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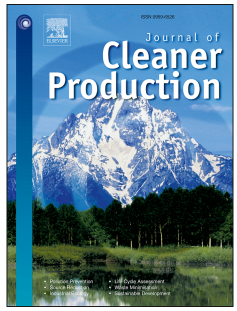

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Characterization of resource consumption and efficiency trends in Bangladesh, India and Pakistan: Economy-wide biotic and abiotic material flow accounting from 1978 to 2017

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Abstract

This study, conducted as a first try, explores the resource metabolism in three main economies in South Asia (in terms of both scale and growing rate of economy) namely Bangladesh, India and Pakistan, with a standard economy-wide material flow accounting approach using the most updated data from 1978-2017. In detail, resource consumption patterns, resource efficiency and productivity, trade related issues, as well as macro-policies affecting regional resource utilization were analyzed in-depth. Results highlighted that, in general, rapid consumption of imported resources, especially construction minerals, fossil fuels, and industrial minerals has emerged. Domestic material consumption per capita increased by 81%, 93% and 46% during 1978 to 2017 in the three countries, respectively, due to the living standards enhancement, improved urban infrastructure as well as rapid industrial development. With rapidly growing resource consumption, improvements in resource productivity were still low compared with mature economies like Japan and United States. It was 410.7 USD/t for Bangladesh, followed by India (358.7 USD/t) and Pakistan (275.0 USD/t), as of 2017. One critical finding was that resource intensive production (e.g., primary materials, textile and agricultural products etc.) was driving most of the bilateral trade among the three countries, which resulted in lower overall resource productivity. The other critical insight was the future increasing pressure on regional and global resource competition, according to the revealed rising inflow of foreign resources in the studied countries. Finally, the macro-policy analysis highlighted that the impacts of environmental protection and resource efficiency policies were far from enough. And, lower per capita GDP of this region was still a significant impediment for integrated environmental and resources management. Higher focus on resource productivity, from a policy perspective, on agricultural and industrial sectors is highly recommended to forward beneficial implications for the selected countries.

Keywords

Material flow accounting, Resource productivity, Dematerialization, Decomposition analysis, Macro-policy analysis, South Asia

Abbreviations

Domestic Extraction	DE
Domestic Material Consumption	DMC
Economy-Wide Material Flow Accounting	EW-MFA
Environmental Kuznets Curve	EKC
Gross Domestic Product	GDP
Harmonized System Classification	HSC
International Resource Panel	IRP
Logarithmic Mean Divisia Index	LMDI
Material Flow Analysis	MFA
Million Tons	Mt
Physical Trade Balance	PTB
Purchasing Power Parity	PPP
Sustainable Development Goals	SDGs

1. Introduction

Resource efficiency is a key to realize the sustainable development goals (SDGs), particularly for transitional economies. Clearly and scientifically identifying the status and driving forces behind resource exploration and utilization, in the procedure of rapid economic growth, industrialization, and urbanization, will be critical for such countries to design innovative and leapfrog pathways towards resource efficient scenarios (Chiu et al., 2017; Dong et al., 2017). In this context, leapfrogging refers to the non-continuous technological advancement while skipping some phases or steps (Chen and Richard, 2011). The leapfrog concept is highly relevant to developing countries which can learn from an efficient transition of developed countries and avoid the risks associated with research and development as well as experimentation (Gray and Sanzogni, 2004; Tan et al., 2018). Among the popular tools to study a resource efficient transition, economy-wide material flow accounting (EW-MFA) provides a systematic analytical approach and looks into the socio-economic progress together with environmental quality upgradation (Patrício et al., 2015). Moreover, this method has been widely acknowledged as a tool for assessing and improving resource efficiency and productivity (Huang et al., 2012). It hence offers a sound approach to support decision making on resource efficient and circular economy policies (Bringezu, 2015; Fischer-Kowalski et al., 2011; Raupova et al., 2014; Wiedenhofer et al., 2019).

As far as the application is considered, most EW-MFA studies focus on material resources (abiotic or biotic) which usually exclude sinks, water, ecosystem services, biodiversity etc. Moreover, EW-MFA has been applied in developed economies like Japan (Krausmann et al., 2011; Moriguchi, 2001) and Australia (Wood et al., 2009); fast developing countries like China (Wang et al., 2012; Xu and Zhang, 2008) and Philippines (Chiu et al., 2017); regions such as European Union (Calvo et al., 2016; EUROSTAT, 2013, 2007) and Latin America (Russi et al., 2008); and at global levels (Giljum et al., 2014). Few cross-country comparisons have also been carried out yet they mostly studied large and developed economies such as China, Australia, and Japan (Schandl and West, 2012) and China, South Korea and Japan (Dong et al., 2017). Results and experiences from these countries and studies are still valuable to provide critical policy insights on sustainable resource management. From the literature review, it is evident that large and low-income developing countries are neglected in this regard and resource use trajectories and country-wide comparisons are absent. Hence, studies on developing economies are very important to analyze past material transactions and provide policy recommendations for future sustainable resource management, particularly in the context of regional and global resource supply chain. Under such research challenges, disparity in economic development phases among different countries is particularly a critical debate linked to local economic conditions, structural characteristics of industry, technological innovation and regional resource efficiency (Giljum et al., 2014). Moreover, environmental sustainability relies on the maintenance and improvement of planet's life supportive capacity through efficient use of natural resources (Moldan et al., 2012) with developing countries at a comparative advantage due to their larger ecological surplus (Sumaila, 2012).

In the developing world, South Asia presents a huge potential for economic and urban development (Sehgal et al., 2017). Given their large populace and resource base, rapid economic growth has been observed during the last decade (ADB, 2017). However, concerns on resource efficiency and associated environmental implications are scarcely reported in the literature. Bangladesh, India and Pakistan are the three largest South Asian economies with a combined global population and gross domestic product (GDP) share of around 22.6% and 3.8%, respectively, as of 2017. Their socio-economic progress has been marked with a largely underutilized economic, natural and human resource potential (United Nations, 2017). Although, these countries achieved varying economic development patterns during last few decades, yet, future economic growth is expected to improve with increasing efforts on security, policy and economic reforms (ADB, 2017). In summary, the varying economic and resource use patterns in Bangladesh, India and Pakistan, with geographical and historical proximity, give rise to several critical scientific questions: (1) how does material consumption and economic growth patterns evolve in subject countries? (2) what are the driving forces behind changes in material consumption overtime in the three selected economies? (3) are the changes in resource intensity and productivity comparable with the rest of the regional economic players? (4) how is bilateral trade among the three countries affecting domestic resource consumption and its efficiency? (5) from a resource productivity perspective, how can developing countries learn from developed economies?

Enlightened by previous works (Chiu et al., 2017; Dong et al., 2017; Schandl and West, 2012), and to address the above mentioned questions as a first attempt, this study aims to explore the resource metabolism in Bangladesh, India and Pakistan with EW-MFA approach and indicators using up-to-date data from 1978-2017. The aim is to highlight the relative importance of developing South Asian countries in regional and global resource consumption at a time when no previous research exists. Particularly, this study attempts to comprehend how the externalization of resource intensive sectors by industrialized countries has altered material consumption and efficiency in selected developing economies. Decomposition analysis based on IPAT equation has been used to explore the driving forces of resource consumption to uncover policy insights from a transitional perspective. The logarithmic mean Divisia index (LMDI) method has been selected for the decomposition analysis. This study further applied environmental Kuznets curve (EKC) hypotheses to examine the level of dematerialization taking place, if any, followed by a detailed macro-policy analysis to uncover a past and future pathways towards resource efficient scenarios.

The rest of the paper is organized as follows: section 2 provides details on the methods involved including material flow indicators and sources of collected data. Section 3 overviews the general socio-economic status of the three countries together with highlighting their environmental challenges. Section 4 presents the results of this work and a discussion on drivers of material consumption. Section 5 conducts an in-depth macro-policy analysis based on environmental policy development in the region along with mutual trade analysis in the context of value addition and economic leverage. And finally, section 6 concludes the main contributions, provides key policy implications, and addresses some of the research limitations of this work.

2. Materials, methods and data

This section will elaborate on the chosen methods and the overall research framework along with the sources of data. Some of the uncertainties associated with the collected data will also be discussed in this section.

2.1. Methodology framework

A methodology framework was developed to address the above stated research questions. The framework comprised of 5 steps and is presented in Fig. 1. Under this framework, step 1 focused on economy-wide resource metabolism in Bangladesh, India and Pakistan. In step 2, analytical structure was established for material flow indicator and efficiency measurements. The panoramic view presented the existing state of resource flows on a macroscopic scale. The economic situation was discussed along with regional trade among the three countries. In step 3, database structure was established and applied to subject countries to verify feasibility of our analytical framework. In step 4, results of this work were presented and analyzed based on material flow indicators (described in step 2), and a macro-policy analysis was conducted for the selected countries. In step 5, conclusion and policy implications were drawn based on step 4.

