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Analysing Nexus between Economic Growth, GHG Emissions, and Energy Consumption for India

Rahil Akhtar Usmania^a

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Abstract

Rising greenhouse gas emissions is an important issue of the current time. India's massive greenhouse gas emissions is ranked third globally. The escalating energy demand in the country has opened the gateway for further increase in emissions. Recent studies suggest strong nexus between energy consumption, economic growth, and carbon emissions. This study has the objective to empirically test the aforementioned interdependencies. The co-integration test and multivariate vector error correction model (VECM) are used for the analysis and the Granger Causality test is used to establish the direction of causality. The time-series data for the period of 1971–2011 is used for the analysis. The results of the study confirm strong co-integration between variables. The causality results show that economic growth exerts a causal influence on carbon emissions, energy consumption exerts a causal influence on economic growth, and carbon emissions exert a causal influence on economic growth. Based on the results, the study suggests a policy that focuses on energy conservation and gradual replacement of fossil fuels with renewable energy sources, which would be beneficial for the environment and the society.

Keywords: Carbon emission, Economic growth, Energy consumption, Multivariate co-integration, Granger causality

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Introduction

Currently, the global climate crisis is more manifested than it ever was. The abrupt surge in emissions of greenhouse gases (GHGs), particularly the rise in atmospheric concentration of carbon dioxide (CO_2) levels, is the reason for the intensification of global warming. The reason for continuously rising GHG emissions is the huge consumption of fossil fuels in the current energy supply. The rising GHG emissions is causing severe damage to the atmosphere which could lead to manifestation of the enormously risky effect of climate change such as tornadoes, droughts, floods, melting of glaciers, and rising sea levels.

India's rapid industrial and services sectors growth led to considerable growth in trade and economic development. It is the reason of massive development and intensification of the transport sector and, hence, caused a considerable increase in CO_2 emissions. There has been a continuous debate for the past few decades on the association between economic growth and environment quality. Conflicting arguments are provided for explaining the nexus between aforementioned variables. Experts and practitioners have been trying to clarify this association with the help of Environmental Kuznets Curve (EKC) or what is called Carbon Kuznets Curve (CKC) hypothesis (Figure 1).

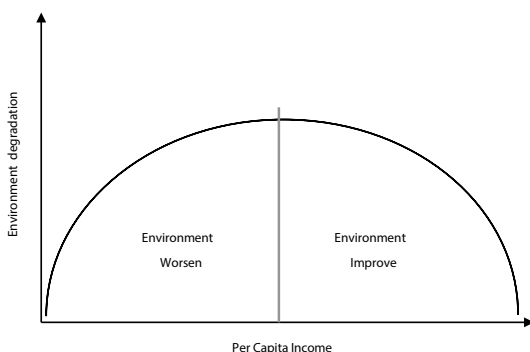


Figure 1 Environment Kuznets curve

Source Dinda (2005)

According to the EKC hypothesis, in the first phase of economic growth the per capita income rises abruptly which leads to higher energy consumption and causes environmental degradation. But after the achievement of a significant level of economic growth, the greenhouse gas emissions tend to decrease.

The international concerns over global warming and climate change have been continuously growing through the last few decades. Mitigation of the negative impacts of climate change has become an intriguing question both economically and politically. The 2002 Johannesburg meet on sustainable development identified the destructive impact of energy consumption on environment. Despite energy consumption having a primary role in economic development, it is considered largely responsible for GHG emissions.

Because of the abovementioned reasons, establishing the relationship between economic growth, energy consumption, and carbon emissions has become one of the critical discussions of recent times. Keeping this in mind, this study attempts to evaluate the aforementioned relationship in India's context. The data of GDP, CO_2 emissions, and energy consumption for the time period 1971–2011 is used for the analysis. All the calculations have been performed on Eviews-8. This study is organized as follows: Section 2 elaborates upon the linkages between economic growth, energy consumption, and CO_2 emissions. Section 3 provides the literature review. Section 4 provides the details of the methodology adopted. Section 5 contains empirical results and discussions. Finally, Section 6 contains conclusion and policy suggestions.

Interrelationship: growth, energy, and CO_2 emissions

Growth versus energy consumption

Economic growth can be equated with gross domestic product (GDP) and measured by total value added across all economic sectors during

Table 1 Energy consumption growth (%)

Countries	00–05	05–10	10–15
China	67.37	30.71	19.82
U.S.	2.25	-4.48	-0.90
India	17.46	33.78	27.27
Russia	5.17	5.84	4.21
Japan	0.39	-4.22	-12.83
Germany	-0.30	-2.68	-6.73
Brazil	14.89	23.15	12.41
South Korea	12.11	18.78	10.67
Canada	7.57	-7.04	0.00
France	6.27	-3.32	-6.11

Source Enerdata (2016)

a particular year. The prominence of energy consumption in economic growth is undermined by not recognizing the role of energy consumed in the production process. It is well known that an increase in the scale of production can lead to economic growth (Su and Yao 2017). However, energy consumed in home heating, operating electrical appliances, and private transport is not directly linked to GDP.

India's energy consumption has substantially increased between 2005 and 2010. The growth rate of energy consumption in India is significantly higher than other countries as exhibited in Table 1. For instance, the total primary energy production increased from 404 Mtoe (million - tonne oil equivalent) to 593 Mtoe between 2005 and 2015, while the consumption of energy during the same period increased from 518 Mtoe to 882 Mtoe. One can observe that the production capacity has grown by 46% (approx.) whereas energy consumption has grown by 70% in the same decade.

In 2015, India's primary energy consumption increased by 5.2% while its share in global primary energy consumption was 5.3%. By looking at source-wise growth in energy consumption, it is clear that fossil fuel sources have dominancy in the primary energy supply. For instance, during 2005–15, the source-wise consumption of energy witnessed CAGR of 6.69% by coal, 5.55% by crude petroleum, 2.86% by natural gas, and 3.36% by electricity (Energy statistics 2016). On comparison with GDP growth, it manifests a high degree of correlation between energy consumption and GDP growth (Table 2).

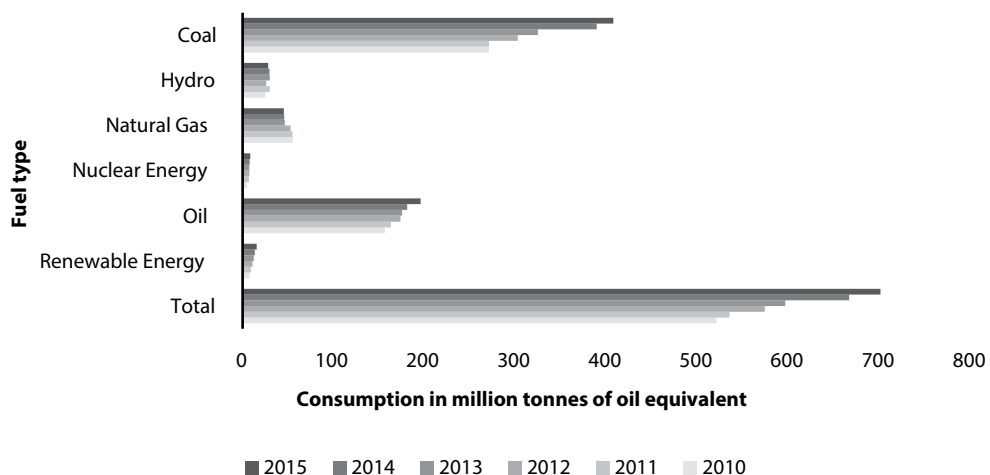
**Figure 2** Primary energy consumption in India between 2010 and 2015

Table 2 GDP growth of largest economies (%)

Countries	2014	2015	2016
U.S.	2.4	2.6	1.6
China	7.3	6.9	6.6
Japan	-.0	0.5	0.5
Germany	1.6	1.5	1.7
U.K	3.1	2.2	1.8
France	.6	1.3	1.3
India	7.2	7.6	7.6
Italy	-.3	.8	.8
Brazil	.1	-3.8	-3.3
Canada	2.5	1.1	1.2
Korea	3.3	2.6	2.7

Source WDI (2017)

Coal has a dominating share in India's energy supply, i.e. 58%, which makes it the second-largest coal consuming country with a global consumption share of 10.6%. India is also the world's third-largest coal producer. Coal production continues to grow at a very high rate, for example, in 2005 by 7.16%, in 2009 by 8.17%, in 2012 by 9.8%, in 2014 by 9.3%, and in 2015 by 4.8 % (Figure 3).

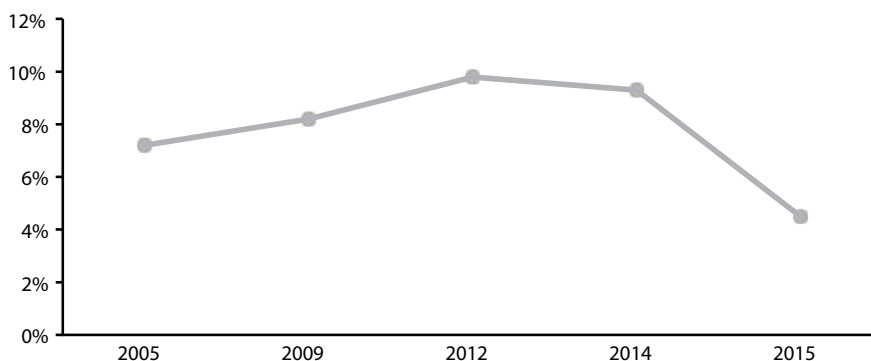
Coal is particularly essential for India's electricity generation, and 63% of its total consumption in 2012 was used for that purpose. Coal consumption in India is continuously

surpassing domestic production capacity and the remaining demand is met through coal imports. India became the largest coal importer in 2015 with the net coal imports of 223.1 MT (million tonnes). India has set an ambitious coal production target for 2020 and is expanding the transport infrastructure to facilitate additional coal production (BP 2016; IMF 2016; Enerdata 2017).

A comparison of CO₂ emissions in India and abroad

The CO₂ emissions represent more than 70% of the total GHGs (Khan and Usmani 2016). For more than a decade India has exhibited an increasing trend for both CO₂ emissions and GDP growth rate. The CO₂ emissions growth rate was 5% in 2015 which was slightly below the average growth rate of 6.8% during 2006–2015 (World Bank 2016). Because of this, it apparently seems that the CO₂ emissions have positive correlation with the GDP growth in India. Since ~66% of India's economy comprises domestic demand, its GDP growth remains relatively unaffected by global recessions (Damodaran 2011).

India ranked among the top three largest CO₂ emitters with more than 6% share in the global CO₂ emission in 2015. This massive share in CO₂ emissions was mainly caused by a 5.1% increase in energy consumption which is basically sourced from fossil fuels (BP 2016). In 2014, coal

**Figure 3** Growth rate of coal consumption

combustion was responsible for 74% of the total CO₂ emissions. The rising coal consumption of India is definitely a reason of concern, because in 2014 the country's emissions from coal surpassed the United States and it became the second largest coal consumer after China (Shearer, Ghio, Myllyvirta, *et al.* 2016). Table 3 shows percentage share in total emissions from the combustion of different fossil fuels.

The coal-dependent electricity production is one of the reasons for CO₂ emissions in India. For example, since 2010, total 33 countries have built new coal-fired power plants which have the capacity of 473.4 TW. China and India have 208 TW and 102 TW respectively, of the new coal powered capacity. These two countries jointly

account for 85% of all the new coal-fired power plants (Shearer, Ghio, Myllyvirta, *et al.* 2016). Despite massive installation of coal-based power plants, still the per capita CO₂ emissions from India is relatively lower from developed countries and the global average (Figure 5). The per capita trend of CO₂ emissions during 1961–2013 shows an exponential growth with the CAGR of 4.32% in China and 3.48% in India (Figure 4).

