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Original Article

The Influence of Air Pollution and Clean Energy on Tuberculosis: The Moderating Role of Urbanization

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Abstract

Background: Air pollution is one of the major threats to human health and well-being. This study aimed to explore the effect of renewable energy consumption and carbon dioxide emissions on tuberculosis (TB) incidences. It further investigates the moderating role of urbanization on the relationship between underlying factors and TB.

Methods: The data of 183 countries over the period 2000 to 2014 were collected and a two-step system GMM technique was utilized to reduce the endogeneity issue. Additionally, we divided the sample into two sub-panels based on country risk for more robust estimates.

Results: Carbon dioxide emissions increase the incidences of TB while renewable energy consumption could restrict these cases. On the other hand, urbanization is positively associated with TB in high-risk. System-GMM estimates also indicated that urbanization further strengthens the positive association between CO_2 emissions and tuberculosis.

Conclusion: Climate-friendly energy technologies, surveillance, and adequate city planning can act as effective mechanisms to improve public health.

Keywords: Renewable energy consumption; CO_2 emissions; Urbanization; Tuberculosis; System-GMM technique

Introduction

Air pollution occurs when toxic substances including biological molecules, particulates, and gases are introduced into the earth's atmosphere. The majority of these pollutants emerge from the burning of fossil fuels (gasoline, natural gas, oil, coal) to produce electricity or power-related projects. Exposure to these pollutant emissions substantially triggers respiratory morbidity and mortality (1). They lead to several cardiovascular and chronic lung diseases including emphysema, chronic obstructive pulmonary disease, lung cancer, and asthma (2-3). Certain neurotoxic ambient air pollution may also elevate the hazards of neonatal neurological disorders (4). Prolonged exposure to toxic emissions adversely affects labor productivity which may also restrict the overall economic growth of a country (5).

Likewise other public health catastrophes, prior studies have also observed that environmental degradation instigated by air pollution is also linked with the high prevalence of Tuberculosis. Tuberculosis (TB) is an epidemic airborne respiratory disease caused by mycobacterium tuberculosis, which is affecting almost 1.7 billion inhabitants of the earth (6). It is a serious infectious disease that affects the lungs and spread through coughs or sneezes from one person to another. Tuberculosis can be spread into other human organs including skin, intestines, sexual organs, urinary tract, and bones. A wide range of studies has manifested an association of indoor (7) and outdoor air pollution with TB (8-9). Pollutant emissions are directly associated with the progression of TB as they weaken the overall immune system and deteriorate the macrophage function, epithelial permeability, and airway resistance (10). We develop a parsimonious model and utilize a substantially large panel data to provide more robust estimates in this regard.

Urban areas in developing countries are more exposed to air pollution and they have shouldered more burden of lung cancer and respiratory diseases as a result of environmental degradation (11). Industrialization in urban areas and rural poverty have increased the pace of urbanization. However, the hysterical and unplanned shift of population from rural to urban areas brings several social, economic, ecological, and health-related issues. Prior studies provide evidence against rampant urbanization as it gives rise to air pollution and accordingly leads to different communicable and non-communicable diseases (12). Accordingly, studies found higher incidences of TB due to overcrowded high-density populations in both Asian (13) and West European cities (14). Thus, we also hypothesized that urbanization strengthens the positive association between pollutant emissions and tuberculosis.

Energy sectors have recognized the essence of environmental protection for future generations and are developing clean technologies to generate energies for long-term sustainability. Accordingly, renewable energy resources (e.g. biomass, geothermal energy, hydroelectric power, wind power, solar energy, etc.) are in the limelight as they reduce several health issues emerge from the air pollution (15). These energy sources improve public health, produce inexhaustible energy, stabilize energy prices, and contribute effectively to economic development (16). Additionally, the global warming emissions linked with renewable energy are minimal even when including the “life cycle” emissions of clean energy (17). Considering that renewable energy consumption improves public health, it can also reduce the incidences of tuberculosis in a country.

Governments are enforced to meet energy demands using non-renewable energy resources with an increase in urbanization. Thus, Salim and Shafiei (18) found a positive association between non-renewable energy consumption and urbanization. Although there is no prior empirical evidence, this study posits that urbanization weakens the negative association between renewable energy consumption and tuberculosis. Along with the aforementioned conceptual contribution, we also consider a comparatively large panel of countries and estimate them with a dynamic system-GMM panel model. The dynamic system-GMM panel data technique allows researchers to mitigate several statistical issues including the problem of endogeneity (19). High-risk developing countries have laxer environmental standards and more health issues compared to low-risk countries. Therefore, two sub-panels were developed (low-risk and high-risk countries) for more robust estimates.