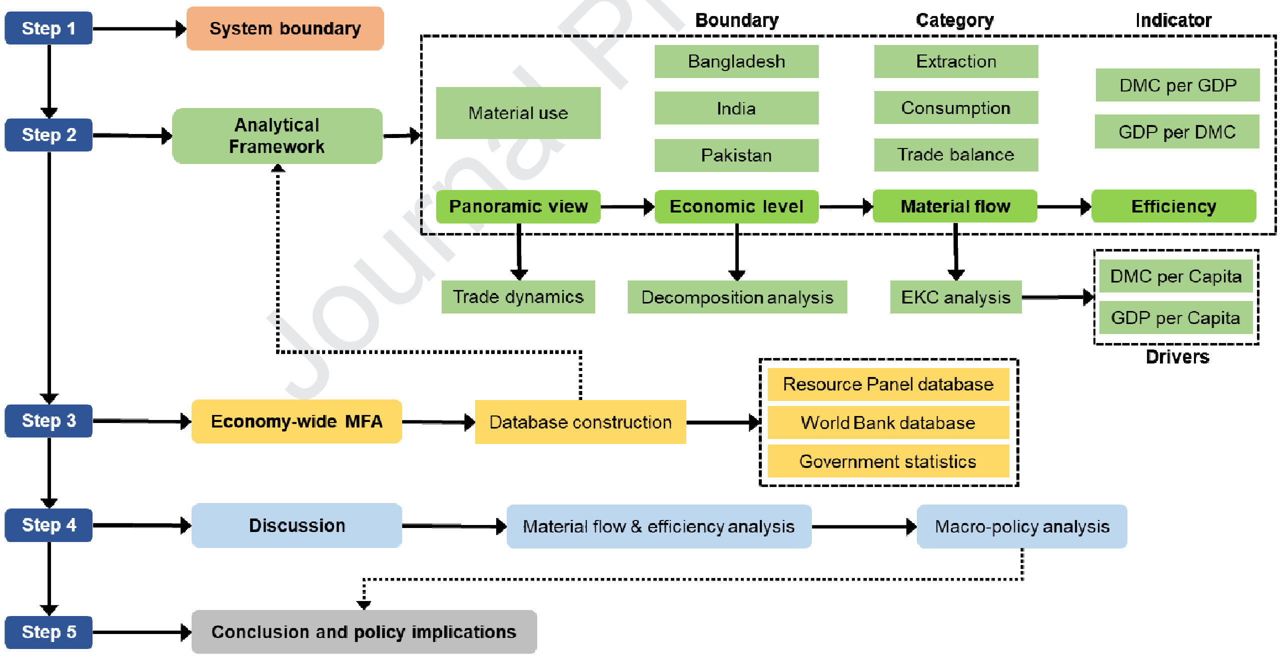

Fig. 1. Methodological framework for this research.

The three countries were selected based on their importance from both geographic and historical perspectives (Broadberry et al., 2015). Historically, all three of them were part of the British India until 1947 when it was partitioned into India and Pakistan, and a later secession of Bangladesh from Pakistan in 1971 – making them regional competitors for natural resources and international trade. Geographically, they are co-located with India sharing borders with both countries – making transboundary trade of primary resources and finished products highly favorable yet challenging at the same time. Moreover, no previous economy-wide MFA studies exist for the selected countries especially when other Asian countries such as China, Vietnam, Japan, South Korea etc. are emerging as strong competitors for both regional and global resources. Therefore, to conduct this analysis, most recent long-time series data, from 1978 to 2017, has been used as per the established guidelines (EUROSTAT, 2013). As 2017 was the end year, the start year was selected to be 1978 considering past studies which have used datasets of 28 years (Chiu et al., 2017), 29 years (Giljum et al., 2014), 35 years (Schandl and West, 2012), and 38 years (Dong et al., 2017). The selected timeline of 40 years was considered to adequately cover both resource use patterns and policy developments in the region. A four-category demarcation of material flows was done into metal ores, fossil fuels, non-metallic minerals, and biomass which is in line with the standard guidelines. Details of material categorization are given in Table 1.

Table 1

Material categorization used in this study.

No.	Main category	Sub-category
1.	Metal ores	Ferrous ores
		Non-ferrous ores
2.	Fossil fuels	Coal
		Natural gas
		Oil shale and tar sands
		Petroleum
3.	Non-metallic minerals	For construction use
		For industrial/agricultural use
4.	Biomass	Crops
		Crop residues
		Grazed biomass/fodder crops
		Wild catch/harvest
		Wood

2.2. MFA approach and indicators

As follow-up of the framework in Fig.1, standard EW-MFA framework was conducted following the methodological guidelines in EUROSTAT (2013, 2007). As complementation, we referred to some recent studies (Chiu et al., 2017; Fischer-Kowalski et al., 2011; Schandl and West, 2012; Wang et al., 2012) to design and define the main indicators. In summary, three basic indicators were applied, namely, domestic material consumption (DMC), domestic extraction (DE), and physical trade balance (PTB). These indicators were also used and analyzed in combination with other socio-economic indicators such as GDP, population etc. Finally, the EKC was developed based on the selected MFA indicators.

In detail, among different material flow indicators, DMC is an important factor representing territorial consumption of primary materials, while at the same time, taking imports and exports into consideration. The second material flow indicator 'DE' refers to domestic extraction within a territorial boundary and is an important indicator for domestic material availability (Eisenmenger et al., 2016). Mathematically, DMC is calculated as: DMC = DE + imports – exports. The third material flow indicator 'PTB' refers to the physical basis of economies and is used to determine the level of self-reliance of a country or a region for different material types (Dittrich and Bringezu, 2010). The PTB indicator is also used to analyze flow of materials between importing regions (consumers) and exporting regions (suppliers) (Lopez N. et al., 2015). All material flows will be expressed in tons (t) or million tons (Mt), where required. Based on DMC, DE and PTB, intensity and efficiency indicators are designed. The intensity indicator is represented by material consumed (in terms of DMC) per unit of economic value generated (in terms of GDP) and is applied to trace the resource consumption intensity. The second efficiency indicator, that is material productivity, is represented by GDP per DMC based on the so called concept of 'resource productivity' which is defined as the economic output per unit of resource consumption (Bartelmus, 2002). It is highlighted that this paper uses DMC as a proxy for economy-wide material consumption.

2.3. Decomposition approach and analysis on driving forces

Finally, based on the MFA indicators, decomposition approach was applied to identify the driving forces of resource utilization. The widely used equation in environmental analysis is the master equation that determines the environmental impacts driven by socio-economic and technological factors (Graedel and Allenby, 2003) and was originally proposed by Ehrlich and Holdren (1971) as given by Eq. (1):

$$I = P \times A \times T \tag{1}$$

Where I denote environmental impact, P accounts for population, A is the economic affluence indicator usually represented by GDP per capita, and T is the technological indicator measured in terms of environmental impact per unit of GDP, thus we can re-write the above as Eq. (2):

$$Environmental\ Impact = Population \times \frac{GDP}{capita} \times \frac{Environmental\ Impact}{unit\ of\ GDP} \tag{2}$$

As environmental impacts are influenced by all of the three components in the master equation, this necessitates a need to gain insights into the drivers of environmental impact (Liu and Ang, 2007), thus, leading to the decomposition of IPAT equation. Among the two widely used decomposition methods i.e. Laspeyres and Divisia index, LMDI is often recommended (Liu and Ang, 2007) and was employed in our analysis to decompose drivers of 'I' in the IPAT master equation. The additive factorial decomposition method has been selected due to its ability to report results in absolute quantity of DMC variations whereas multiplicative factorial decomposition is often used when relative contributions are required, however, both produce similar results (Jeong and Kim, 2013). As per our selected method, drivers of change in DMC can be calculated according to Eq. (3) to (6).

$$\Delta I \text{ (environmental impact)} = \Delta DMC \text{ (tons)} = DMC_{t_1}\text{(tons)} - DMC_{t_0}\text{(tons)} = \Delta P + \Delta A + \Delta T \quad (3)$$

$$\Delta P \text{ (population change)} = \sum \frac{DMC_{t_1} - DMC_{t_0}}{\ln DMC_{t_1} - \ln DMC_{t_0}} \times \ln \frac{P_{t_1}}{P_{t_0}} \quad (4)$$

$$\Delta A \text{ (affluence change)} = \sum \frac{DMC_{t_1} - DMC_{t_0}}{\ln DMC_{t_1} - \ln DMC_{t_0}} \times \ln \frac{A_{t_1}}{A_{t_0}} \quad (5)$$

$$\Delta T \text{ (technological change)} = \sum \frac{DMC_{t_1} - DMC_{t_0}}{\ln DMC_{t_1} - \ln DMC_{t_0}} \times \ln \frac{T_{t_1}}{T_{t_0}} \quad (6)$$

Where ΔDMC is the environmental impact indicator representing changes in DMC from the starting year t_0 (1978) to end year t_1 (2017), ΔP represents the influence of population change, ΔA represents the contribution of economic affluence (in terms of GDP per capita), and ΔT represents the influence of technology (in terms of DMC per GDP), respectively, on changes in DMC.