India's population growth has been one of highest in the world with an average growth rate of around 2%, in comparison to China's 1.31%, USA's 1.06% vis-a-vis the world's 1.62% between the period 1961–2015 (WDI 2017). The per capita income is also growing with a CAGR of 7.35% in China, 3.24% in India, 2.06% in USA,

Table 3 CO₂ emissions % of India's energy consumption

Years	Coal	Petroleum	Natural gas	Total energy
2005	67.349	26.588	5.924	100
2009	68.356	25.198	6.323	100
2012	70.597	24.746	4.601	100
2013	72.605	24.097	3.233	100
2014	73.917	23.182	2.837	100

Source IEA Statistics (2015), IES (2016)

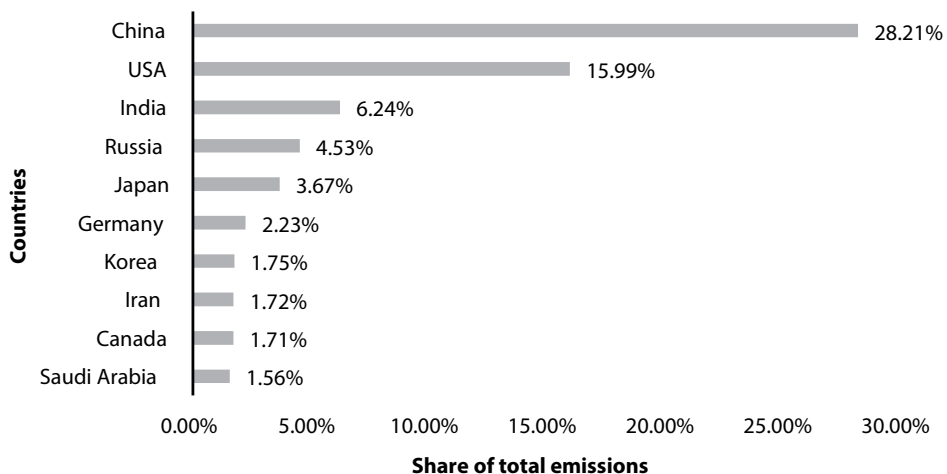


Figure 4 World's largest emitter of CO₂ in 2015

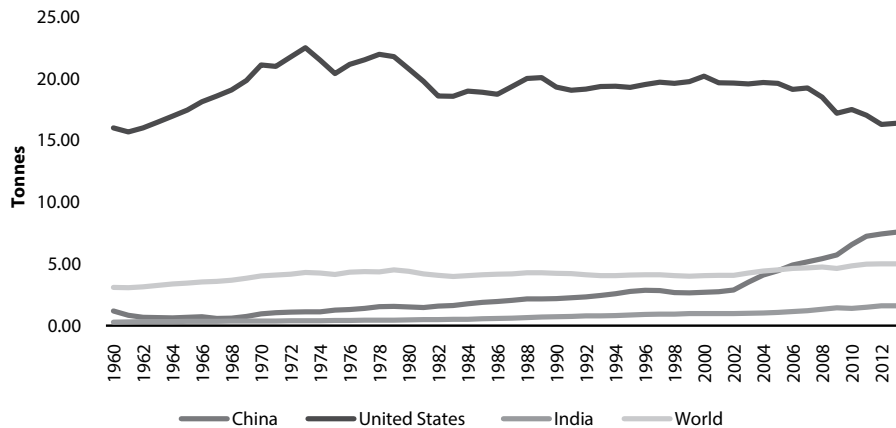


Figure 5 CO₂ emissions per capita

and 1.85% of World over the period 1961–2015. These intense trends of CO₂ emissions and per capita income need to be explored to give future directions.

Literature review

In a brief review of existing literature, we categorize existing studies into three groups. The first group of empirical studies considers those literatures that explore the link between economic activities and CO₂ emissions and emphasize on the fact that growth in an economy is achieved through various economic activities. Although these activities lead to economic growth and development, it may also cause considerable damage to the environment (Hettige, Lucas and Wheeler 1992; Cropper and Griffiths 1994; Selden and Song 1994; Grossman and Krueger 1995; Martinez-Zarzoso and Bengochea-Morancho 2004). The continuous growth in national income adversely affects the environment, a hypothesis which is validated by EKC. It proposes that the relationship between economic growth and the environmental pollutants resembles an inverted U-curve. The empirical findings show that emissions are consistently increasing with income levels (Shafik 1994; Holtz-Eakin and Selden 1995).

The second category of studies examines the causal relationship between economic growth

and energy consumption. Pioneering work of Kraft and Kraft (1978) finds a unidirectional causality running from economic growth to energy consumption in the U.S. Existing studies have extensively explored the economic growth–energy consumption relationship. However, diverse and contradictory evidences are often found in extant literature. For example, Yu and Hwang (1984), Hwang and Gum (1992), Yang (2000), Glasure (2002), Hondroyannis, Lolos, and Papapetrou, *et al.* (2002) and Oh and Lee (2004) find no causality or bidirectional causality, while Abosedra and Baghestani (1989), Cheng and Lai (1997), Yemane (2004), Lee (2005), among others, find unidirectional causality from either energy consumption or economic growth or vice versa.

The third category of experimental studies have sought to combine the above two issues of experimental literature and investigate the dynamic causal relationships between environmental pollutants, energy consumption, and economic growth within the same framework. Soytaş, Sari, and Ewing (2007), Ang (2008), Soytaş and Sari (2009), Zhang and Cheng (2009) and Halicioglu (2009) are some of the contributors on such relationships. The aforementioned relationships between environmental pollutants, energy consumption, and economic growth have been concluded with

mixed reviews under time-series methodologies. Table 4 provides a snapshot of the studies reviewed to evaluate the correlation between environmental pollutants, energy consumption, and economic growth.

Assessments of existing literature indicates that most studies have emphasized on the relationship between economic growth and pollution or economic growth and energy consumption while very little effort has been

Table 4 A visit of literature VECM methodology

S No.	Authors	Method	Period	Region	Causality	EKC H_0	Journal
1	Masih and Masih (1996)	Error-correction model	1955–1990	Malaysia, Singapore, and the Philippines	Non-cointegrated	No	Energy Economics (E)
				India	Energy→Income		
				Indonesia	Income→Energy		
				Pakistan	Energy↔Income		
2	Glasure and Lee (1997)		1961–1990	South Korea and Singapore	Energy↔Income	No	Resource and Energy Economics (E)
3	Masih and Masih (1998)		1955–1991	Sri Lanka and Thailand	Energy→Income	No	Applied Economic (Taylor & Francis)
4	Yang (2000)		1954–1997	Taiwan	Energy↔Income	No	Energy Economics (E)
5	Asafu-Adjaye (2000)		1973–1995	India and Indonesia	Energy→Income	No	Energy Economics (E)
				Thailand and Philippines	Energy↔Income		
				Turkey	Energy→Income		
6	Soytas and Sari (2003)		1950–1992	Argentina	Energy↔Income	No	Energy Economics (E)
				Korea, Italy	Income→Energy		
				Turkey, France, Germany, and Japan	Energy→Income		
7	Oh and Lee (2004)		1970–1999	South Korea	Energy↔Income	No	Energy Economics (E)
8	Paul and Bhattacharya (2004)		1950–1996	India	Energy↔Income	No	Energy Economics (E)
9	Jumbe (2004)		1970–1999	Malawi	Income→Energy	No	Energy Economics (E)
10	Ang (2008)		1971–1999	Malaysia	EG↔EC CO ₂ →EG	No	Journal of Policy Modeling (E)
11	Fodha and Zaghdoud (2010)		1961–2004	Tunisia	EG→CO ₂ & SO ₂	Yes	Energy Policy (E)

Table 4 Contd...

S No.	Authors	Method	Period	Region	Causality	EKC H_0	Journal
12	Tiwari (2011)	Error-correction model	1971–2005	India	$CO_2 \rightarrow EG$ $EC \leftrightarrow CO_2$	No	Journal of International Business and Economy
13	Wang, Zhou, Zhou, <i>et al.</i> (2011)		1995–2007	China	$CO_2 \leftrightarrow EC \leftrightarrow EG$	Yes	Energy Policy (E)
14	Binh (2011)		1976–2010	Vietnam	Income $\rightarrow$ Energy	No	International Journal of Energy Economics and Policy
15	Hamit-Haggar (2012)		1990–2007	Canada	EC $\rightarrow$ GHG EG $\rightarrow$ GHG	Yes	Energy Economics (E)
16	Arouri, Youssef, M'henni, <i>et al.</i> (2012)		1981–2005	Middle East and North African Countries	$CO_2 \rightarrow EC \rightarrow EG$	Yes	Energy Policy (E)
17	Apergis and Danuletiu (2012)		2000–2011	Romania	Energy $\rightarrow$ Income	No	International Journal of Energy Economics and Policy
18	Saboori and Sulaiman (2013)		1980–2009	Malaysia	$EG \leftrightarrow CO_2 \leftrightarrow EC$	Yes	Energy Policy (E)
19	Omri (2013)		1990–2011	MENA Countries	$EC \leftrightarrow EG$ $EC \rightarrow CO_2$ $EG \leftrightarrow CO_2$	No	Energy Economics (E)

Source Author's Compilation

made to examine these two relationships under the same framework due to its inter-connectedness. This study tries to fill this gap. India is one of the highest growing economies among the developing nations as well as the second most populous country in the world (World Bank 2020), which means that its energy consumption and CO_2 emissions are anticipated to rise in future. It has also experienced a substantial rise in energy consumption and CO_2 emissions in past decades. The rationale behind this study is based on the fact that India has been the fourth largest energy consumer in the world (Annual Energy Review, 2011), and third biggest CO_2 emitter in the world (World Energy

Outlook 2011). Further the demand of carbon intensive 'coal' remains on higher side because of its price affordability. Obviously, there is a need to examine the intertemporal association between economic growth, CO_2 emissions, and energy consumption that will assist in developing environmental strategies.

Research methodology

Data collection

The study uses yearly data of carbon emission, energy consumption, and GDP in per capita terms from the period 1971–2011. All data are acquired from the World Bank Development

Indicators 2015. The data has been converted into natural log forms.

Data analysis

The two objectives have been considered in empirical estimation. First, we investigate whether the variables are associated in the long run. Second, we examine the dynamic causal relationship between the variables. The trivariate model has been constructed for estimation purpose. Three steps are involved in the testing procedure. In the first step, the stationarity of the time series is checked by using ADF (Augmented Dicky Fuller) unit root test. In the second step, co-integration is tested using the Johansen approach for the VARs constructed in levels. Our causality tests are dependent on co-integration results since the existence of co-integrated relationship has insinuations for the way in which causality test is carried out. In the third step, causality is tested to find the direction of relationship.

Test of co-integration

Co-integration indicates the existence of the long run relationship between the variables but it does not specify the direction of the causal relationship. We examine whether the three series are co-integrated, or, in other words, whether a linear combination of the three series is stationary. The stationary linear combination of the three variables comes together to a long-run equilibrium over a period and is termed as the co-integrating equation. There are numerous possible tests for confirming the co-integration. Among them, the most commonly used test is the multivariate test which is based on the autoregressive representation discussed by Johansen (1988) and Johansen and Juselius (1990). The Johansen maximum likelihood method provides two different likelihood ratio tests; one is based on the trace statistic and the other is based on the maximum Eigen value, in order to define the number of co-integrating equations. The test for co-integration is used for ascertaining the causality.

The generalized co-integration equation is given here.

$$\Delta X_t = \mu + \sum_{l=1}^{p-1} \Gamma_l X_{t-l} + \Pi X_{t-1} + \varepsilon_t$$

where X_t is an $(n \times 1)$ column vectors and the variables between co-integration is analysed. Π denotes the coefficient matrices. It contains the information of long run adjustment to change in X_t . P is the number of variables in the model. Δ is the operator of the first difference and k indicates lag length.

Weak exogeneity

To find out the direction of causality in the short run among the variables, VEC Granger Causality/Block Exogeneity Wald Test is employed. It will help to understand how the growth of GDP, CE, and EU stimulates the growth of each other.

We construct an index for each series in order to present data series in the same scale using 1971 as the base year. Figure 6 indicates that all the three series tend to be very closely associated over time and a long-run co-integrating relationship may likely be present. Though, casual assessment always has its limitations, hence it is essential to conduct formal testing procedures to validate our acceptance.

Empirical results and discussion

In this section the result of the empirical analysis is reported under different headings. In Table 5, the results of ADF have been presented, with the null hypothesis that a unit root is present in a time series sample, and the alternate hypothesis that the time series does not have the unit root. The variables stationary at level got rejected on the basis of the p -value.

It is well observed that GDP, carbon emissions, and energy consumption are non-stationary at levels but become stationary at the first difference. It confirms that Johansen test of co-integration can be applied.

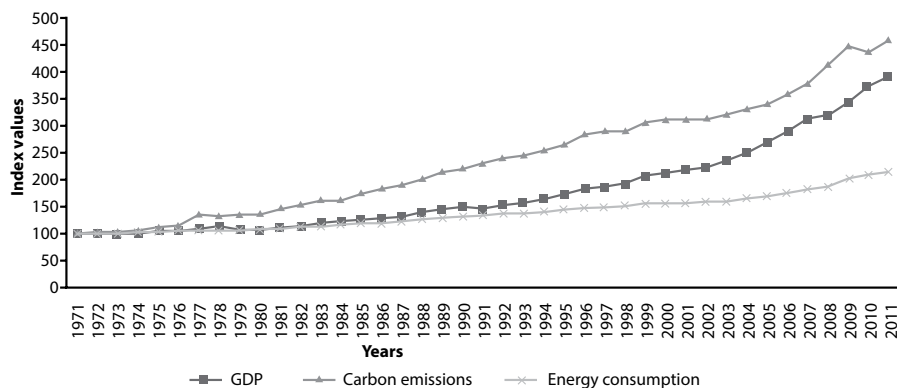


Figure 6 Comparative trend GDP, energy consumption, and carbon emissions

Note Before taking logarithms 1971 = 100 for Index Calculation

Table 5 Test for stationary (Augmented Dickey-Fuller Test)

At level				
	Intercept		Intercept and trends	
	<i>T-value</i>	<i>P-value</i>	<i>T-value</i>	<i>P-value</i>
Gross Domestic Product (LGDP)	3.780	1.000	-0.962	0.937
Carbon Emissions (LCE)	-0.341	0.909	-2.194	0.479
Energy Consumption (LEC)	3.310	1.000	-0.294	0.988
First difference				
	Intercept		Intercept and trends	
	<i>T-value</i>	<i>P-value</i>	<i>T-value</i>	<i>P-value</i>
Gross Domestic Product (LGDP)	-5.709	0.000	-7.855	0.000
Carbon Emissions (LCE)	-7.077	0.000	-6.987	0.000
Energy Consumption (LEC)	-4.704	0.000	-5.602	0.000

The results from Johansen co-integration tests show that there is a long-term relationship between variables. The values of Trace Statistics (33.93*) and Max-Eigen Statistics (23.738*) are more than the critical value as well as *p*-value is also less than 0.05 (Table 6). It shows (H_0), i.e. there is no co-integration among variables rejected. And the alternate hypothesis ($H_{(a)}$), i.e. a long-term relationship between the variables is accepted.