We aimed to explore the effect of renewable energy consumption and carbon dioxide emissions on tuberculosis (TB) incidences along with the moderating role of urbanization.

Methods

Operational Model and Estimation Procedure

An empirical model was developed to investigate the moderating effect of urbanization on the relationship between renewable energy consumption, carbon dioxide emissions, and tuberculosis. The statistical model is described below:

$TUB_{it} = \alpha_0 + \alpha_1 RENEW_{it} + \alpha_2 CO2_{it} + \alpha_3 URB_{it} + \alpha_4 RENEWURB_{it} + \alpha_5 CO2URB_{it} + \varepsilon_i$ …... (Eq. 1)

Where TUB represents tuberculosis, REWEW=Renewable energy consumption, CO2=carbon dioxide emissions, URB=urbanization, RENEWURB= interaction

of renewable energy consumption with urbanization and CO2URB=interaction of carbon dioxide emissions with urbanization. The subscript i (i = 1, …, N) indicates a panel of countries with N being equal to 183 while t (t = 1, …, T) denotes time period. ε is the error term.
We utilized the system-GMM technique to reduce the endogeneity and omitted variables biases. Endogeneity can be detected when the lagged dependent variable is also an explanatory variable (20). The empirical model for system-GMM is as follows:

$TB_{it} = a_0 TB_{i,\ t-1} + \sum_{j-1}^{8} \beta X'_{it} + \mu_{it} + \varepsilon_{it}$ …………………………………………………… …… (Eq. 2)

i = 1, …, 183; t = 2000, …, 2014

X is a vector of core explanatory variables used to model criterion variable and μ is the country-specific effects.

Statistical Analysis
Data and Methodology

We retrieved the data of tuberculosis (incidence of tuberculosis per 100,000 people), renewable energy consumption (percentage of total final energy consumption), carbon dioxide (metric tons per capita), and urbanization (percentage of urban population). Since the data of tuberculosis is available from the year 2000 while the data of CO_2 emissions is available up to 2014, the time-series was restricted from 2000 to 2014. Missing data were discarded from the dataset and accordingly, the global panel consists of 183 countries. However, we further divided this large panel into sub-panels based on their country risk to evaluate more robust estimates. We categorized 50 countries in the low-risk panel while 133 countries in high-risk panel (21). The method of Im et al. (22) was utilized to perform the panel unit root test.

Results

All variables were stationary due to which all of them were retained in their level form (Table 1). The influence of explanatory variables on tuberculosis varies across panels (Table 2). There was an insignificant influence of lagged TB across all panels (β = 1.33, *P*>0.1; β=0.84, *P*>0.1; β=1.27, *P*>0.1), therefore, the endogeneity issue was mitigated by system-GMM technique. There was a negative effect of renewable energy consumption (β=-0.54, *P*<0.1; β= -0.45, *P*<0.05; β= -0.51, *P*<0.1) while positive effect of carbon dioxide emissions (β=0.04, *P*<0.05; β=1.32, *P*<0.05; β=0.09, *P*<0.1) on tuberculosis across all panels. The impact of urbanization on TB was positive and statistically significant (β=0.003, *P*<0.1) in high-risk countries only. This relationship was insignificant in low-risk countries (β= 0.04, *P*>0.1) and global panel (β=0.06, *P*>0.1).

Table 1: Panel unit root test

Variable	*High Risk*		*Low Risk*		*Global*	
	Statistic	Prob.	Statistic	Prob.	Statistic	Prob.
Tuberculosis	-0.882*	0.002	-1.054*	0.000	-0.614*	0.003
Renewable Energy Consumption	-1.688*	0.000	-1.838*	0.000	-2.607*	0.000
CO_2 Emissions	-1.782*	0.000	-0.550*	0.002	-1.428*	0.000
Urbanization	-1.936*	0.001	-0.385*	0.000	-2.112*	0.002
RENEWURB	-3.201*	0.001	-1.232*	0.001	-2.162*	0.000
CO2URB	-3.703*	0.000	-2.669*	0.003	-1.264*	0.001

*Statistical significance at the 1% level

In the case of interaction terms, the results showed no significant moderating effect of urbanization on the relationship between renewable energy consumption and TB (β= -0.12, *P*>0.1; β= -0.13, *P*>0.1; β=-0.26, *P*>0.1) in all underlying panels. However, the moderating role of urbanization on the association between carbon dioxide emissions was statistically significant and positive in high-risk countries (β=1.30, $P<0.05$) and global panel (β=1.29, $P<0.05$). In the case of low-risk panel, results were insignificant (β=1.99, $P>0.1$). The estimates of Hansen J-test showed that the over-identification restrictions were valid and the instruments used in the model were appropriate. Furthermore, there was also no issue of autocorrelation in all three models due to insignificant p-values.