2.4. Data source

In this research, we used the "International Resource Panel database" (www.resourcepanel.org), launched by the United Nations Environment Program and collaborated by multiple organizations, as the data source for economy-wide material flows from 1978 to 2017. According to International Resource Panel (IRP), the material flows and consequent resource productivity indicators can be used for monitoring changes in the patterns and rates of resource use with high accuracy and reliability.

Although material flow data until 2017 is available, yet some of the datasets are projected based on values from previous years (IRP, 2018). In detail, data from 1978 to 2012 is real without any projections. For the years 2013-2014, most of the data is real but partially complemented by projected values, while the data for 2015-2017 is mostly based on projections from previous years[1], due to the reason that original official statistics usually lag for some years in some developing countries including those selected for this study. In detail, socioeconomic data like GDP and population is real data for all the periods, while, due to the difficulty of collection of physical data, some materials flow data is projected in the above periods, based on the methods like regression analyses on existing time series data. Further details about material flow data can be found in IRP's official technical annex[2].

[1] Based on our consultation with data experts at Secretariat of the International Resource Panel and review of the technical annex.
[2] "Technical annex for Global Material Flows Database (2018)" is available at: www.csiro.au/~/media/LWF/Files/CES-Material-Flows_db/Technical-annex-for-Global-Material-Flows-Database.pdf.

Even though the projected data might generate uncertainty, to our best knowledge, this dataset is the best available one to conduct this research. And to keep the consistency of the data source, all material flows data from 1978 to 2017 was derived from this internationally acknowledged database. As complementary information on the uncertainty concerns, an investigation on the features of projected data, in comparison to real data, was made and is provided in the "appendix" section. According to the technical explanations of the data experts from IRP and the comparison, the projected data was recognized as solid with no significant effect on the results. A more detailed discussion on the data uncertainties has been presented in section 6.3.

Moreover, the socio-economic statistics are adjusted based on constant 2010 US dollar prices (or otherwise indicated) available at the World Bank's statistical archives (data.worldbank.org). Dollar prices based on exchange values were used in this study instead of purchasing power parity (PPP) as they accurately represent a stable value of economic activity within a country (Schandl and West, 2010). This was done to avoid any overestimation of resource productivity or underestimation of resource intensity that may occur due to inflated nominal GDP values reported by individual countries.

3. Overview on case countries

Bangladesh, India and Pakistan are the three largest South Asian economies, yet their environmental issues are rarely studied from a macro-policy and transitional perspective. The detail socio-economic status of Bangladesh, India and Pakistan is summarized in Table 2, while more details like the annual GDP growth rates during 1978-2017 presented in Fig. S1 in the "supplementary information (SI) file".

Table 2

General socio-economic data of the three selected countries, as of 2017.

	Bangladesh	India	Pakistan
Population, million	164.67	1,339.18	197.02
Population rank (world)	8th	2nd	6th
GDP, billion USD [a]	179.99	2,660.37	240.86
GDP rank (world)	43rd	6th	40th
GDP rank (South Asia)	3rd	1st	2nd
Avg. GDP growth rate, 1978-2017	5.04%	6.05%	4.95%
Per capita GDP, USD	1,093	1,987	1,223
Per capita DMC, tons [b]	2.66	5.54	4.45

[a] GDP figures are based on constant 2010-dollar prices

[b] DMC = domestic material consumption

Moreover, with vast areas of land covered by these countries – around 3.84 million square kilometers – and an enormous population, the hunt for natural resources is ever increasing in order to support regional development and rapidly evolving economic and urban paradigms. In Bangladesh, significant economic growth has been fueled by its agricultural, textile manufacturing, and ship building and breaking industries especially during the last two decades (Asadullah et al., 2014; Ethirajan, 2012; Reuters, 2013). India, the largest South Asian economy with a huge population, is an aggressively developing country at rapid growth rates where 1990's economic liberalization and rising foreign direct investments have helped sectors including information technology and software, services, manufacturing and processing, and agriculture etc. to significantly contribute to the national economic growth (Kathuria et al., 2018; Mazumdar, 2014; WTTC, 2016). Similarly, Pakistan is also making significant economic progress with rapid urbanization occurring during the last two decades mainly attributable to the growing agricultural and light-manufacturing industries, opening trade with the global markets, surging population and a strategic partnership with China under the 'Belt and Road Initiative' (Ahmad et al., 2018; Mumtaz et al., 2018; Rashid et al., 2018; Ullah et al., 2018). Nevertheless, most of the industrial sectors in Bangladesh, India and Pakistan are resource, energy and pollution intensive carrying low-to-medium economic value, thus, resulting in an ecological burden (Hu et al., 2019; Sumaila, 2012; Worrell, 2018; Wu et al., 2018).

According to above, we can say that the varying economic and resource use patterns in Bangladesh, India and Pakistan, with geographical and historical proximity, give rise to gigantic questions about resource efficiency in terms of: what is the resource use pattern and how this pattern is related to the socio-economic development and environmental policy evolution (requires to analyze the resource efficiency, productivity and driving forces with various periods). With retreating the past disperse efforts on the resources efficiency and environmental protection policies, what kind of pathway towards a future resource efficient scenario is needed (requires to analyze the macro-policies based on the MFA analysis). And, how bilateral trade among the three countries is affecting domestic resource consumption and its efficiency, considering the three countries are with critical geographical and historical proximity (requires an analysis focusing on the interrelationships of the three countries and the trade dynamics).

4. Results and discussion

This section will discuss some of the important outcomes of this work. With the help of material flow analysis, key policy implications will be drawn. The section also discusses the drivers behind material consumption in subject countries.

4.1. Quantitative indicators

According to the case countries' condition and the applied MFA approach, quantitative indicators including basic indicators and combined indicators are calculated and analyzed as follows.

4.1.1. Domestic extraction (DE) and domestic material consumption (DMC)

As per the results, local resource exploration and extraction has increased, almost uniformly, during the last four decades fueling national economic growth and regional infrastructure development. Net domestic extraction of resources increased from 109.9 Mt (1978) to 398.9 Mt (2017) in Bangladesh; from 1,914 Mt (1978) to 6,991 Mt (2017) In India; and from 217.7 Mt (1978) to 831.3 Mt (2017) in Pakistan. Table 3 presents per capita domestic extraction and material consumption in Bangladesh, India and Pakistan at five different temporal points. Total DE and DMC trends are provided as Fig. S2 and Fig. S3 in the SI file. Interestingly, DE per capita during 1978 was highest in Pakistan followed by India and Bangladesh, however in 1996, India's per capita DE (3.6 t/capita) surpassed that of Pakistan (3.5 t/capita) while Bangladesh was still at the third place (1.5 t/capita). As of 2017, India's DE per capita was more than double the Bangladesh's per capita DE – indicating large-scale material extraction taking place in India.

Table 3

Per capita DE and DMC in subject countries, tons.

DE per capita	1978	1988	1998	2008	2017	%change [a]
Bangladesh	1.43	1.36	1.69	2.10	2.42	69.8
India	2.88	3.16	3.56	4.46	5.22	81.5
Pakistan	2.97	3.42	3.61	4.04	4.22	41.9
DMC per capita						
Bangladesh	1.47	1.44	1.81	2.25	2.66	81.2
India	2.87	3.16	3.62	4.56	5.54	92.8
Pakistan	3.04	3.53	3.74	4.18	4.45	46.2

[a] % change in 2017 relative to the year 1978

Among the DE of specific material categories, an increasing share of non-metallic minerals used for construction was observed for all countries. One the one hand, the relative share of construction-based aggregate minerals in total DE increased from 2.1%, 27.5%, and 10.1% in 1978 to 28.9%, 45.1%, and 24.8% in 2017 for Bangladesh, India and Pakistan, respectively, indicating rising extraction of these resources to support the national infrastructure development. While on the other hand, relative share of locally extracted biomass reduced for all countries during the 1978-2017 period, indicating a transition towards fossil fuel-based growth coupled with rising shares of construction-based minerals. In the subject countries, extraction of fossil fuels has increased noticeably. Fossil fuel extraction increased from 0.6 Mt in 1978 to 20.2 Mt in 2017, in Bangladesh, from 109.5 Mt in 1978 to 797.1 Mt in 2017, in India, and from 5.1 Mt in 1978 to 32.7 Mt in 2017, in Pakistan. Although, considerable quantities of energy resources are being locally extracted within these countries, however, rising urbanization and industrialization has caused enormous demand of energy resources especially in India which imported additional 430 Mt of fossil fuels in 2017 (mainly comprising coal and petroleum products) to sustain the economic expansion. This highlights the unavailability of local resources in subject countries and their rising dependence on global resource supply networks.