Table 7 shows the results of VEC Granger Causality. It is found that the null hypothesis of energy consumption does not Granger Cause GDP is rejected at 5% level of significance, which means that energy consumption causes GDP in the short run. Similarly, the results indicate that carbon emissions Granger causes GDP and that in the short run carbon emissions stimulate GDP. It is also found that GDP growth is a Granger cause of carbon emissions. The bidirectional

Table 6 Johansen test of co-integration

No. of CE(s)	Trace statistic	0.05 critical value	P-value
None *	33.93*	29.80	0.0158
At most 1	10.19	15.49	0.2665
At most 2	0.62	3.84	0.4298
Max-Eigen Test			
No. of CE(s)	Max–Eigen Statistic	0.05 Critical Value	P-value
None *	23.738*	21.132	0.021
At most 1	9.565	14.265	0.2421
At most 2	0.623	3.841	0.4298

* Denotes rejection of the hypothesis at the 0.05 level

Note Trace and Max–Eigen Statistic value indicate that there is one co-integration equation

Table 7 VEC granger causality/block exogeneity wald tests

H ₀	Wald test/ χ^2	p-value	Conclusion
D(LEU) does not Granger cause of D(LGDP)	7.640**	0.022	Causality
D(LCE) does not Granger cause of D(LGDP)	10.25*	0.006	Causality
D(LGDP) does not Granger cause of D(LEU)	0.129	0.937	No Causality
D(LCE) does not Granger cause of D(LEU)	0.969	0.616	No Causality
D(LGDP) does not Granger cause of D(LCE)	6.518**	0.038	Causality
D(LEU) does not Granger cause of D(LCE)	1.791	0.409	No Causality

* Indicates significant at 1%, ** Indicates significant at 5%

relationship is found between carbon emissions and GDP while causal relationship between carbon emissions and energy consumption is not so strong in the short run.

Diagnostic tests

Diagnostic tests such as serial correlation, lag range multiplier, heteroskedasticity, and test for residual normality have been conducted to test the stability of the model. Desirable results are found in the test, indicating neither Serial Correlation nor Heteroscedasticity is present as residuals are normality distributed. Tables 8, 9, and 10 provide the snapshots of model summary, serial correlation, and heteroskedasticity tests.

Table 8 Model summary

R-squared	0.543696
Adjusted R-squared	0.437225
F-statistic	5.106513
Prob(F-statistic)	0.000664
Durbin-Watson stat	2.133002

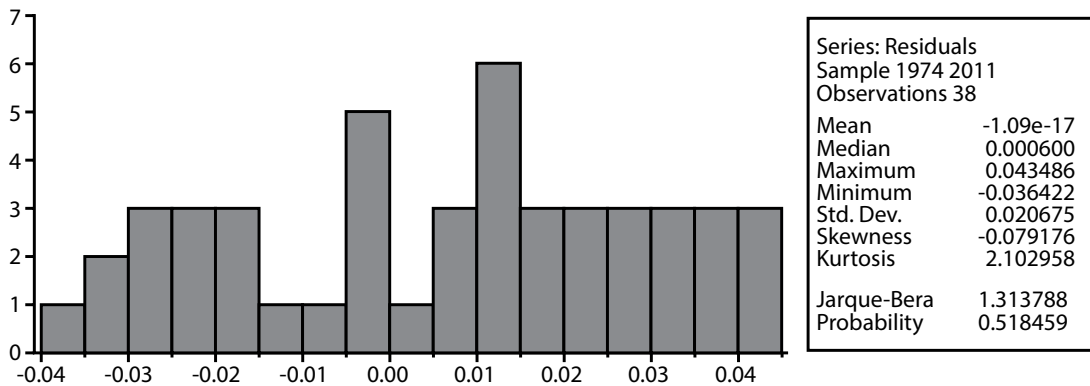
Table 9 Breusch godfrey serial correlation LM test

F-statistic	0.918	Prob. F(2,28)	0.411
Obs*R-squared	2.338	Prob. Chi-Square(2)	0.311

Table 10 Breusch pagan godfrey heteroskedasticity test

F-statistic	0.489	Prob. F(9,28)	0.870
Obs*R-squared	5.158	Prob. Chi-Square(9)	0.820
Scaled explained SS	1.773	Prob. Chi-Square(9)	0.995

reason behind increasing emissions from economic growth is a result of huge dependence on fossil fuels such as coal and petroleum. Since energy consumption is a driver for economic development, the execution of energy

**Figure 7** Jarque-Bera test for normality

Conclusion and policy implications

The results of the study confirm the relationship between energy consumption, CO₂ emissions, and economic growth. The co-integration test and multivariate vector error correction model establish the association between these variables during 1971–2011 for India. The findings of the co-integration analysis explain that there is a short run association among economic growth, carbon emissions, and energy consumption. Further, the VEC Granger Causality results confirm the weak exogeneity between variables which prove that economic growth causes carbon emissions, carbon emissions causes economic growth, and energy consumption causes economic growth. On the other hand, economic growth does not cause energy consumption, carbon emissions does not cause energy consumption, and energy consumption does not cause carbon emissions.

The results are supported by the fact that a significant amount of economic growth in India has been driven by industrial growth, which requires intensive use of energy. The

conservation policies may severely affect economic performance and impede economic development. The alternative arrangement for reducing carbon emissions can be seen through green energy, hydropower, nuclear power and natural gas, and it can possibly be a suitable strategy for India. In this sense, India needs to transit to a sustainable economy by emitting less CO₂ and consuming less fossil energy. Moreover, investments in the renewable energy and creation of renewable energy supporting infrastructure are extremely essential. The guidelines to be settled and policies to be executed must aim to lessen our reliance on foreign energy sources and eradicate it in the long run to avoid slowing down of the economy.

The study has some important policy implications for designing India's renewable energy policy. The study strongly suggests the increasing use of renewable transport fuels. The transport sector is responsible for maintaining material flow in the economy and a major contributor of carbon emissions. Decarbonizing the transport sector by replacing petroleum-based fuels with biofuels is one of the major policy recommendations of this study.

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Assessment of the Regulatory Aspects of Supply Chain Management of Hazardous Materials HAZMAT with Respect to the Indian Chemical Industry

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Introduction: HAZMAT and Indian
Chemical Industry
Chemical Management In India
REACH – A Perspective
India's Multilateral Agreements for
Management
Some Other HAZMAT Regulations
Findings and Gap Analysis
Industrial Survey Results

Abstract

HAZMAT, defined as materials which can harm people, organisms, and the environment, are a critical part of the industry supply chain as raw material, intermediates, or finished products. A strong and effective regulatory framework for dealing with HAZMAT and its proper management is of utmost importance for ensuring adequate safety and minimizing the risks during different stages of supply chain (manufacturing, storage, transportation). In view of this, the objective of research was to study the prevailing regulatory framework for supply chain management of HAZMAT in the context of Indian chemical industry.

Keywords: HAZMAT regulations, India, Supply chain

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Introduction:HAZMAT and Indian chemical industry

HAZMAT (hazardous materials)¹ are defined as materials that can harm people, organisms, and environment, either by itself or by complex interaction with other factors. These materials are critical part of the supply chain process, as raw materials used in manufacturing, intermediates or finished products. Strong and effective regulatory framework for dealing with HAZMAT and proper management are of utmost importance to ensure adequate safety and to minimize the risks during the different stages of supply chain (manufacturing, storage, transportation).

The chemical industry is among the oldest industries in India and has made significant contribution to industrial growth. It is also the largest consumer and generator of HAZMAT. A large number of small, medium, and large scale units manufacture over 80,000+ commercial products.² The Indian chemical industry was valued at nearly USD 163 billion/annum in 2017/18 and is projected to reach USD 403 billion/annum by 2025. India ranks fourth in Asia and sixth in the world in chemical sales and has witnessed sizeable growth. Between 2010 and 2015, it posted a strong CAGR of 13% and is forecasted to have a CAGR of 8% to 10% by 2025. Increasing development across multiple end-user sectors coupled with growing middle class and increased urbanization are compelling drivers for this growth. India's preparedness with respect to

HAZMAT is therefore quite important in order to ensure safety and risk reduction during different phases of the supply chain and to ensure that this growth momentum in 'chemical industry' continues.

Chemical management in India

The Ministry of Environment, Forests and Climate Change (MoEFCC) is the main nodal agency for the 'chemical management' in India. Under the Environmental (Protection) Act, 1986, 1991, it stipulates the foundation for HAZMAT regulations.

HAZMAT are materials possessing any one of the following characteristics (as per Schedule I of Act)³:

Toxicity: Materials having the values of acute toxicity as given in Table 1 and which, owing to their physical and chemical properties, are capable of producing major risks to human health and other living organisms.

Flammability: Materials with flash point of 20 deg C or below

Explosivity: Materials which may explode under the effect of flame, heat, or photochemical conditions or any other material under the Indian Explosive Act.

Acidity: Materials with PH ≤ 5 which may be corrosive by chemical reaction and cause severe damage when in contact with living tissue.

Alkalinity: Materials with PH ≥ 9 , which may be corrosive and will cause severe damage when in contact with living tissue

Table 1 Different toxicity level

S No.	Degree of toxicity	Medium lethal dose by oral route (oral toxicity, LD50) (mg/kg)	Medium lethal dose by dermal route (dermal toxicity, LD50) (mg/kg)	Medium lethal dose by inhalation route (~4 h), LD50, (mG/kg)
1	Extremely toxic	1–50	1–200	0.1–0.5
2	Highly toxic	51–100	201–2000	0.5–2.0

¹ HAZMAT definition, Institute of hazardous materials management, www.ihmm.org

² www.investindia.gov.in/sector/chemicals

³ India Parliament, Environmental (Protection) Act. 37th year of the republic of India, No. 029, Delhi, India, 23rd May 1986

Carcinogenicity: Materials which through exposure can cause cancer in humans and animals

Under Schedule III,⁴ HAZMAT materials have been defined as given in Table 2.

Multiple act and rules have been laid down for chemical management in India. Broadly, these are classified into the following groups:

- Laws related to manufacturing of chemicals
- Laws related to transportation of chemicals

their regulatory agencies are responsible for implementing the respective laws.

The Environment (Protection) Act, 1986, 1991

- Manufacture, Storage, and Import of Hazardous Chemicals, 1989, 2000⁵
- Hazardous and others wastes (Management, Handling & Transboundary Movement) Rules, 1989, 2000, 2016 (see Footnote 4)

Table 2 Different classifications of HAZMAT

UN Class *	Code	Characteristics
1	H1	Explosive
3	H3	Flammable liquids
4.1	H4.1	Flammable solids
4.2	H4.2	Substances or wastes liable to spontaneous combustion
4.3	H4.3	Substances or wastes which in contact with water emit flammable gases
5.1	H5.1	Oxidizing
5.2	H5.2	Organic peroxides
6.1	H6.1	Poisonous (acute)
6.2	H6.2	Infectious substances
8	H8	Corrosives
9	H10	Liberation of toxic gases in contact with water or air
9	H11	Toxic (delayed or chronic)
9	H12	Eco-Toxic

UN Class:-Corresponds to the hazard classification system included in the United Nations Recommendations on the Transport of Dangerous Goods(ST/SG/AC.10/1Rev.5,United Nations, NewYork, 1988)*

- Laws related to protection of environment and public health

Acts and Rules have been framed for each of the above groups. However, the Environment (Protection) Act, 1986, 1991 serves as an umbrella Act and can link other Acts in one way or another, without interfering with their autonomy. Various ministries at the central and state levels with

- Chemical Accidents (Emergency Planning, Preparedness and Response) Rules,1996⁶

- The Ozone Depleting Substances (Regulation and Control) Rules, 2000⁷

We have attempted to classify the HAZMAT regulations as given in Figure 1 as per the applicability within the various critical stages of supply chain Table 3 lists the various acts and rules.