Table 2: Two-step System-GMM Panel Estimation Regression

Variable	*High Risk*	*Low Risk*	*Global*
Lagged Tuberculosis	1.332 (0.241)	0.839 (0.381)	1.274 (0.325)
Renewable Energy Consumption	-0.537*** (0.081)	-0.448** (0.042)	-0.510*** (0.051)
CO_2 Emissions	0.039** (0.034)	1.321** (0.046)	0.092*** (0.069)
Urbanization	0.003*** (0.070)	0.035 (0.231)	0.058 (0.105)
RENEWURB	0.118 (0.174)	0.129 (0.229)	0.260 (0.233)
CO2URB	1.296** (0.047)	1.991 (0.337)	1.293** (0.044)
Constant	3.810** (0.048)	1.084*** (0.081)	2.773** (0.027)
Hansen J-test (p-value)	11.828 (0.161)	12.327 (0.225)	16.248 (0.184)
AR2 test (p-value)	0.373 (0.423)	0.180 (0.417)	0.559 (0.831)

Dependent variable is renewable energy consumption. Values in parenthesis are the estimated p-values. Hansen J-test refers to the over-identification test for the restrictions in GMM estimation. The AR2 test is the Arellano-Bond test for the existence of the second-order autocorrelation in first differences. *, **, and *** indicate significance at the 1%, 5%, and 10% levels, respectively

Discussion

Renewable energy consumption decreases the cases of tuberculosis across all panels. Although any specific study in the context of tuberculosis is not available, these results can be supported by similar studies. For instance, renewable energy can provide many health benefits to the general public by displacing emissions from carbon-intensive electrical generating units (15). In contrast, serious health risks and the burden of diseases can be arisen due to the lack of clean electricity usage (23). Thus, renewable energy consumption can reduce many health risks and the occurrence of related diseases including tuberculosis.

Our results also purported that carbon dioxide emissions lead to an increase in the incidences of tuberculosis. A wide range of literature has supported the argument that the pollutant emissions is one of the critical reason of poor health in many countries. The U.S. is suffering from early death cases every year due to combustion emissions (24). In reference to tuberculosis, it can be caused by both indoor and outdoor air pollution (7-10). A prior study also supports this notion that various environmental factors and atmospheric pollutants are associated with the TB incidences (25).

The results for urbanization were significant for the high-risk panel only. A higher number of tuberculosis cases can occur in high-risk countries with an increase in their pollutant emissions. Previous studies also support this argument that urbanization is one of the main sources of communicable and non-communicable diseases in developing countries (12-13). A higher level of income in industrialization has forced rural pollution to shift from villages to the cities. However, this gradual increase in an urban population gives rise to chronic morbidity, crime, and pollution in the absence of balanced infrastructure development and strong regulatory policies. Overcrowded housing in the high-density population can be more exposed to communicable diseases including tuberculosis due to which the rate of TB is higher in the urban population as compared to rural (13-15).

Contrary to our propositions, urbanization does not moderate the relationship between renewable energy consumption and tuberculosis while it positively moderates the association between CO_2 emissions and tuberculosis in global and high-risk panels. Likewise other detrimental social and environmental effects of urbanization, a wide range of literature also proved that urbanization is positively associated with pollutant emissions (17, 26). Thus, the combined effect of urbanization and carbon dioxide emissions is more noxious for public health as they give rise to several infectious diseases including tuberculosis.

Conclusion

Our proposed model test the effect of renewable energy consumption and carbon dioxide emissions on tuberculosis along with the moderating role of urbanization. Although the estimates slightly vary across the underlying panels but in general, we found that air pollution and urbanization increase the incidences of TB while renewable energy consumption could reduce its prevalence. To restrict air pollution and global warming, governments should restrict the unclean energy resources and promote cost-effective renewable energy technologies to meet public demand, especially in high-risk countries. Additionally, surveillance and adequate city planning can be considered as cogent mechanisms to enhance the quality of life and mitigate the issues of communicable diseases.

Ethical considerations

Ethical issues (Including plagiarism, informed consent, misconduct, data fabrication and/or falsification, double publication and/or submission, redundancy, etc.) have been completely observed by the authors.

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Conflict of interest

The authors declare that there is no conflict of interest.

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