Coming to DMC trends in three countries, as given in Table 3, overall DMC per capita has been on the rise quite similar to DE results with varying shares of each material type. Moreover, the DMC growth pattern was almost uniform within each of the economy. During 1978-2017, Bangladesh's DMC increased from 113.1 Mt to 438.3 Mt, India's DMC increased from 1,912 Mt to 7,417 Mt, while that in Pakistan increased from 222.6 Mt to 875.8 Mt – all countries showing manifolds increase. Compared to the per capita DMC in other regional countries in 2017, Bangladesh, India and Pakistan had a lower per capita DMC than that of China (25.4 t/capita), South Korea (15.7 t/capita), Vietnam (14.7 t/capita), Bhutan (10.3 t/capita), Maldives (10.3 t/capita) and Japan (9.0 t/capita) – indicating their developing economic status. However, rapid urban, industrial, infrastructure and regional socio-economic development is expected to drive per capita DMC in coming years.

With regards to specific material categories, DMC patterns nearly coincided with DE patterns with construction-based minerals showing almost a similar growth trend within each of the three countries. As far as DMC of biomass is concerned, in spite of its rising sheer mass, its relative share reduced to 62.3% (from 95.3%) for Bangladesh, to 37.5% (from 63.8%) for India, and to 66.4% (from 85.3%) for Pakistan, during 1978-2017. The reduced share of biomass was compensated partly by fossil fuels and mostly by non-metallic minerals that were used in construction, industrial and agricultural activities. Moreover, biomass remained a major shareholder in DMC for Bangladesh and Pakistan throughout this period. However, this was not the case with India where construction minerals surpassed biomass consumption, both in sheer mass and relative share after 2010, highlighting expansion of transport infrastructures, industrial facilities, residential buildings, urban development etc. Also, India's material use has become increasingly dependent on coal and petroleum resources whose relative share in DMC increased from 6.6% in 1978 to 16.0% in 2017. This becomes more important in the wake of global supply fluctuations and oil export bans on Iran (Dudlák, 2018), which has been a substantial supplier of petroleum fuels to India (The World Bank, 2018). On the contrary, Bangladesh and Pakistan have a smaller share of fossil fuels (below 7%) in total DMC and are unlikely to be immediately affected by international trade bans and supply instabilities.

To further analyze natural material independency of these countries, the ratio of DE over DMC was computed analyzed. In 1978, DE/DMC was 0.97 in Bangladesh and 0.98 in Pakistan - indicating marginal resource inflow from other countries to meet the local resource demand. While in India, DE/DMC was equal to 1.0 indicating somewhat balanced extraction and consumption status. However, in 2017, the situation has drastically changed as all three countries have a reduced DE/DMC ratio of 0.91 (Bangladesh), 0.94 (India) and 0.95 (Pakistan) - indicating higher domestic consumption and increasing reliance on foreign material inflow. Particularly, India transformed from a resource-neutral country to a resource-deficient country importing higher quantities of natural materials. By 2017, all three countries had become net importers of primary resources. Factors that may have affected increased resource demand and net resource imports include insufficient local material extraction, higher demand for locally unavailable resources, limited or declining material reserves, incentives on certain material imports, and an increased overall economic and industrial activity. However, for dematerialization to begin, developing countries need to develop locally applicable policies for reducing material consumption with efficient technologies so that resource sustainability is achieved with reduced per capita DMC at all economic levels.

4.1.2. Physical trade balance (PTB)

The PTB trends for three countries during 1978-2017 are presented in Fig. 2 while aggregate PTB patterns are provided in Fig. S4 in the SI file. PTB trends provide insights into the net resource flows to and from an economy with a positive PTB indicating net resource import and vice versa. As shown in Fig. 2 (a) and (c), Bangladesh and Pakistan have traditionally been net importers of resources - though with relatively small aggregate volumes. Back in 1978, Bangladesh's net resource import was equal to 3.2 Mt with imports only of fossil fuels (1.7 Mt, mainly petroleum and coal) and biomass (1.6 Mt, mainly agricultural crops). In 2017, however, Bangladesh's net resource import reached 39.3 Mt (~12 times higher than that in 1978) with all imports including non-metallic minerals (14.1 Mt, mainly construction minerals), biomass (13.4 Mt, mainly agricultural crops and wood), fossil fuels (7.8 Mt, mainly petroleum and coal) and metal ores (1.6 Mt, mainly ferrous ores). For Pakistan, net resource import in 1978 was 4.9 Mt with all imports comprising fossil fuels (3.9 Mt, mainly petroleum products), metal ores (0.4 Mt, mainly ferrous ores), non-metallic minerals (0.3 Mt, industrial, agricultural and construction minerals), and biomass (1.6 Mt, mainly wood). Whereas in 2017, Pakistan's net resource import reached 44.5 Mt (~9 times higher than that in 1978) with imports of fossil fuels (26.2 Mt, mainly petroleum and coal) and non-metallic minerals (21.1 Mt, industrial and agricultural minerals), and exports of metal ores (1.5 Mt, non-ferrous metals) and biomass (1.3 Mt, mainly wood). Future growth in Pakistan's GDP is expected to exacerbate energy intensity causing higher dependency on imported fossil fuel resources (Rehman et al., 2019), thus, policy measures on energy efficiency and diversification with non-renewable resources can be highly beneficial.

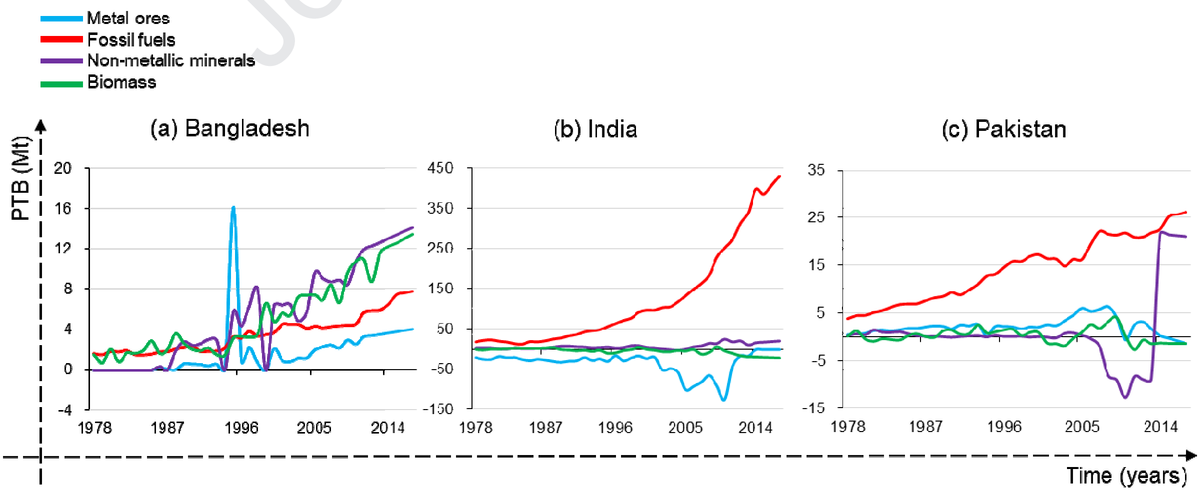

Fig. 2. PTB trends for three countries during 1978-2017.

As shown in Fig. 2 (b), India's PTB profile shows two different phases – before and after the year 1990. During 1989, India's net exported resources amounted to 0.5 Mt comprising imports of fossil fuels (27.5 Mt, mainly petroleum and coal) and non-metallic minerals (6.0 Mt, mainly industrial and agricultural minerals) with exports of metal ores (32.5 Mt, mainly ferrous ores) and biomass (1.5 Mt, mainly agricultural crops). However, in 2017, India's net imported resources (imports minus exports) equaled 426.3 Mt comprising imports of fossil fuels (430.1 Mt, mainly petroleum, coal and some natural gas) and non-metallic minerals (18.7 Mt) with exports of biomass (20.9 Mt, mainly crops) and metal ores (1.6 Mt, mainly ferrous ores). Thus, India's transition from a primary resource exporting economy in 1978 to a large resource importing country in 2017 highlights increasing demand of natural resources from developing countries and calls for increasing efforts on improving domestic resource efficiency which will be discussed in section 3.2.