⁴ The Hazardous waste (Management, Handling & Transboundary movement) Rules 2008,2009. Gazette notification, SO 2265 (E), 24th Sep 2008, SO 1799 (E), 2009

⁵ Manufacture, Storage & Import of Hazardous Chemicals, Gazette notification, SO 966 (E), Ministry of

⁶ Environment & Forests (MOEF), 27th November 1989 Chemical accidents (Emergency planning, preparedness & response) Rules 1996, Ministry of Environment & Forests (MOEF), Notification GSR 347 (E), 1996

⁷ Ozone depleting substances (Regulation & Control) Rules, 2000, notification SO 69 (E), Ministry of Environment & Forests (MOEF)

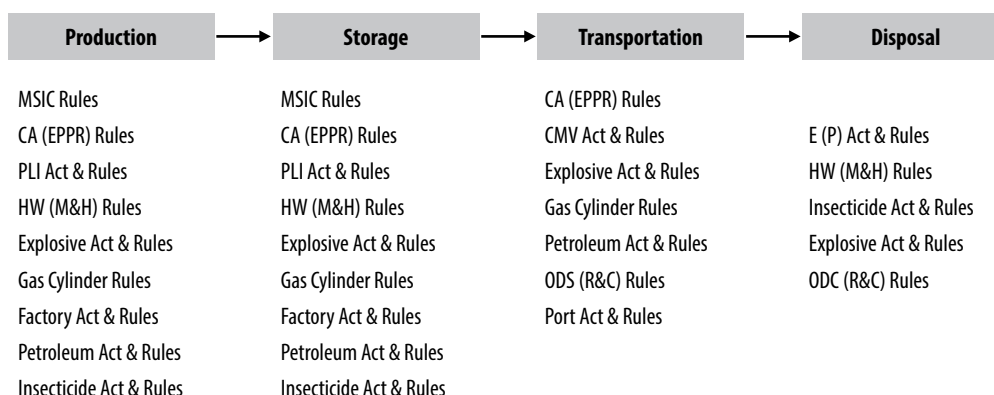


Figure 1 Classification of HAZMAT regulations as per the applicability

Table 3 Compilation of multiple acts and rules

Acts and Rules Related to Environmental Management	The Environment (Protection) Act, 1986, amended 1991 (see Footnote 3) Environment Protection Rules, 1986 (amended 1999, 2001, 2002, 2004) Hazardous Waste Management & Handling Rules, 1989, 2000, 2003, 2016 (see Footnote 4) Ozone Depleting Substances (Regulation & Control) Rules, 2000 The Air (Prevention and Control of Pollution) Act, 1981, 1987 The Water (Prevention and Control of Pollution) Act, 1974, 1988 The Water (Prevention and Control of Pollution) Rules, 1975 Ozone Depleting Substances (Regulation and Control) Rules, 2000 (see Footnote 7)
Acts and Rules Related to Chemical Safety and Emergency Management	Manufacture, Storage and Import of Hazardous Chemicals Rules, 1989, 2000 (see Footnote 5) Chemical Accidents (Emergency Planning, Preparedness and Response) Rules, 1996 (see Footnote 6) Public Liability Insurance Act, 1991, 1992⁸ Public Liability Insurance Rules, 1991, 1993 Factories Act, 1948⁹ The Dock Workers (Safety, Health and Welfare) Act, 1986 The Dock Workers (Safety, Health and Welfare) Rules, 1989
Acts and Rules Related to Specific Chemical Category/ Container	Petroleum Act, 1934¹⁰ Petroleum Rules, 2002 Explosives Act, 1884 Explosives Rules, 1983 Gas Cylinder Rules, 2004 Insecticides Act, 1968 Insecticide Rules, 1971
Acts and Rules Related to Transportation	Motor Vehicles Act, 1988, 2019 (see Footnote 10) Central Motor Vehicles Rules, 1989 The Merchant Shipping Act, 1958 amended in 2002 and 2003 The Merchant Shipping (Carriage of Cargo) Rules 1995
Other Acts Related to Chemical Management	Customs Act, 1962, Indian Ports Act, 1908 National Disaster Management Act, 2005

⁸ India, Parliament, Public Liability Insurance Act, 1991

⁹ Factory Act, 1948, 1987

¹⁰ Central Motor Vehicle Rules, 1989

REACH—a perspective

European Union Regulation Governing HAZMAT Substances (REACH)

REACH (Regulation concerning the Registration, Evaluation, Authorization and Restriction of Chemicals)¹¹ is an EU Regulation. It addresses production and use of chemical substances, potential impact on human health and environment, and life cycle analysis of the impact of HAZMAT. REACH makes the industry responsible for assessing, managing, and mitigating the risks posed by chemicals and provides comprehensive safety information to all the members in the supply chain (manufacturers/importers, upstream and downstream users). REACH entered into force on 1 June 2007, with phased implementation over the next decade. It mandates all companies manufacturing or importing chemical substances into the EU in quantities of 1 tonne or more per year to register these substances with a new European Chemical Agency (ECHA) in Finland. REACH also addresses continued use of chemical substances of very high concern (SVHC) because of their potential negative impact on human health and environment. The ECHA needs to be notified of the presence of SVHC in articles if the total quantity used is more than 1 tonne/year and the SVHC is present at more than 0.1% of the mass of object. The authorization procedure also calls for detailed plans to replace the use of SVHC with safer alternatives or substitutes.

One of the major elements of REACH regulation is the requirement to communicate information on chemicals up and down the supply chain. This ensures that manufacturers, importers, and also customers are aware of the information related to the health and safety of the products supplied. Having detailed

information on the substances present in their products will also allow retailers to work with the manufacturing base to substitute or remove potentially harmful substances from the products.

As of date nearly 143,000 substances have been registered under REACH and the strong data information management system under REACH (EUCLID system¹²) allows for exchange of critical HAZMAT information among all the members of the supply chain.

India's multilateral agreements for HAZMAT management

India is also a signatory to a number of multilateral international agreements, under the UN Charter, for HAZMAT materials. Some important agreements are as follows:

- **Basel Convention¹³ on the Control of Transboundary Movement of Hazardous Waste, 1989:** This is broadest and one of the most significant international treaties on the transboundary movement of hazardous wastes. The objective is to have strict control on the movement of hazardous wastes over international borders. The Government of India has ratified the Basel convention on the control of transboundary movement of hazardous wastes and their disposal (under the aegis of the UNEP). The provisions and certain decisions of the Basel convention have been harmonized within the domestic legislation according to India's commitment to the convention.
- **Rotterdam Convention¹⁴ on the Prior Informed Consent (PIC) on Certain Hazardous Chemicals and Pesticides in International Trade, 1999:** The aim is to promote shared responsibilities between the exporting and the importing countries in protecting human health and

¹¹ REACH, Regulation Concerning the Registration, Evaluation, Authorization & Restriction of Chemicals, details available at www.echa.europa.eu/regulations/reach/understanding-reach

¹² IUCLID, details available at www.iuclid6.echa.europa.eu

¹³ International uniform chemical information database, Basel convention, details available at www.basel.int

¹⁴ Rotterdam convention, details available at www.pic.int

the environment from the harmful effects of hazardous chemicals, by enabling trade to be controlled and monitored. According to the Rotterdam Convention, export of a chemical can only take place with the prior informed consent of the importing party. The convention contains provisions for the exchange of information among parties about the potentially hazardous chemicals that may be exported and imported, and provides for a national decision making process regarding import and compliance by exporters.

- **Cartegena Protocol on Bio-Safety, 2000:** This protocol seeks to protect biological diversity and human health from the potential risks posed by the living modified organisms (LMO) resulting from modern biotechnology. It establishes an advanced informed agreement (AIA) procedure for ensuring that countries are provided with the necessary information to make informed decisions before agreeing to import such organisms into their territory.
- **Stockholm Convention on Persistent Organic Pollutants (POP), 2001¹⁵:** The objective is to eliminate and restrict the production and use of Persistent Organic Pollutants (POPs). POPs are defined as chemical substances that persist in the environment, bio-accumulate through the food-web, and pose a risk causing adverse effects to human health and environment. The list includes 22 major chemicals, some of which are DDT, Aldrin, Heptachlor, PCB (Polychlorinated biphenyls), Hexachlorobenzene, Lindane, Chlordecone, Dieldrin. Many of these listed chemicals have been used in insecticides, agrochemicals, pharmaceutical, and electronic industry. There is well defined procedure for identifying and screening POPs on parameters related to persistence, bioaccumulation, toxicity and potential for long range transport (LRET)

- **Chemical Weapons Convention, 1993:** This treaty outlaws the production, stock-piling, and use of chemical weapons and its precursors. It defines chemical weapons as a hazardous chemical, which through its chemical action on life processes can cause death, temporary incapacitation or permanent harm to humans or animals. Schedule 3 chemicals, in the list, can have legitimate uses in various industries, such as plastics, pharma, agrochemicals, batteries, resins, under regulated control, approval and monitoring system.

Some other HAZMAT regulations

Restriction of Hazardous Substances was adopted by the EU in February 2003 and took effect on 1 July 2006. The directive restricts the use of six hazardous materials in the manufacture of various types of electronic and electrical equipment and is closely linked with the Waste Electrical & Electronic Equipment (WEEE). More specifically, RoHS, which is often referred to as the lead-free directive, restricts the use of lead, mercury, cadmium, hexavalent chromium, PBB (polybrominated biphenyls), PBDE (Polybrominated biphenyl ether), the latter two being used as flame retardants in some plastics. It limits the maximum concentration of such materials to 1000 ppm by weight of material. Even though the directive is confined to the EU, it has far reaching implications. China has regulations, often referred to as China RoHS, that have similar restrictions. The U.S. has the Electronic Waste Recycling Act (EWRA) that took effect on January 2007. One can expect to see RoHS variations in effect in most countries globally in the near future.

WEEE (Directive on Waste Electrical and Electronic Equipment) became law in the European Union along with the RoHS in February 2003. This directive imposes the responsibility for the disposal of waste

¹⁵ Stockholm convention on POP, details available at www.pops.int

electrical and electronic equipment (WEEE) on the manufacturers of such equipment. The companies are required to establish an infrastructure for collecting WEEE in such a way that users of electronic and electronic equipment from private households have the provision of returning WEEE free of charge.

United Nations (UN) Model Regulations¹⁶ cover all aspects of transportation necessary to provide international uniformity. It includes comprehensive criteria-based classification system for HAZMAT transportation. Hazards addressed include explosiveness, flammability, toxicity (which include oral, dermal, inhalation), corrosivity to human tissue and metal, reactivity, radioactivity and environmental hazards. It prescribes standards for packaging and multimodal tanks used for transporting HAZMAT. It includes a system of communicating the hazards of substances in transport through hazard communication requirements which cover labelling and marking of packages, placarding of tanks, freight containers and vehicles, and documentation and emergency response information required to accompany each shipment.

Many national, regional, and modal regulations governing the transportation of HAZMAT are now based on the UN recommendations. For instance, the International civil aviation organization has developed dangerous goods regulations for air transport of HAZMAT substances that are based on the UN model but modified to accommodate unique aspects of air transport. Individual airline and governmental regulations are incorporated with this by the International Air Transport Association to produce the widely used IATA Dangerous Goods Regulations (DGR). Similarly, the International Maritime Organization has developed the International Maritime Dangerous Goods Code (IMDG Code) for transportation of dangerous goods by sea. The Intergovernmental Organization for International Carriage by Rail has developed the regulations concerning the

International Carriage by Rail (RID). The global harmonized system of classification and labelling of chemicals is an internationally agreed upon system set to replace the various classification and labelling standards used in different countries. GHS will use a consistent criterion for classification and labelling at a global level.

Findings and gap analysis

- On the legislation front, from cradle to grave, India seems to have the requisite number of Acts and Rules governing the management of HAZMAT substances. Adequate number of regulatory frameworks is in place. Further, since India is a signatory to the various multilateral agreements under the UN Charter, the HAZMAT regulations are being constantly reviewed and updated.
- However, due to multiple stakeholders (ministries) involved in the implementation of regulations, there is a possibility of overlap of functions (some stakeholders act solely as regulators, while others as developers, operators and regulators). Better coordination and synchronization mechanism would help in the implementation.
- Implementation of regulations needs to be strengthened and there is also need for tougher procedures for inspection, vigilance, and penalty. This is critical to ensure that any potential HAZMAT risks are well controlled and eliminated as soon as investigated, because any lapses in implementation can result in catastrophic failures, grave injury and loss of lives, at a later stage. The Bhopal Gas tragedy, due to leakage of Isocyanate gas from the Union Carbide pesticides plant, is still well entrenched in the minds of many Indians. It resulted in the loss of over 4000 lives and many were seriously injured. This grave incident could have been very well prevented if the HAZMAT regulations in the Union Carbide plant were strictly enforced by stricter inspection, vigilance, and penalty.

¹⁶ UN Model Regulations, details available at www.unece.org/trans/danger

- Although there is progress towards centralized database for HAZMAT in India, there needs to be much more agile with real-time updates of HAZMAT inventory and facilitating better exchange of information within the various members of the supply chain (upstream, manufacturers, distribution channel, downstream users). At present most of the data is managed by respective governmental agencies. Data analysis and latest analytics tools will help in evolving proper action plans. Crucial areas which need improvement include
 - » Real-time updates on HAZMAT inventory facilitating better exchange of information within the supply chain.
 - » Integrated data on health of industrial workers
 - » Integrated data on HAZMAT accidents, online reporting, and analysis
 - » Real-time exposure data and tracking of chemicals
- Greater focus on technical training of ‘workers and public’ on HAZMAT management and respective regulations (Figure 2).
- Increased involvement of industry, professional bodies, and academic institutions. Constantly imbibing best practise from the world, as a dynamic process.
- Capability building/infrastructure for emergency response
- Graduating to tougher laws such as (REACH) (see Footnote 11), which call for end-to-end life-cycle management of chemicals and ensure greater degree of safety to the environment and public health.

