay the oil companies. Continuing reliance on fossil fuels has badly failed in country to get positive results from it. Therefore, government should provide a social and legal framework for controlling high circular debts, maintaining stable energy prices and encouraging investment in renewables.
2. Besides it, technological advancement provides an opportunity to generate clean, affordable, reliable, and sustainable energy.
3. Skilled manpower is also needed to operate grid stations so that transmission and distribution loss can be reduced and achieve the target of production. Because energy related economic policies can make a country healthy, improved, and energized homeland.

The current study has some constraints and limitations. This input-output model's only analyzed the loss of output values of individual sectors, but other failures like raw materials damage, hazardous gas leakage, reworking cost, and post-incident clean-up were not included in it. Time scale of this study is limited to the year 2017. The I/O table shows the circulation and distribution status of products between various sectors in a specific year within the economic system and the creation of input-output table is arduous. This I/O model is restricted to emphasis on production and does not tell the particular pattern of inputs and outputs in an economy. Therefore other techniques like the RAS method can reduce errors in the computation of row and column modifications. Future studies can make a comparative study and extend the time scale.

## Disclosure statement

No potential conflict of interest was reported by the authors.

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