Nevertheless, as of 2017, all three countries had a positive net PTB with increasing dependence especially on non-renewable energy resources and non-metallic minerals used for industrial and agricultural activities – indicating their rising vulnerability to global resource supply perturbations and price fluctuations. Factors affecting this rising dependence include domestic resource limitation coupled with increasing overall material requirement which is usually further deteriorated in developing countries due to lack of technological development, low value addition capability and internalization of material-intensive sectors. This becomes more important at a time when important regional countries such as China, Japan, and South Korea are also seeking higher resource inflows (Schandl and West, 2012) requiring that either domestic extraction is greatly expanded or resource trade flows are redirected (Schandl and West, 2010) – all leading to a greater competition for regional and global resources.

4.2. Material efficiency trends

As a measure of material efficiency, material intensity (DMC per unit of GDP) indicates how efficiently three economies are consuming resources per unit of economic output. As given in Fig. 3 (a), material intensity has reduced considerably in all three countries during 1978-2017 with highest reduction achieved in India (57.4%) followed by Bangladesh (41.7%) and Pakistan (37.9%). The reduced material intensity highlights the fact that increasingly less resources are being consumed per unit contribution to national GDP. Interestingly though, during this period, Pakistan's population grew by 169.2% while that of India increased by 101.2%, thus, indicating an inverse relationship between population growth and material intensity.

As of 2017, material intensity was highest in Pakistan (3.6 kg/USD) followed by India (2.8 kg/USD) and Bangladesh (2.4 kg/USD). Such levels of material intensity were comparable with China (3.5 kg/USD) but were quite low as compared to Vietnam (7.9 kg/USD). On the contrary, subject countries were much more material intensive as compared to developed countries such as Japan (0.2 kg/USD), United States (0.4 kg/USD), and South Korea (0.6 kg/USD). This endorses the view that material intensity improvements achieved by post-industrial economies have been counter-balanced by material intensive countries in the developing world – offsetting some of the material efficiency gains made at the global scale (Bithas and Kalimeris, 2018).

Nevertheless, developing countries can reduce their material intensities through light-weight design approaches, extended product lives, and increased re-use, remanufacturing and recycling approaches (Stahel and Clift, 2015).

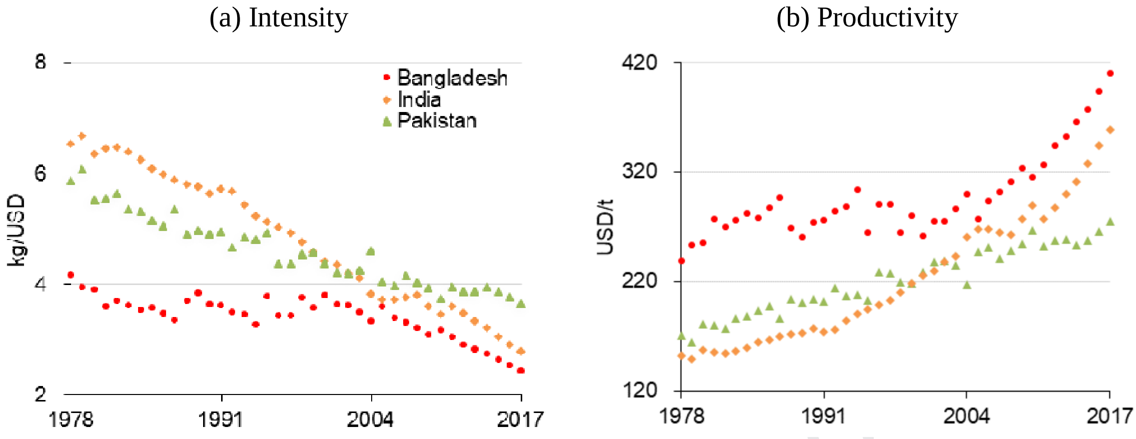

Fig. 3. Material efficiency trends for three countries.

Material or resource productivity, expressed as the economic output produced per unit of DMC, is an important indicator to compute economic contribution per unit of material consumed. Results for material productivity, as shown Fig. 3 (b), indicated considerable improvements within the subject countries. As per the results, resource productivity during 1978-2017 improved by about 72%, 135%, and 61% in Bangladesh, India, and Pakistan, respectively, indicating significant improvements made especially by India. In spite of such improvements, resource productivity in 2017 was highest in Bangladesh (410.7 USD/t) followed by India (358.7 USD/t) and Pakistan (275.0 USD/t). Comparatively, productivity here was significantly low compared to industrialized economies such as Japan (5,393 USD/t), United States (2,628 USD/t) and South Korea (1,664 USD/t), yet similar or even higher as compared to China (288.7 USD/t) and Vietnam (125.1 USD/t). Interestingly, India and Bangladesh had higher productivity than China, yet, their comparatively lower resource consumption translates into lesser economic output. Nonetheless, as material intensity reduction complements productivity improvement, steps such as process innovation, industrial restructuring, design change, and material intensity reduction are particularly important for developing countries to achieve significant resource productivity such as Japan and United States (Lee et al., 2014). One approach to improve resource productivity is to outsource low-value and material intensive manufacturing and promote resource-frugal, high-tech industries and services. But on the flipside, higher productivity at one place, at the cost of higher material intensity at another, adds no value to the system as a whole. Some even argue that mimicking the urban development model of developed countries may actually lead to 'concrete forests' with unsustainable material consumption patterns (Kapoor, 2001; Sheraz, 2014). However, a transition towards service-oriented economy can also be a key measure to promote resource efficiency (Koskela et al., 2013) coupled with regional resource management policies that incorporate local economic, social and environmental dimensions.

4.3. IPAT equation and its drivers

With the help of IPAT framework, drivers of change in material use were investigated for Bangladesh, India and Pakistan. The environmental impact (ΔDMC) was decomposed into population, affluence (GDP/capita) and technology (DMC/GDP) and the overall results are presented in Fig. 4. In Bangladesh and India, rising DMC was driven partly by population and mainly by economic affluence, however, technological enhancement played a major part in slowing the growth of DMC. Among the drivers of DMC increase, the role of population was relatively less yet very significant as compared to affluence, highlighting large resource consumption due to expanding urban and social lifestyles. In Bangladesh and India, contribution from technology in reducing DMC was lower than the impact of affluence in increasing DMC, yet it was able to partially offset growth in resource use driven by the other two factors. In Pakistan, rising DMC was driven largely by population followed by affluence, however, technological enhancement played a relatively smaller role to curb ΔDMC. This indicated significant impacts of rapid population growth in Pakistan which has led to higher human consumption of resources without much contribution to national economy. In fact, population growth rates in Pakistan are among the highest in South Asia (DGIS, 2008) but are usually overlooked due to socio-political reasons. Nonetheless, to minimize impacts of population on ΔDMC in Pakistan, efforts should also be directed towards discouraging extravagant resource use in modern-day lifestyles and controlling rapid population growth rates in the country.

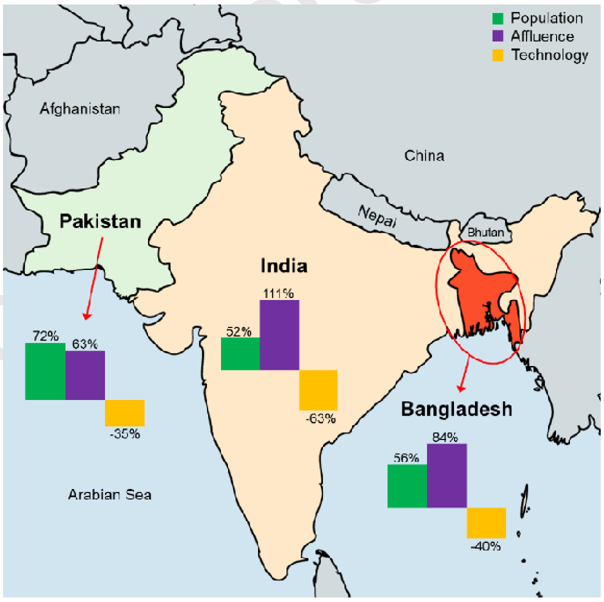

Fig. 4. Drivers of domestic material consumption in three countries during 1978-2017.

The decomposition results for individual 10-year periods are presented in Table 4. Interestingly, ΔDMC was significantly higher during 1998-2017 as compared to 1978-1997, which is in accordance with large urban and infrastructure development in three countries as discussed in section 3.1. During the last decade (2008-2017), large material consumption has taken place in Pakistan due to the development of large-scale infrastructure projects and special economic zones under the ‘Belt and Road Initiative’ in partnership with China (Shah et al., 2019; Ullah et al., 2018; Wang, 2017) – causing DMC to rise significantly especially for construction minerals and energy resources. In India and Bangladesh, rising exports coupled with rapid urbanization has fueled economic affluence which in turn has pushed rising resource consumption. As of now, all three countries show a large potential for technological innovation that can be strengthened through improved environmental management via eco-industrial development and promotion of sustainable agriculture – the two major economic sectors in this region.

Table 4

Decomposing ΔDMC during four decades.