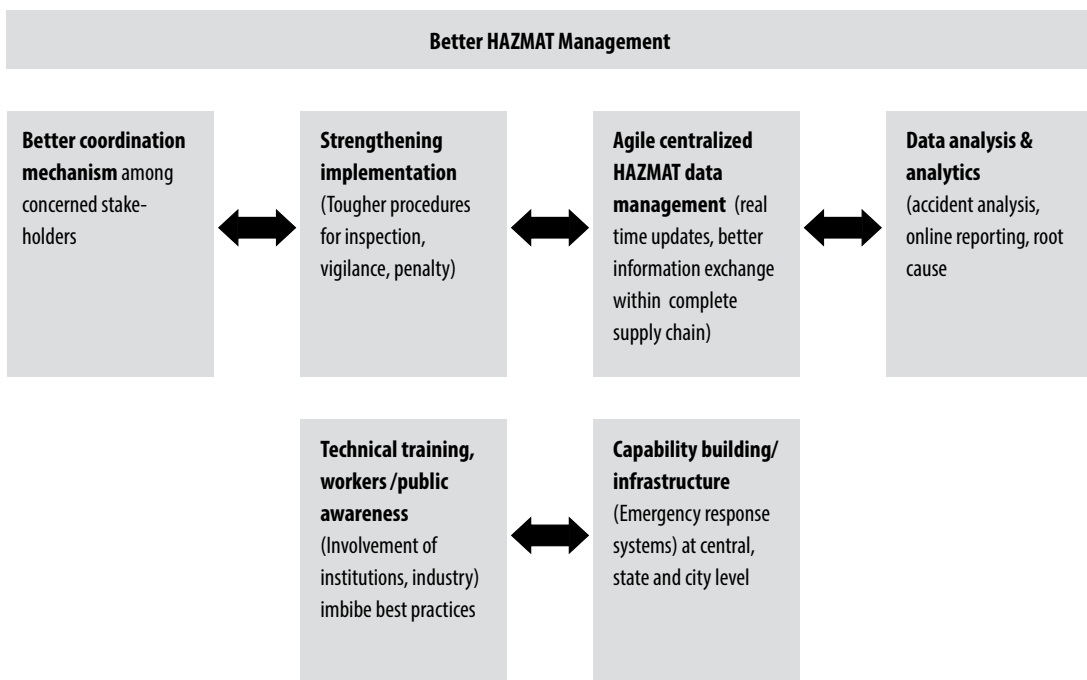


Figure 2 Framework illustrating improved HAZMAT management

Industrial survey results

A survey was conducted involving 20 chemical industries across India with revenues exceeding US\$ 25 million per annum to gain better insight of the four main input factors (Xs) contributing to improvement in HAZMAT practices (Y)

in India. The survey was conducted by mail followed by telephonic questionnaire (Table 5). It was determined that nearly 46% of the respondents felt that capacity building (cb) is a major contributor to improvement of HAZMAT practices. Next 24% respondents

Table 4 Recommendation from REACH framework

REACH	India's HAZMAT
Integrated regulation governing HAZMAT. Replaced over 45 different regulations across EU	Increased integration will facilitate better HAZMAT management
Strong HAZMAT data-capture, analysis and management under system, called IUCLID IT [30] (International Uniform Chemical Information Database)	HAZMAT data management to be made more agile with real-time updates and better information exchange
Strong inventory for over 143,000 substances and constantly growing	Database on HAZMAT inventories to be augmented deploying latest analytics
Focus on life cycle analysis of HAZMAT and their impact on human health and environment (air, water, soil, aquatic life, plant life). Mechanism to track persistence in environment (short, medium, long term) and eco-toxicity and bioaccumulation	Focus is primarily on direct impact of HAZMAT on human health and environment. The need to build capabilities for executing life cycle analysis
Makes industry (manufacturers, importers) responsible for managing the risks posed by HAZMAT and provides information within the supply chain. Forces the industry to substitute serious HAZMAT substance and plan for substitution in such cases	Responsibility mainly with the occupier of HAZMAT. A governing mechanism for substitution of serious HAZMAT is needed.

Table 5 Results of industrial survey

S No.	Input parameters (Xs)	Scales (5 - extremely important, 3 - medium important, 1 - low important, 0 - not important)
1	Better coordination mechanism (Bcm)	2 (scored 5), 3 (scored 3), 4 (scored 1), 11 (scored 0), (total score 29)
2	Strengthening implementation (Si)	2 (scored 5), 4 (scored 3), 6 (scored 1), 8 (scored 0), (total score 28)
3	Agile HAZMAT data management (Dm)	3 (scored 5), 7 (scored 3), 8 (scored 1), (total score 44)
4	Capacity Building (Cb)	13 (scored 5), 6 (scored 3), 2 (scored 1), 1 (scored 0) (total score 85)

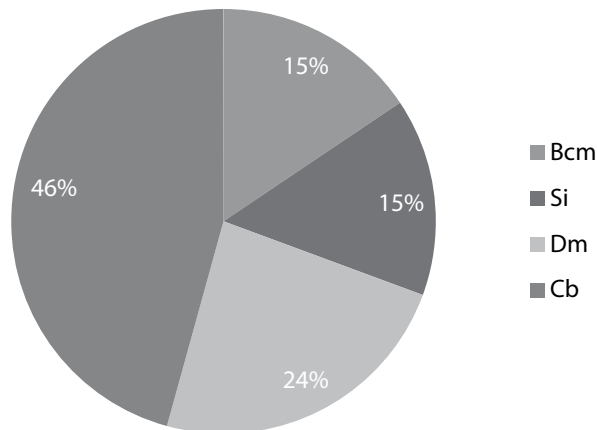


Figure 3 Results of the survey

believed data management as a contributor to improving HAZMAT practices. Of the remaining 30%, 15% gave importance to strengthening implementation and 15% to better co-ordination mechanism (Figure 3).

Hence, it is recommended that future efforts be driven towards greater capability building and infrastructure for HAZMAT management along

with more agile data management capabilities, to ensure sharing of information across the entire supply chain. Most respondents are also of the opinion that over the years the coordination mechanism between various HAZMAT agencies has significantly improved and there is adequate legal framework for ensuring proper implementation.

Impact of Odd–Even Scheme on Travel Pattern in Delhi

Palak Thakur^{a,*} and Sharif Qamar^a

Journal of Resources, Energy, and Development 17(1): 27–38

Introduction
The Problem of Air Pollution and
Solutions: Focus on Odd–Even
Scheme
Methodology
Findings
Conclusion
References

Abstract

The paper intends to assess the impact of the odd–even scheme on the travel pattern of the daily commuters in Delhi. The objective of the paper is to assess the impact of the odd–even scheme on mode choice for daily work trips, shift in travel patterns – before, during, and post-implementation – of the odd–even scheme, and to understand people perception regarding the odd–even scheme. Based on the primary survey, the paper concludes that the odd–even scheme brought a significant impact in the travel pattern in terms of occupancy, travel cost, travel time, and modal shift, and statistically not so much on the air quality gain. It was observed that the scheme helped increase the occupancy rate in cars as well as ridership of buses and Delhi metro. The scheme had a huge impact on congestion, which was evident from both perception analysis and the change in travel time. The modal shift, with an improvement in public transport services and a reduction in car users, is one of the key successes of the scheme resulting in decrease in air pollution caused by private vehicles. To improve the outcome of the odd–even scheme on air pollution, two-wheelers should not be exempted going forward.

Keywords: Odd–even, Delhi, Travel pattern, Congestion, Mode share, Air pollution

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Introduction

Significantly high levels of exposure to particulate matters are one of the key reasons for death in South Asia, including India (HEI 2019). As per the report released by the State of Global Air, 2019, $PM_{2.5}$ pollution contributed to nearly 3 million early deaths in 2017. More than half of this disease burden fell on people living in China and India. The causes and impact of measures undertaken by authorities to curb extremely high levels of particulate matters, especially in North India during peak season (October–February, 2019), continues to be fiercely debated amongst citizens, think tanks, and authorities each year. However, the situation has persistently deteriorated with the average ambient air quality index (AQI¹) levels registering three to four times higher than the standards set by the Central Pollution Control Board (CPCB).

As indicated in Figure 1, India's average PM_{10} has been consistently above the National Ambient Air Quality Standards (NAAQS) over the last two decades. As per CPCB, the average $PM_{2.5}$ level has been rising and remained above NAAQS during 2018. It is to be noted that NAAQS adopted by

India [40 micrograms (μg)/ m^3 for $PM_{2.5}$ and 60 $\mu g/m^3$ for PM_{10}] is much higher than the standards set by the World Health Organization (10 $\mu g/m^3$ annual mean for $PM_{2.5}$ and 20 $\mu g/m^3$ annual mean for PM_{10}) (WHO 2005). The key reasons contributing to the air pollution through the release of emissions in India include rapid urbanization, increasing dependence on road transport primarily running on conventional fuel, heavy reliance on biomass for cooking, industrialization, coal-based power generation, and agricultural activities. Some of the reasons are regional and some are location-specific issues, and, therefore, specific efforts could be undertaken and responsibilities could be fixed based on such classification.

Through this paper, the authors aim to understand the impact of odd–even schemes implemented by the Delhi Government, including people's perception of the scheme. The paper attempts to throw light on the impact of the odd–even scheme and its impact on air quality, as well as on traffic, congestion, and travel pattern and mode choice – in particular the shift towards public transportation.

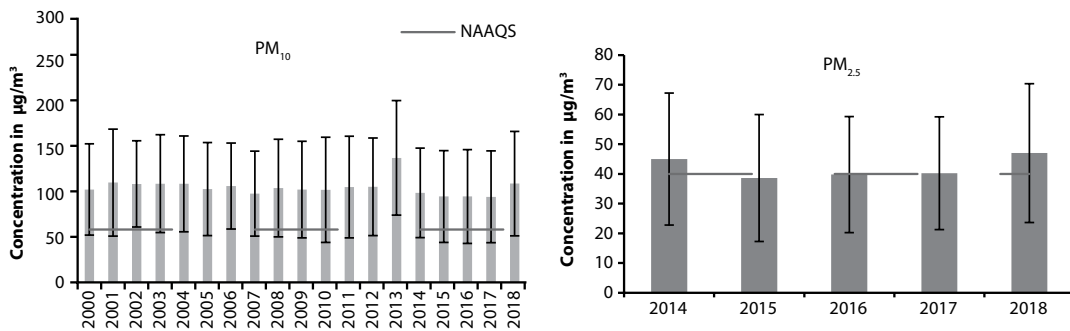


Figure 1 National average air quality index for PM_{10} and $PM_{2.5}$

Source CPCB

1 Air quality index is a tool which transforms complex air quality data of various pollutants into a single number (index value), nomenclature, and colour. There are six AQI categories, namely good, satisfactory, moderately polluted, poor, very poor, and severe. Air quality sub-index and health breakpoints are evolved for eight pollutants – PM_{10} , $PM_{2.5}$, NO_2 , SO_2 , CO , O_3 , NH_3 , and Pb . Details available at <https://cpcb.nic.in/displaypdf.php?id=bmFoaW9uYWwtYWlyLXF1YWxpdkHktaW5kZXgvQWJvdXRFQVFIJnBkZg>, last accessed on 28 November 2019

The problem of air pollution and solutions: focus on odd–even scheme

The winter season comes with deteriorated air quality and unhealthy living conditions in Delhi. Though meteorological conditions have shifted the burden of poor air quality to the neighbouring states of crop burning, intracity pollution sources such as transport, construction waste, and industries among others have been significant contributors to the poor air quality in Delhi all year round. As per TERI's Source Apportionment Study 2018, the average concentrations of $PM_{2.5}$ from monitoring sites of Delhi NCR in summer and winter seasons were 90 ± 17 mg/m³ and 168 ± 45 mg/m³, respectively. Though average concentrations of $PM_{2.5}$ are more than the prescribed standard limit by the CPCB all year round, however higher concentration is observed in the winter season (Figure 2). Amongst the sources within Delhi, the share of the transport sector is significant (39%) in $PM_{2.5}$ emissions. This reduces to 13% in the case of NCR due to the presence of other major sources such as road dust, industries, among others (ARAI and TERI 2018).

Based on the alarming air pollution trend, the Supreme Court approved the Graded Response Action Plan (GRAP) prepared by Environment Pollution (Prevention and Control) Authority (EPCA) in 2016. As per the GRAP, in the case of emergency or severe air pollution odd–even scheme comes into action. The odd–even scheme is a transport rationing mechanism, in which access to some resource is restricted to some of the population on any given day. In the case of Delhi, it is restricting the number of on-road private four-wheelers per day. As per the scheme, the cars were classified into odd and even categories based on the last digit of car license plates. Only vehicles with odd-numbered license plates could ply on odd-numbered dates and even-numbered plates on even dates. The scheme was effective during the hours of 8 am and 8 pm.

The odd–even scheme first came in place in 2016 when Delhi government announced a series of emergency measures (Government of NCT 2015). It was implemented for the first 15 days of January 2016. The second round of the odd–even scheme was implemented during the same year between April 15 and April 30. Thereafter, the odd–even scheme was not

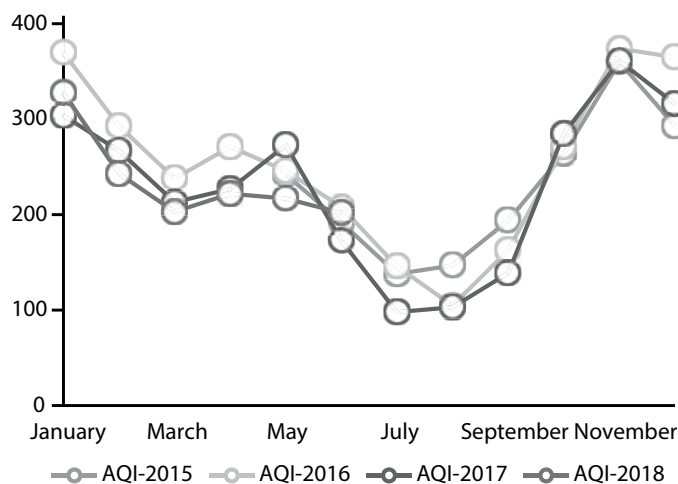


Figure 2 Delhi AQI showing spike during winters

Source CPCB

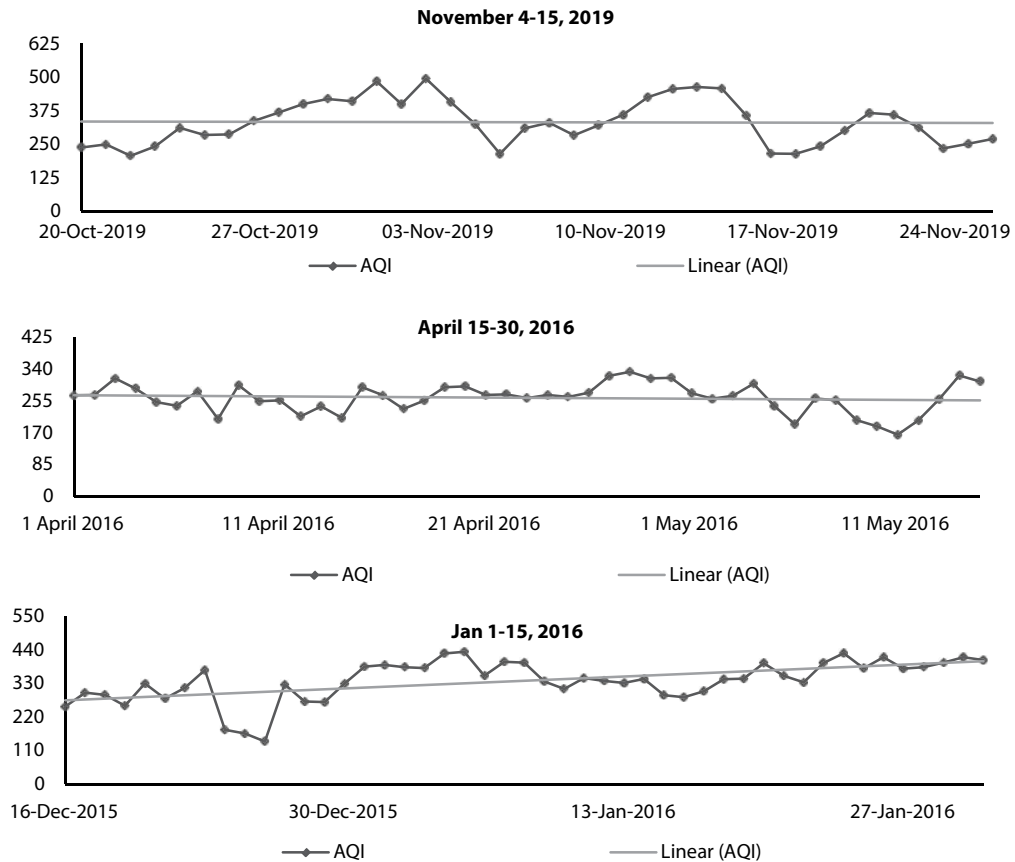


Figure 3 Impact of odd–even schemes on air pollution

Source CPCB

implemented during 2017 and 2018 even though the air quality deteriorated during the winter season. Delhi government's plan to implement odd–even scheme during November 13–17, 2017 was dropped when NGT questioned the decision of exempting women drivers and two-wheelers. Also, the issue related to inadequate public transport was raised by Delhi government in case two-wheelers are not exempted. Most recently, the scheme came into effect during November 4–15 in 2019 (Table 1). The impact of the odd–even scheme on air pollution as illustrated in Figure 3 is very limited.

Despite the limited impact on air pollution, on account of meteorological and crop residue burning conditions, the odd–even scheme has a huge effect on the travel pattern and behaviour of the daily commuters. A commuter survey was conducted by TERI, with the following objectives to assess/capture:

- Impact of odd–even scheme on mode choice for daily work trips
- Travel pattern before, during, and post-implementation of the odd–even scheme
- Perception of people regarding the odd–even scheme

Table 1 Key vehicles exempted during three phases of odd–even schemes implemented in Delhi

Odd–even phases	Key exempted vehicles
January 1–15, 2016	All private cars fitted with government-approved CNG kit and CNG stickers Electric vehicles and hybrid vehicles Women only vehicles, including children of age up to 12 years travelling with them Vehicles being used for medical emergencies (will be trust-based) Vehicles are driven/occupied by handicapped persons.
April 15–30, 2016	All two-wheelers, three-wheelers, and cars with commercial registration All private cars fitted with government-approved CNG kit and CNG stickers All government vehicles, including emergency, fire, police, embassy, defence ministry Women driving the car alone or with other women friends in the car Women driving the car with kids up to 12 years of age Cars carrying school children in uniform Vehicles with differently abled people
November 4–15, 2019	Women only vehicles including children of age up to 12 years travelling with them Electric vehicles Vehicles with differently abled people Vehicles exclusively carrying child/children in school uniform in addition to the driver All government vehicles including emergency, fire, police, embassy, defence ministry All two-wheelers, three-wheelers, and commercial vehicles

Source Transport Department, Delhi

Methodology

The methodological approach adopted to achieve the above-mentioned objectives is listed here.

The demand for mobility in Delhi soared to an all-time high spurred by population growth, economic development, and urbanization. There has been a rise in the per capita trip rate (excluding walk trips) from 0.72 in 1981 to 0.87 in 2001 and exponentially more in 2019 (MoUD, GoI, 2016). This translates into an increase from 45 lakh trips in 1981 to around 118 lakh trips in 2001 and 144 lakh trips till 2008. The choice of these trips and their travel patterns are immensely impacted by the available choice set, the purpose of the trip, part of the city, travel time, age of commuter, and weather conditions. Thus, the variables are defined first to study the impact on mode choice.

Choice set: The mobility demand is catered by non-motorized modes, private and public transport with mode share of 40%, 24%, and 36%, respectively (MoUD, GoI 2016). Thus, a daily commuter in Delhi making his or her work trip has a choice set of the metro, bus, suburban train in the public transport category, auto-rickshaw in the intermediate public transport category, car/taxi and two-wheelers in the private mode category, and walking, cycling, and cycle rickshaw in non-motorized mode category. Thus, the above-mentioned modes are used as choice set in the survey.

Trip purpose: The paper intends to capture only daily work trips within the schedule during which the odd–even scheme was implemented, i.e. 8 am to 8 pm.

Part of the city: The survey captured commuters who travelled daily within Delhi, including those travelling from NCR for their work trips.

Sampling: As per MoHUA 2016, about 220 lakh daily trips were made in Delhi. Out of which, 70% is assumed to be work trips – about 154 lakh which are being targeted to be captured in the survey. Empirically a minor but significant sample can signify the larger pool from which it is extracted.

The following formula was employed to assess the sample size:

Based on the Cochran formula for sample size calculation, the following sample size is estimated:

$$n = \frac{n^o}{1 + \frac{(n^o - 1)}{N}} \quad n^o = \frac{pqZ^2}{e^2}$$

where, n^o is Cochran's sample size recommendation, N is the population size, n is the new, adjusted sample size, e is the desired level of precision (i.e. the margin of error is 5%), p is the (estimated) proportion of the population which has the attribute in question, q is $1 - p$. For 95% confidence level, Z value is 1.96.

Based on the above formula, the estimated sample size is 384 trips.

Outcomes: Impact on travel time and choice of mode are captured. Change in travel patterns in terms of peak hour changes and the modal shift is analysed. Perception analysis based on the impact is captured.

Findings

The online targeted survey was conducted from 4 November to 20 November 2019. In total, the authors received 469 responses to the survey questionnaire.

Respondent's characteristics

Gender: Out of the total 269 respondents, 71% were male and the remaining were female.

Age: In the age category, around 76% of the respondents were in the age group of 18–45 years, while 21% and 3% were in 45–60 years and above 60 years categories, respectively.

Educational qualification: Around 76% of the respondents were postgraduate and 20% and 4% were graduates and others, respectively.

Monthly income: A composite of 2%, 17%, 33%, and 48% was observed with respondents with no income or less than Rs 10,000, with income group of Rs 10,000–40,000, with income group of Rs 40,000–80,000, and above Rs 80,000, respectively.

Vehicle ownership: Amongst the total respondents, 24% had no car and 58% had one car. Further, 16% and 2% of the respondents were observed owning two cars and more than two cars, respectively. For two-wheelers, 67% of the respondents had no two-wheelers while 29% and 4% of the respondents owned one and more than one two-wheelers, respectively.²

Private vehicle usage: Out of the total respondents 56% use private vehicles for their daily work-related commute. Amongst the 56%, 92% were car owners and 7% were two-wheeler users, while the remaining 44% of the respondents did not use any private vehicle.

Vehicle characteristics

Amongst the private vehicle users, the following vehicle characteristics were observed:

Age of the cars: Of the total car users, about 64% owned relatively new cars with an age of less than 5 years. About 32% and 4% of the car users had cars in the age group of 5–10 years and more than 10 years, respectively.

Fuel type: A fuel mix of 68%, 23%, 5%, and 4% is observed for fuel-type petrol, diesel, CNG, and CNG-petrol, respectively.

Number plate: Around 51% of the people had vehicle registration numbers ending with even number, while 45% of the respondents had vehicle registration numbers ending with odd numbers. The remaining 4% of the respondents stated both number plates – indicating ownership of multiple vehicles.

² This include users with more than one car irrespective of their number plate.

Travel characteristics: before the odd–even scheme

Average occupancy: Around 61% of the car users reported single occupancy and 29%, 6%, and 4% observed occupancy rate of two, three, and four passengers, respectively. The average occupancy of car users before the odd–even scheme is estimated to be 1.52 (Figure 4).

Average daily km: Around 57% of the

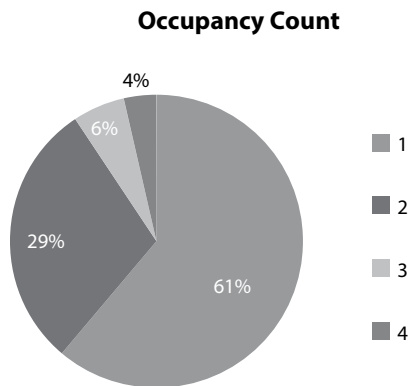


Figure 4 Occupancy count

Source Primary Survey

respondents travel more than 20 km with 26% travelling more than 40 km (Figure 5). About 36% of the commuters travelled 5 to 20 km daily, with 24% of the trips catering 10–20 km. More than 67% of the car users travel more than 20 km daily. Around 27% each two-wheeler users travel 5–10 km and 20–14 km daily. Around 30% of the non-private users travel 20–40 km daily (Figure 6).

Average daily cost of travel: On average 38% of the daily commuters spend Rs 100–200 on daily commuting. Around 32% of the daily commuters spend more than Rs 200–400, amongst which 7% spend more than Rs 400. Around 22% and 8% of the daily commuters spend between Rs 50 and Rs 100 and less than Rs 50, respectively. Around 70% of the car users spend between Rs 100 and Rs 400 for their daily travel. Around 45% of the two-wheeler users spend between Rs 50 and Rs 100. Around 40% of the non-private transport users spend between Rs 100 and Rs 200 (Figure 7).

Peak hours: A morning peak hour from 9 am to 9:30 am was observed and a staggered evening peak hour from 5 pm to 7:30 pm was observed.

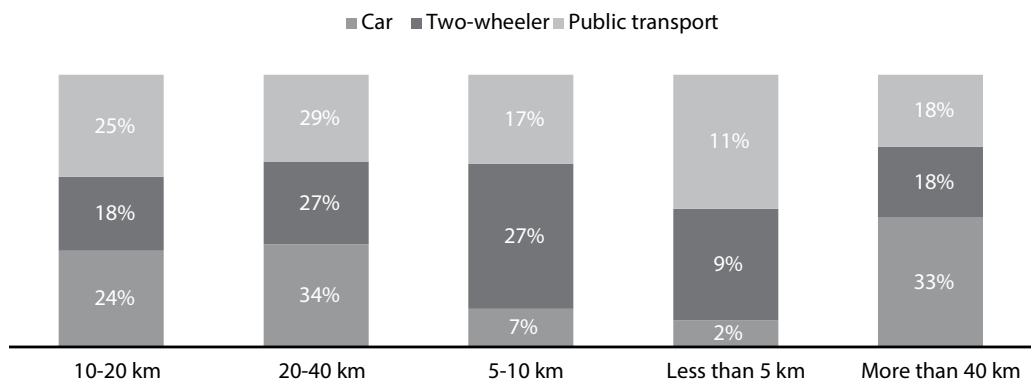


Figure 5 Mode-wise average daily km travelled

Source Primary Survey

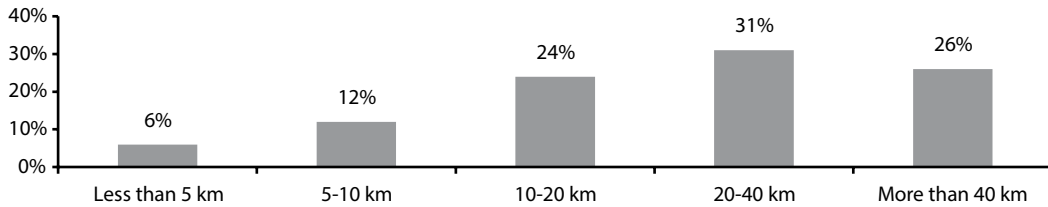


Figure 6 Average daily km travelled

Source: Primary Survey

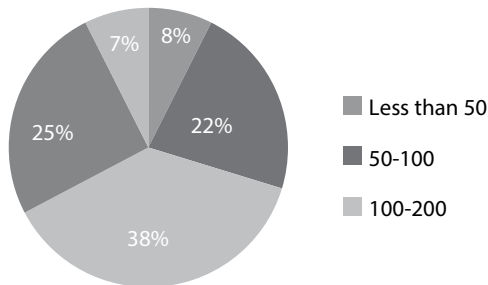


Figure 7 Travel cost

Source: Primary Survey

Mode share: The mode share of the sampled population was observed to be 61% of the car users and 21% of the metro users (Figure 8).