Driver (%)	1978–87	1988–97	1998–2007	2008–17
	Bangladesh			
ΔDMC (Mt)	32	84	105	104
Population	109	49	43	37
Affluence	38	47	99	164
Technology	-47	3	-42	-103
	India			
ΔDMC (Mt)	723	1045	1780	1957
Population	71	59	42	37
Affluence	66	100	114	165
Technology	-37	-59	-56	-102
	Pakistan			
ΔDMC (Mt)	135	137	189	192
Population	69	82	66	75
Affluence	68	42	72	66
Technology	-37	-24	-38	-41

4.4. Application of EKC hypothesis

Based on the material use and economic indicators, EKC curves were developed and examined. The vertical axis was used to represent environmental impact (DMC/capita) while the horizontal axis was used to represent economic development (GDP/capita) using the second order regression curves. As per the results, EKC of Bangladesh, India and Pakistan are given in Fig. 5. Comparatively, EKC of China, South Korea, Japan, and United States are also presented in Fig. 5.

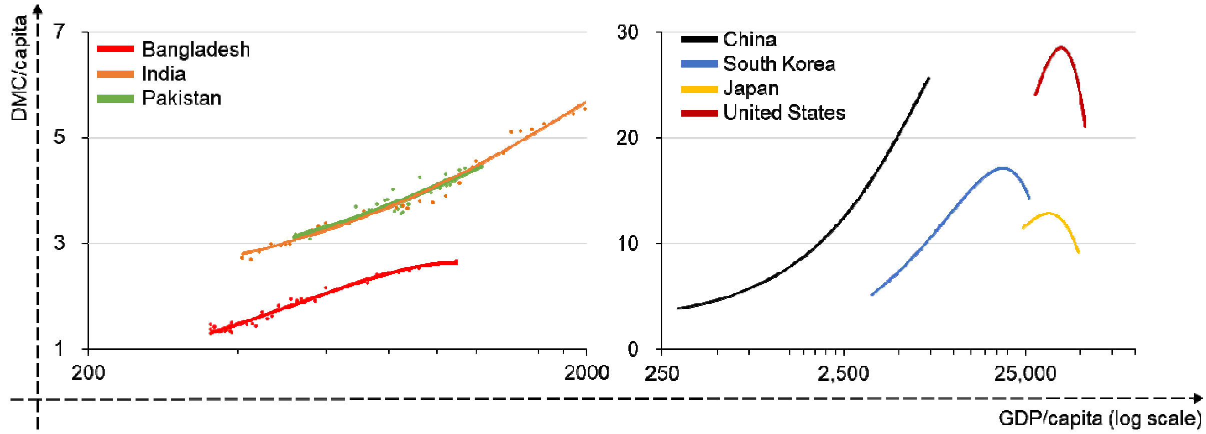

Fig. 5. EKC for different countries during 1978-2017.

As per the analysis, countries who achieved dematerialization did not follow a straight economic path, rather their economic capacity varied at the time of crossing the inversion point. Among the developed countries presented here, Japan was first to reach the inversion point in 1987 with a per capita GDP of around 32,000 USD. United States was next to achieve dematerialization in around 1997 when their per capita GDP surpassed 40,000 USD which was then followed by South Korea which reached EKC inversion with a per capita GDP of about 20,000 USD in 2007. Although, these results are based on 2010-dollar prices, however, the EKC inversion point does not appear to be correlated with any particular income range. This shows that DMC can be decoupled from economic growth at a lower economic stage as seen in the case of South Korea. As with China, it has crossed per capita DMC of Japan and South Korea and is about to reach that of United States, indicating a potential dematerialization taking place sooner probably at a per capita GDP below 20,000 USD. This highlights the significance of sustainable development policies adopted by China in order to promote cleaner production, eco-friendly industrial development and resource efficiency – all under the ambit of a circular economic model (Su et al., 2013). Although, Bangladesh, India and Pakistan are still far behind to reach the EKC inversion point, they however need not to follow the same development path of matured economies, rather, they should focus on applying locally developed innovative technologies and efficient resource management strategies to decouple rising resource consumption from economic growth (Dasgupta et al., 2002).

5. Macro-policy analysis

At a macro-level, some of the economic and material indicators, in three dimensions, are presented in Fig. 6 using second order polynomial regression curves. Based on Fig. 6, some of the discernable aspects are discussed below:

(1) All three countries achieved considerable and uniform GDP growth with India making fastest economic progress.

(2) GDP/DMC improvements in Bangladesh were relatively less uniform but highest compared to other two countries. The period after 2000 showed highest improvements in all three countries.

(3) As a consequence of rising GDP and material consumption, carbon dioxide (CO_2) emissions have also been on a uniform rise during 1978-2014. As shown in Fig. 6, per capita CO_2 emissions in 2014 were consistently highest in India (1.73 t), followed by Pakistan (0.90 t), and Bangladesh (0.46 t). More interestingly, Pakistan's per capita CO_2 emissions during 2007-2014 actually reduced by 9.5% whereas its per capita GDP increased by 6.7%, indicating decarbonization of economy mainly coming from reduced material consumption fossil fuels – applicable to that timeframe only. Reduced per capita CO_2 emissions during this period were driven by a prolonged energy crisis in Pakistan due to generation capacity issues, demand-supply gaps, price hikes, load management etc. (Ali et al., 2019). The energy crisis in Pakistan was also aggravated by the energy price surge during the 2008-2009 global financial crisis (Bekhet et al., 2016). As a result, domestic consumption of fossil fuels remained stagnant during 2007-2014 while population continued to grow rapidly – making the per capita CO_2 emissions to drop slightly. Although, policies in Pakistan are now becoming better aligned with climate change issues, particularly with increasing public-private partnership on efficient resource management and government's resolve to tackle rising environmental pollution (Javid and Sharif, 2016; Shah and Zeeshan, 2016), however, their quantitative impact on CO_2 emissions is still unreported and can be explored as a follow-up of this work.

(4) Per capita PTB was positive throughout the study period in Bangladesh and Pakistan, however, in India, per capita PTB changed from negative to positive in the year 1990, indicating impacts of trade liberalization on physical inflow of resources. Based on R^2 values, per capita PTB was least uniform in all countries mainly due to large year-on fluctuations in supply and demand of imported resources.

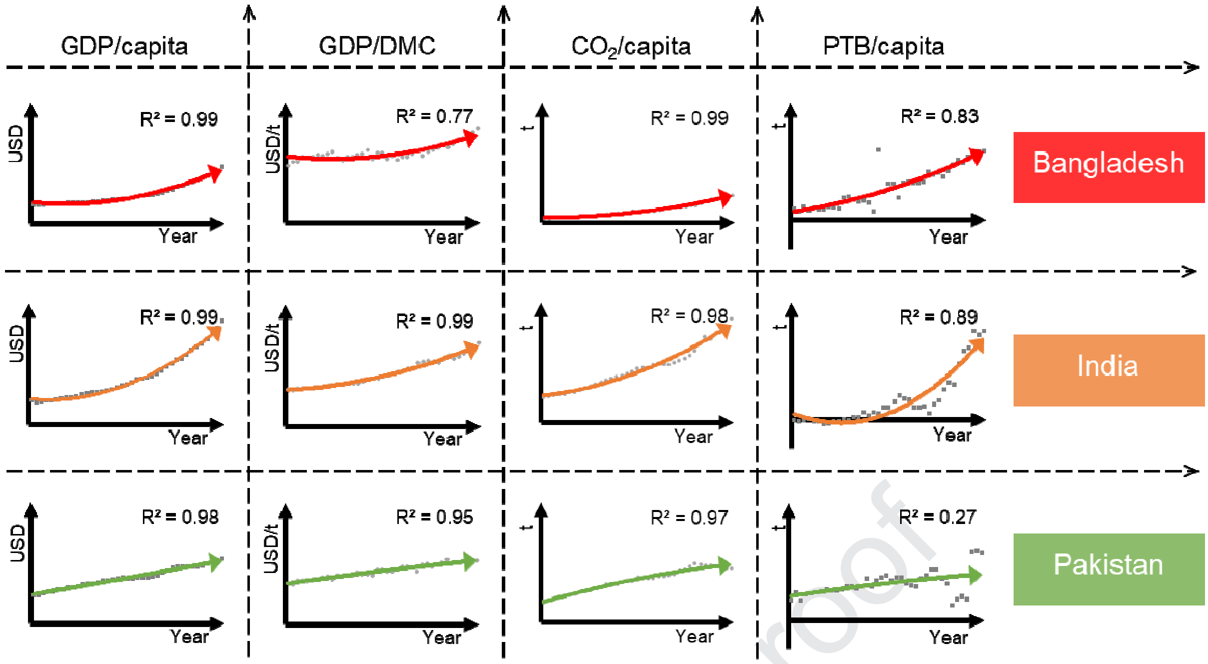

Fig. 6. Overview of economic, environmental and material flow indicators in three dimensions (vertical and horizontal axis bounds are uniform for each indicator).

5.1. Overview on the environmental policy development

This section will present an overview of the environmental management in subject countries. The changing regional economic dynamics with open trade policies especially since the 1990's has aided rising exports and consequently higher material consumption in the subject countries. As a result, changes in regional economic affluence began in 2001 when India's per capita GDP (854 USD/capita) surpassed that of Pakistan (847 USD/capita) for the very first time and has been at the top since then. During the same year, per capita DMC of India (3.7 t/capita) also exceeded that of Pakistan (3.6 t/capita) – indicating a correlation between material use and economic affluence among the regional countries. Therefore, it is important to understand the evolution of environmental governance and material consumption in subject countries against national economic development – before and after the year around 2001. Thus, the two prominent stages of environmental governance against per capita GDP were identified, as presented in Fig. 7.

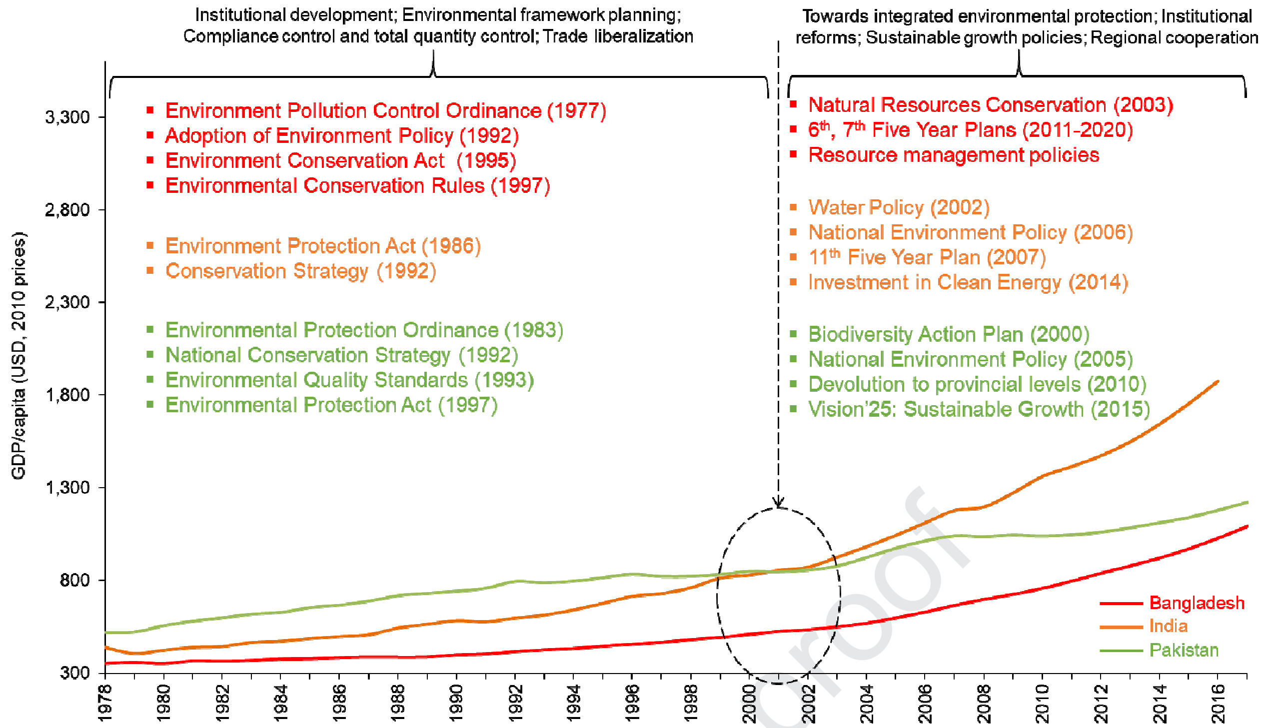

Fig. 7. Environmental protection development in three countries.

As presented, environmental policy synthesis in Bangladesh, India and Pakistan mostly began during late 1970's and continued for the next two decades. Prior to 2001, the subject countries mainly dealt with institutional development and environmental framework planning and execution, compliance and total quantity control along with trade liberalization with the world markets to boost local industries and export sectors. During 1980's and early 1990's, local environmental issues came in the limelight and role of state institutions in environmental management was strengthened to some extent. Later in 1990's, enhanced environmental compliance and emission control regulations were developed in all three countries. This period also showed some environmental improvements at regional levels when some of the major environmental laws were implemented along with multiple resource conservation policies. The time during 2000's presented rising GDP growth rates, though, performance on resource conservation, energy efficiency, and environmental management was still in early stages. During the late 2000's, rapid economic growth, especially in Bangladesh and India, helped them to strengthen their institutional ability and integrate environmental protection with sustainable development policies. During this time, Bangladesh implemented the seventh five-year plan for accelerating growth and empowering citizens, India began following cleaner production policies, while Pakistan initiated a sustainable development policy (Vision 2030) for the next fifteen years. The integration of environmental policies with economic development was also a result of global developments following the 2030 Agenda for Sustainable Development (UN, 2015).

Having said that, environmental compliance is always less prioritized in developing countries as compared to developed countries (Nakicenovic and Swart, 2000). Moreover, as developing countries grow economically, investments in environmental infrastructure and compliance increase gradually – even when environmental laws already exist (Schandl and West, 2010). Thus, with a per capita GDP below 2,000 USD, environmental protection had understandably been fragile in subject countries. A traditional practice of "pollute now and clean up later" is also highly relevant to developing countries where later environmental expenditures become significantly large (Chiu and Yong, 2004; Shenoy, 2015). As resource efficiency has improved in all three studied countries, thus, indicating a potential positive effect of relevant policies in the region with more improvement observed during the last two decades. Nevertheless, the socio-economic impacts of national level policies need to be further explored in future so as to optimize environmental resource management.

5.2. Bilateral trade dynamics

Mutual trade dynamics among Bangladesh, India and Pakistan were also analysed to synthesize key policy implications for regional resource supply availability and competition. Most recent trade statistics were analyzed to assess current situation and provide futuristic perspectives. Figure 8 presents the inter-country trade of commodities based on harmonized system classification (HSC) for the year 2017 and reported in current dollar prices (Simoes and Hidalgo, 2011; The World Bank, 2018; USITC, 2019).

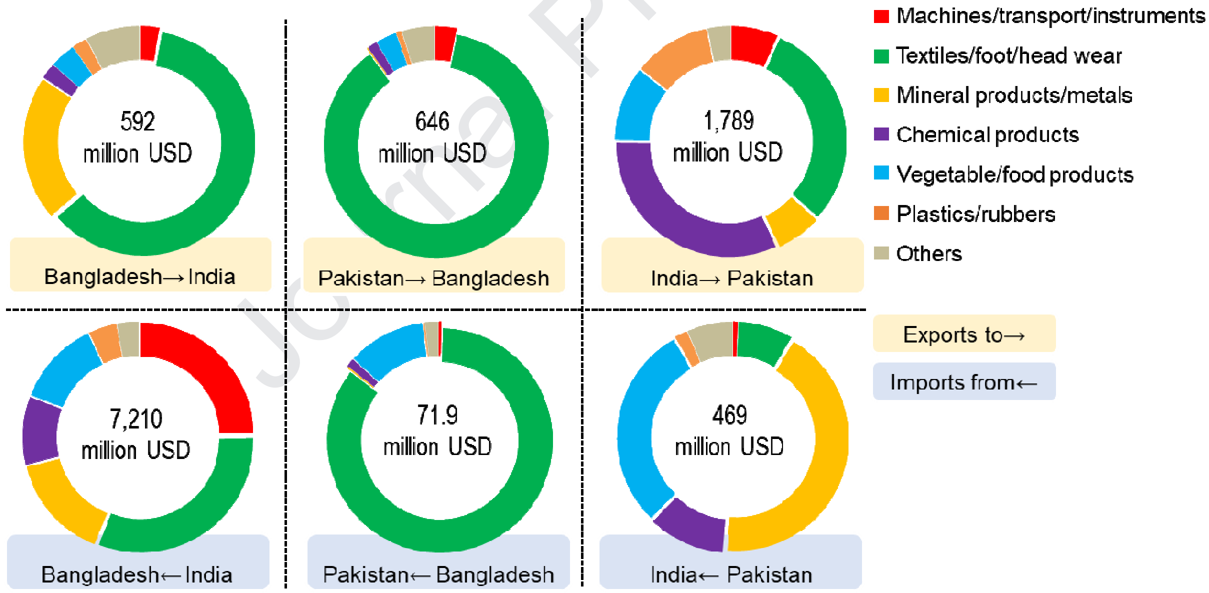

Fig. 8. Bilateral trade based on harmonized system classification, as of 2017.