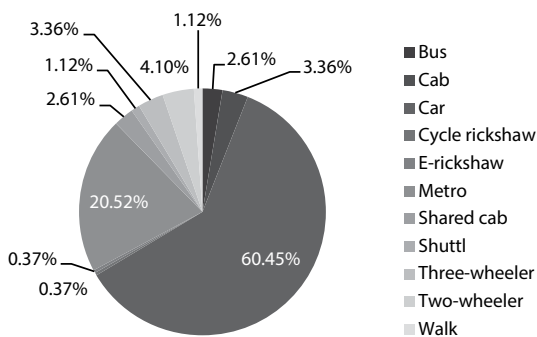


Figure 8 Mode share before odd-even

Source: Primary Survey

Travel characteristics: during the odd-even scheme

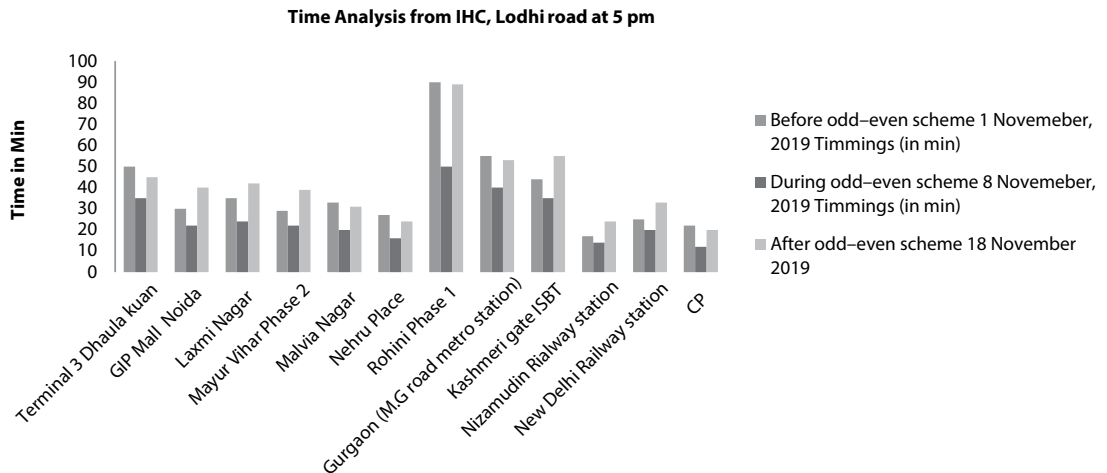
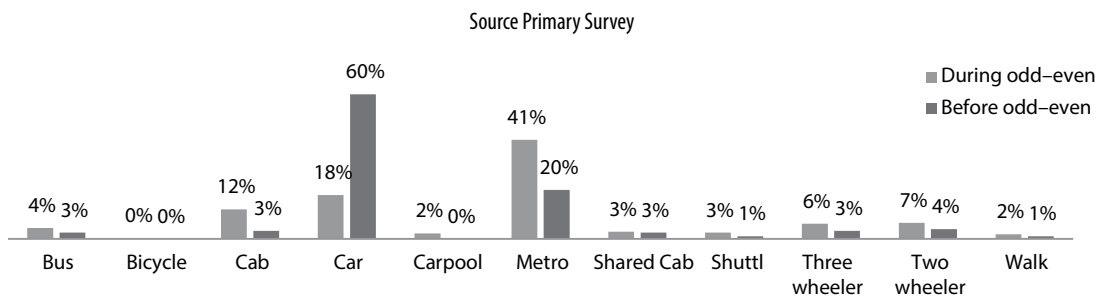
The implementation of the odd-even scheme had a significant impact on travel characteristics, reduction in travel time, and travel costs.

Average occupancy: It was indicated that among the car users, 2% opted for carpool. Though it was not a very significant number yet efforts to increase the occupancy were evident, especially by the long-distance respondents.

Time analysis: The authors undertook a very basic analysis to understand the difference in travel time – before, during, and after the odd-even scheme. A particular day and time during the three phases were selected and travel time on Google map was recorded for 12 origin-destinations. A time saving of 12 min and 25 seconds was observed during the odd-even scheme (Figure 9).

Mode share shift: Before the odd-even scheme, 61% of the respondents used cars, while only 18% of the respondents used cars during odd-even scheme. An increase of 21%, 9%, and 3% was observed among the metro, cab, and two-wheeler users, respectively. A slight increase of 1% and 3% was also observed in the bus users and shuttle users. About 58% of the respondents expressed willingness to continue with the mode used during the odd-even scheme (Figure 10).

Daily cost: It was indicated that more than 55% of the respondents had no change in travel costs. However, a small yet significant percentage of 16% indicated a reduction in their travel cost and 28% expressed an increase in amount.

**Figure 9** Travel time reduction**Figure 10** Modal shift

Source Primary Survey

Perception analysis

The survey findings indicate improvement in traffic congestion and a reduction in travel time. However, the perception of commuters varies concerning the benefits and inconveniences related to the implementation of the odd–even scheme. The inconveniences faced by most of the public transport users were overcrowding of

public transport, inadequate public transport, and lack of affordable first/last mile connectivity modes. The inconvenience to time and cost had mixed responses with around one-fourth of the commuters strongly agreeing with the higher travel cost and increased travel time on account of using other modes (Figure 11).

In terms of commuting experience, about 90% of the people agreed that there was a reduction in traffic during odd–even scheme. More than two-thirds of the survey respondents agreed with the reduction in travel time. For travel cost, the mixed response has been observed – 27% of the people agreed to availability of affordable travel options during the scheme while 30% have a neutral response and 42% disagreed. This could be because the respondents might have

shifted to the costlier cab hiring option for their travel demand during odd–even scheme. For those using the metro, it would have resulted in a costlier option because of the first/last-mile connectivity issues. Similarly, the mixed response has been observed for air quality – around 30% of the people disagree with better air quality, 20% had neutral response, while approximately 50% agreed that the air quality had improved (Figure 12).

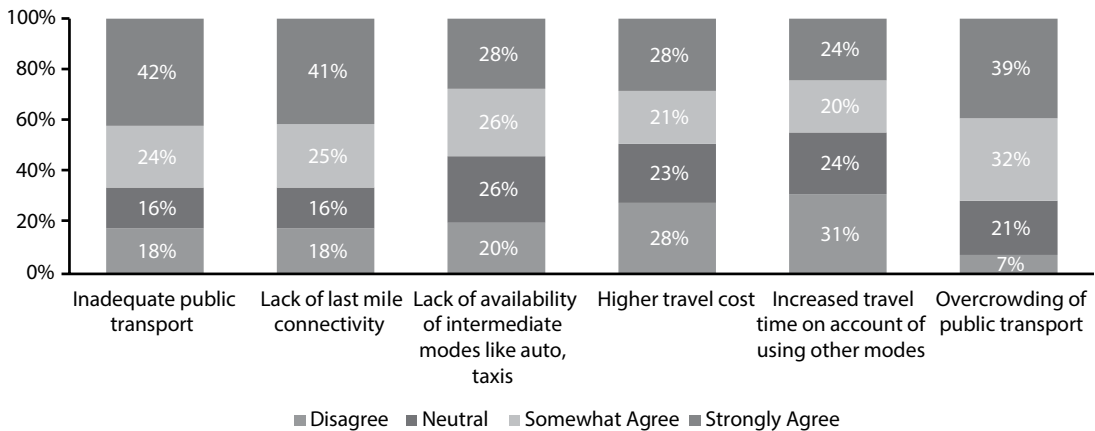


Figure 11 Perception analysis of inconveniences faced during scheme

Source Primary Survey

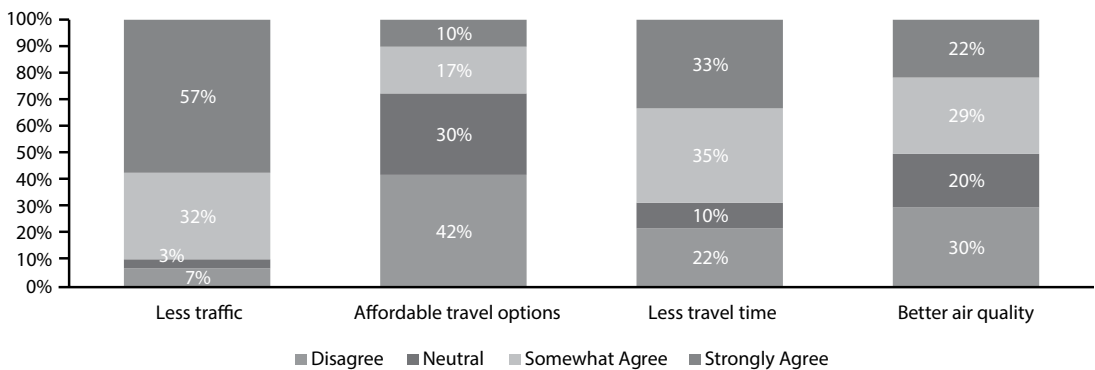


Figure 12 Perception analysis of benefits of odd–even scheme

Source Primary Survey

Conclusion

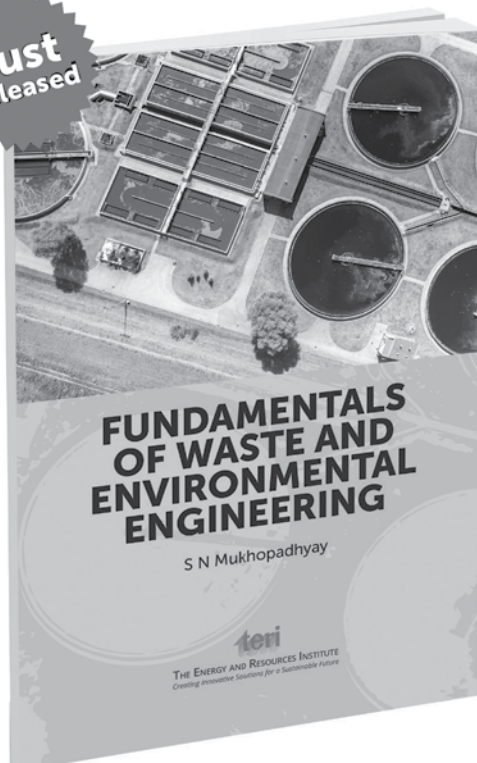
To sum up, the paper concludes that the odd–even scheme brought significant impact in the travel pattern in terms of occupancy, travel cost, travel time and modal shift, and statistically not so much on the air quality gain. It was observed that the scheme helped increase the occupancy rate in cars as well as ridership of buses and Delhi metro. The scheme had a huge impact on congestion, which was evident from both perception analysis and the change in the travel time. The modal shift, with an improvement in public transport services and a reduction in car users, is one of the key successes of the scheme resulting in decrease in air pollution caused by private vehicles. To improve the outcome of the odd–even scheme on air pollution, two-wheelers should not be exempted going forward. Furthermore, to create a more lasting impact of the scheme carpooling should be promoted.

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Commentary

Analysing Nexus between Economic Growth, GHG Emissions, and Energy Consumption for India

Paribha Vashista^a and Sunil Sharma^b

Journal of Resources, Energy, and Development 17(1): 39–44

Introduction

In 2016, India ratified the Paris Agreement and committed to the objective of reducing emissions intensity (ratio of emissions per unit of product) of its gross domestic product (GDP) by around 33–35% by 2030, compared to the 2005 emissions level. India's ultimate aim is to achieve its nationally determined contributions (NDCs), which refer to the intended reductions in greenhouse gas emissions under the United Nations Framework Convention on Climate Change (UNFCCC). In order to meet this goal, it has embarked on a plan to convert 40% of its installed power-generation capacity to non-fossil-fuel-based.¹

As a pioneering force under the leadership of PM Narendra Modi, India initiated the International Solar Alliance, which is an association of 121 'sunshine countries' with the primary objective of working towards efficient exploitation of solar energy to reduce the overall dependence on fossil fuels.² In addition to this, the Government of India has set a target to achieve 175 GW of installed renewable energy capacity by the end of 2022, with a 100 GW target for solar installations specifically. In this 100

GW target, a 40 GW target was set for installed rooftop solar capacity, out of which only 4.4 GW has been achieved as of December 2019.³

In the context of this target and the critical need to control emissions, the paper will focus on highlighting the various socio-economic and environmental benefits that accompany rooftop solar deployment, the important challenges that need to be urgently addressed to facilitate large-scale rooftop solar adoption, and the unique ways in which these impediments can be addressed.

Case for Rooftop Solar Adoption

1. *The importance of promoting rooftop solar*

There is a need to encourage the adoption of rooftop solar (RTS) primarily because it will help in considerably reducing greenhouse gas (GHG) emissions. It also has several advantages over large solar plants, such as zero land and additional transmission capacity cost, better management of peak demand and Capex deferral for utilities, reduction in transmission and distribution costs as less volume of electricity is carried and is instead utilized at the load end itself, and so on.

^a Sanskriti School, New Delhi

^b BSES Yamuna Power Limited, New Delhi

¹ <https://economictimes.indiatimes.com/industry/energy/power/india-targeting-40-of-powergeneration-from-non-fossil-fuel-by-2030-pm-modi/articleshow/66043374.cms?from=mdr>

² <https://www.isolaralliance.org/>

³ <https://energy.economictimes.indiatimes.com/news/renewable/indias-rooftop-solar-capacity-reached-4-4-gw-in-2019-report/74208295>

Besides being an eco-friendly source of electricity, RTS is able to contribute towards job creation, which seems very lucrative for a nation where unemployment is a serious challenge.

Rooftop solar power, being more labour intensive than other renewables, has a potential to provide 24.72 job-years per MW in comparison to 3.45 job-years per MW for ground-mounted solar power and 1.27 job-years per MW for wind power, according to a June 2017 report titled 'Greening India's Workforce: Gearing up for Expansion of Solar and Wind Power in India'.⁴

Moreover, a team of researchers at UC San Diego Jacobs School of Engineering led by Professor Jan Kleissl pointed out in a study that a building's ceiling is up to 5 degrees Fahrenheit cooler under an array of solar panels than under an exposed section of the roof. They also suggested that the panels could help keep heat inside the buildings at night during winters.⁵ This research study sheds light on the advantages of thermal effects of RTS.

India realizes that there are several socio-economic and environmental benefits accruing out of RTS adoption and the COVID-19 pandemic has further accentuated that the 'business as usual' model based on a linear economy will fail to work in the long-run. Instead, the need of the hour is to adopt a resource-efficient circular economy model and embrace collaborative solutions aiming at sustainable development. The large-scale adoption of solar rooftop is one such step in that direction. However, there are certain obstacles that need to be overcome to facilitate the transition to this clean energy source. Some major challenges have been discussed in the subsequent section of this article.

2. *Challenges that need to be addressed to provide a fillip to rooftop solar deployment*

The expense of storage batteries is a prime concern and has been a deterrent to large-scale solar deployment for a long time. But

analogous to how the price of solar panels has plummeted over time and the number of solar installations has skyrocketed due to research and development, learning by doing, and economies of scale, it can be safely assumed that the price of storage batteries, especially lithium ion batteries, will considerably reduce in the future if due importance is given to cost reduction.

The passive role of the electricity distribution companies (DISCOMs) in the implementation process for solar rooftop, especially in government-owned entities, is also often considered as a serious reason behind the slow growth of the RTS sector. But DISCOMs can play a significant role in accelerating the growth of the RTS sector as they are at the tail end of electricity supply chains and constitute a crucial link with the consumers. However, most DISCOMs are not able to realize their maximum potential and are, therefore, unable to effectively promote rooftop solar, as they suffer from high financial losses due to poor operational practices, irregular peak demand patterns leading to haphazard network augmentations and lack of planning, poor grid infrastructure, billing inefficiency, delays in the disbursement of state subsidies, and electricity thefts. In this context, the increase in RTS deployment exacerbates the concerns that DISCOMs have over the anticipated revenue losses. Moreover, since RTS systems provide a cheaper alternative over grid-supplied electricity to high-paying commercial and industrial consumers who cross-subsidize low-paying residential and agricultural consumers, there is a high probability that the DISCOMs will lose their best-paying or prime consumers, thereby losing an important revenue source that could possibly ameliorate their poor financial condition and this factor is more relevant in state-owned utilities as highlighted in a report by the Council on Energy, Environment, and Water (CEEW). Also, since the cross-subsidy burden is passed on to the non-

⁴ <http://www.indiaenvironmentportal.org.in/files/file/CEEW%20NRDC%20-%20Greening%20India's%20Workforce%20report.pdf>

⁵ https://www.researchgate.net/publication/251496714_Effects_of_solar_photovoltaic_panels_on_roof_heat_transfer

solar consumers as well, they too may have to bear a higher electricity tariff rate if penetration of RTS increases.⁶

DISCOMs have identified that the lack of consumer awareness about the benefits and procedures of RTS adoption and capacity building of the DISCOM personnel on various aspects of solar rooftops, such as grid management, solar technologies, and business models are also significant obstacles that need to be appropriately dealt with. At the Distribution Utilities Forum (DUF) organized by The Energy and Resources Institute (TERI) in February 2019, the DISCOM representatives highlighted the problems associated with the RESCO business model, specifically emphasizing the concern that the risk of the RESCO business model lies solely on the developer, instead of individual consumers or residents.⁷

The COVID-19 lockdown has only further added to the woes of the DISCOMs. In April 2020, the 'India Rating and Research' agency reported that the DISCOMs would be facing a negative impact on their collections and cash flows owing to a decrease in demand from industrial consumers, an increase in aggregate technical and commercial (AT&C) losses, and their dependence on direct collections from consumers instead of subsidies.⁸

However, there are several advantages that the RTS system offers to the DISCOMs, which, unfortunately, have not been properly quantified in the Indian context. These have been highlighted in the following section along with potential steps to be taken to address the aforementioned concerns.

3. *Solutions to address the challenges in rooftop solar adoption*

In spite of the challenges, the adoption of rooftop solar is a crucial requirement from an

environmental and socio-economic standpoint. Several solutions have therefore been suggested to overcome the deterrents in the path towards rooftop solar adoption. There is a greater need for DISCOMs to conduct power flow simulation studies in order to assess the impact of increased penetration of rooftop solar on the distribution network and the means of mitigation. DISCOMs also need to be entrusted with a special role by the Central and State Governments. They should not only promote RTS in their license area but also empower them to enable regulatory interventions and customized business models as that would allow RTS to grow as a profitable venture. The main focus should be to formulate a strategy that effectively strengthens the financial position of the electricity distribution companies. Creating awareness amongst the masses is also vital as they lack basic knowledge on rooftop solar. The 'Master Plan' for rooftop solar implementation prepared by TERI, which was approved by the MNRE in 2012, and was being pushed forward by the Chandigarh Renewable Energy and Science & Technology Promotion Society (CREST), has been successfully able to do so through e-media, newspapers, solar camps, and door-to-door campaigning. The government also has an important role to play in reducing the potential losses to the DISCOMs and in providing a level playing field to the stakeholders (consumers and DISCOMs) to ensure that it is a win-win situation for the parties involved.⁷

In the current scenario, the BSES Yamuna Private Limited (BYPL) – a DISCOM having a 200 km² operational area in the Eastern and Central parts of the National Capital – does not foresee any significant impact on the revenue side as rooftop penetration and subsequent energy generation is quite low. However, in the foreseeable future, RTS would help BYPL

⁶ <https://www.ceew.in/publications/valuing-gridconnected-rooftop-solar-framework-assess-cost-andbenefits-discoms>

⁷ https://www.teriin.org/sites/default/files/2019-08/DUF_Solar-Rooftop.pdf

⁸ <https://energy.economictimes.indiatimes.com/news/power/covid-19-impact-turbulent-times-for-powerdistribution-sector/75420652>

in managing peak demand and network augmentation efforts as its license area has a very high consumer density and there is very little space for augmenting the network. Hence, it can be inferred that the impact on the DISCOMs' finances would vary from state to state depending on the amount of solar rooftop penetration, consumer mix, network topology, levels of cross-subsidy, and other pressing needs.

A report by the Council on Energy, Environment, and Water (CEEW) also highlights the importance of RTS system installations in balancing demand at peak and off-peak hours, decongesting the distribution network, avoiding energy procurement from expensive generators, fulfilling renewable purchase obligations (RPOs), and significantly decreasing transmission and distribution losses. RTS reduces dependence on grid power, diesel generators, and is a long-term reliable power source for consumers (see Footnote 6).

In recent times, the role of DISCOMs has increased. The MNRE has made them responsible for their actions in increasing the RTS adoption. DISCOMs have been given the charge to develop a dedicated online portal for transparent consumer approvals. Additionally, they are expected to head consumer awareness and publicity drives for the success of the programme.

Subsidies are now available to all eligible households, which as per Phase-II of MNRE's rooftop solar programme is 20% or 40% of the project cost depending on the capacity.

This initiative by the government will surely motivate the consumers to go for RTS and DISCOMs will also be able to get renewable energy at reasonable rates to meet their RPO requirements. The Ministry has also highlighted some innovative business practices adopted by DISCOMs, including the RESCO (Renewable Energy Service Company) model, credit risk

mechanism and demand aggregation, which will further help in the implementation of this programme.⁹

Understanding this and to further promote rooftop solar through the RESCO model, BYPL is facilitating the implementation of systems through novel models and partnerships with RESCO players to mitigate project risk. Additionally, with the introduction of Group Virtual Metering and Virtual Net Metering as in Delhi, consumers who do not have access to rooftop space would also be able to gain from it.

Furthermore, there is a need to promote rooftop installations in the commercial and industrial sectors, with the focus on agro-based industries and MSMEs, since they receive subsidized electricity from the DISCOMs and, thus, the adoption of RTS by this segment will not significantly impact the finances of the DISCOMs. For this reason, it is crucial for the various governmental departments, financial institutions, environmental agencies, and DISCOMs to converge to develop path-breaking plans to promote rooftop solar in the small industries as the MNRE Phase-II programme focuses on the residential sector only. BYPL, in collaboration with GIZ India, took a lead in this direction by organizing a focused campaign for industrial units to go solar rooftop.

Among the other challenges the issue of addressing the economic viability of solar systems is under major consideration at a global level. Rooftop solar has an advantage in this regard as the installation of a battery that operates while directly connected to the grid (as in the case of RTS) is much cheaper than the installation of a battery that typically operates off-grid.

The investment challenge in RTS adoption is gaining attention of the government and banks. In Lakshadweep, the government has laid down favourable policies, subsidies, and incentives to

⁹ <https://www.bloomberquint.com/re-invest-2018/growth-of-rooftop-solar-in-india-opportunitieschallenges-and-way-forward>

promote solar adoption. These include exemption from banking charges, wheeling charges, and cross-subsidy surcharges to the solar users, and the option to take a loan of up to 10 lakh for solar system installations under the Priority Sector lending.¹⁰ Moreover, in 2017, the State Bank of India, under the World Bank-funded capacity development programme, committed to financing rooftop projects worth Rs 400 crore, which would add at least 100 MW of solar rooftop capacity to the grid while driving down the cost of financing substantially and leveraging the latent strength of the nascent rooftop solar market.¹¹

Conclusion

Rooftop solar, being a sustainable and low carbon energy source, requires scaling up to ensure that a substantial amount of world energy demand

is met over the century and the process of decarbonization is largely successful. However, there are various pressing challenges that need to be overcome. These include the expense of storage batteries and the passive role of the financially weak DISCOMs in the rooftop solar implementation, which has further exacerbated due to the COVID-19 economic slowdown.

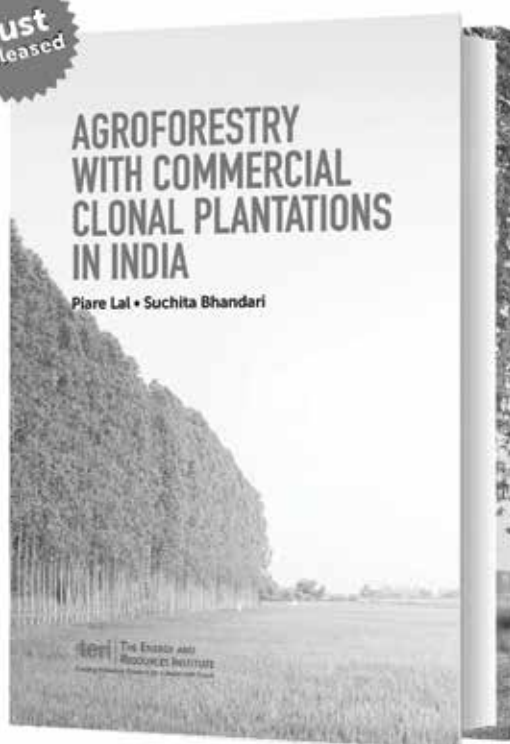
Thus, disseminating the right information about RTS systems, providing special loans and subsidies as incentives, increasing investments in solar technology research, and developing and implementing innovative business models, will certainly help India in overcoming the bottlenecks in the attainment of its 40 GW of RTS installations target by 2022 and ultimately emerge as a 'green energy leader' in the global economy.

¹⁰ <https://economictimes.indiatimes.com/small-biz/productline/power-generation/solar-policiesubsidies-and-other-incentives-for-the-installationof-solar-rooftop-systems-in-lakshadweep/articleshow/71505097.cms?from=mdr>

¹¹ <https://www.worldbank.org/en/news/press-release/2017/06/02/state-bank-ofindia-approves-100mw-grid-connected-rooftop-solarprojects-under-word-bank-program>

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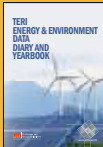
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