As shown, the traded items mostly belong to material intensive and low-value sectors such as textiles, agricultural products, minerals and chemicals - all possessing higher environmental footprint (Barrett et al., 2018; Hammond, 2000). Therefore, the import dominant trade in subject countries with insignificant exports of high-value finished products can be a good area for improving resource efficiency especially when labor availability and their associated costs are comparatively low in this region. With current market dynamics, the trade balance relatively favors India whose exports to the other two countries amounted to 8.7 billion USD while imports from the two countries equaled about 1 billion USD. Understandably, India's large agro-industrial and manufacturing sector is able to substantially provide trade surplus with its neighboring economies. Pakistan and Bangladesh, however, need to make a transition towards energy-efficient and value-added manufacturing industries through which they can produce products of higher economic value but lesser environmental footprint. This can be done through industry restructuring, technological upgradation in existing industrial areas, phasing-out resource intensive agricultural products, value-addition in primary and intermediate production industries, and increasing shares of finished products and capital services.

Mutual trade of goods based on their processing stage depicts an interesting picture. India's exports to both Pakistan and Bangladesh comprise about 15% raw materials, 47% intermediate goods, and 38% consumer and capital goods. Bangladesh's exports to India and Pakistan include around 27% raw materials, 28% intermediate goods and 45% consumer and capital goods. Pakistan's exports to Bangladesh and India consist of nearly 18% raw materials, 68% intermediate goods, and 14% consumer and capital goods. Therefore, with significant share of primary materials and intermediate goods in exports, the region understandably lacks high resource efficiency. Since agriculture and industries contribute roughly in the range 40-50% to national GDP in all three countries, self-sufficiency in agricultural chemicals and fertilizers, fossil fuel carriers and industrial minerals is very crucial from futuristic policy perspective. Furthermore, as primary and secondary products usually carry low economic value compared to the finished products, a transition towards higher value addition and high-end production can help these countries to sufficiently increase their resource productivity. With regional exporting countries such as China, Japan and South Korea, competition for future resource supply and entry into new foreign markets for trade, at time of protectionist policies by some countries, is also very challenging for most of the developing countries including Bangladesh, India and Pakistan.

6. Conclusion and policy implications

This section will highlight the important findings of this study. Based on the results, key policy insights are also provided. The section will conclude by presenting some of the limitations of this work.

6.1. Main findings and conclusion

This study examined the economy-wide resource metabolism in Bangladesh, India and Pakistan – three largest and rapidly growing economies in South Asia – for the period 1978-2017. Various material flow and efficiency indicators were analyzed in the context of regional and global resource supply chain. The domestic drivers of material consumption, potential dematerialization of economic growth, policy impacts on resource efficiency, and regional bilateral trade dynamics were also analyzed. As per the results, per capita GDP levels have risen uniformly with India showing fastest growth. With rising income levels, the expansion of urban centers, agricultural output, transport infrastructure, industrial facilities, residential buildings etc. have led to a steady increase in DMC especially for construction minerals, fossil fuels, and industrial and agricultural minerals. This rapidly rising DMC has resulted in increasing inflows of foreign resources indicating a potential competition for regional and global resources especially when important regional economies such as China, Japan and South Korea have already become net importers of primary resources. Material efficiency in subject countries was comparable with other developing countries, but significantly lower than developed economies – indicating a higher resource consumption per unit contribution to the national economy coupled with internalization of energy and material intensive sectors. This was also reflected by higher mutual trade of primary and intermediate products among the three countries mostly comprising textiles, agricultural products, industrial minerals and chemicals. Based on the macro-policy analysis, environmental policy synthesis was found to begin during 1970's, though, higher GDP growth during early 2000's provided more opportunities for environmental protection and resource efficiency policies. With considerable legislative progress, current per capita GDP levels were, however, a huge impediment for integrated environmental management.

6.2. Policy implications

Based on our findings, we hereby present some of the important policy implications for Bangladesh, India and Pakistan:

(1) Resource productivity need to be improved, from a policy perspective, particularly in agricultural and industrial sectors which represent a significant chunk of national economy. In the industrial sector, steps including process innovation, substitution of raw materials, reduced material loss, restructuring, and promotion of resource-frugal, high-end production can have positive impacts. In the agricultural sector, minimizing the use of imported chemicals and fertilizers without compromising the net yield, and expanding domestic extraction of such resources can produce beneficial outputs.

(2) Based on the IPAT analysis, technological improvement was found to offset rising material consumption and reduce material intensity in all three countries. From 1998-2017, highest contribution from technological improvement was observed in slowing the growth in DMC that was driven mainly by affluence and partly by population. However, technological contribution usually drops with economic growth (Dong et al., 2017), therefore, continued policies on resource conservation and waste reduction must concurrently be implemented in subject countries.

(3) Lesson from developed countries can also be drawn and incorporated in national level policies from a resource conservation and waste reduction point of view. The application of 'circular economy model' in China (Su et al., 2013), 'eco-towns' in Japan (Low, 2013) and 'eco-industrial development' in South Korea (Park et al., 2018), all provide practical solutions to developing countries for improving domestic material efficiency. Nonetheless, rebound effects of industrial and economic development can be avoided using jump-forward approach and should be considered during the policy development phase.

(4) As dematerialization in South Korea came at lower per capita GDP (20,000 USD) compared to Japan and United States, similar pattern can be achieved by other developing countries. Though, dematerialization in one country at the cost of higher materialization in another country adds no value to the system as a whole yet these factors must be considered appropriately by policy makers.

6.3. Discussion on the limitations of this research

Research limitations and future concerns to address are presented here. First of all, data availability in annual transactions which may neglect manufactured stock materials (Wiedenhofer et al., 2019) is critical, therefore, data segregation on a lower time resolution can be helpful to incorporate impacts of material stocks. Resource management through international trading point of view can also be a handy research addition in this area which may also be complemented by life cycle and input-output approaches.

The other critical issue is the uncertainty generated by the projected data. As some of the available material flow data are projections based on previous years, an up-to-date database development is also of utmost importance. For countries with incomplete data, a complementary bottom-up approach (such as a survey of a specific area, individual unit or a sector) for data compiling will be helpful to improve the accuracy of data projection. Application of economic and econometric methods to uncover more information may also offer good data validation and value-added findings (which is also a follow-up work of this research). Nevertheless, uncertainty in macro level data, even when partially projected, is always a limitation for such type of a study, thus, a necessary investigation of data constraining factors is suggested.

Lastly, quantifying the socio-economic impacts of environmental and resource management policies at a national level is also an interesting area and needs to be explored in future.

Acknowledgements

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Appendix

In this section, we compared the material flow data with some existing socio-economic data, based on the basic assumptions as below:

$$\text{Resource consumption} = \frac{\text{resource consumed}}{\text{economic output}} \times \text{economic activity} \quad \text{(Eq. A1)}$$

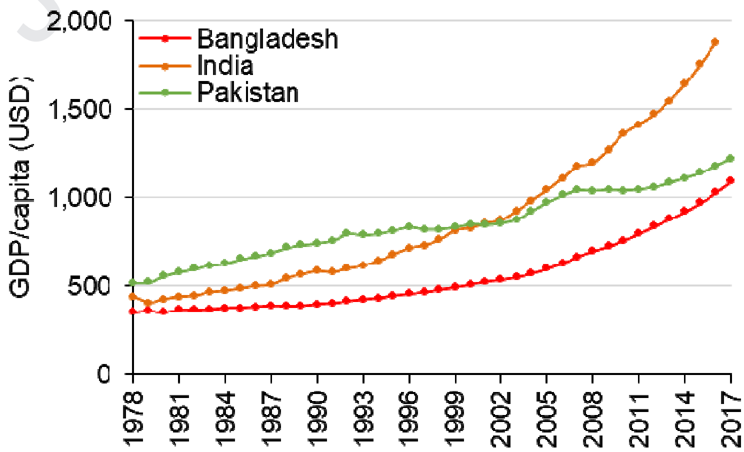
Where economic activity may include economic output, industrial production etc. Or we can write as:

$$\text{Resource consumption} = \text{resource consumed per capita} \times \text{activity} \quad \text{(Eq. A2)}$$

In these equations, 'resources over output' represents the technical efficiency, which usually does not have a leap in short years without a technological revolution or significant economic structural change. Hence the basic trend will remain uniform. Similarly, resources consumed per capita change cannot occur abruptly during short periods of time without any significant societal change. This is the foundation for projections and future estimations. Especially for countries such as Bangladesh, India and Pakistan, lack of real data availability is usually addressed through data projection and estimation. Here, we have used the most available socio-economic data (GDP, GDP/capita, and population) to have a comparison with the real material flow data (1978-2012) to projected material flow data (2013-2017).

As a basic analysis, Figure A1 (a) presents the GDP/capita of the three countries, which illustrates that from 2013-2017, it is a stable development period for the subject countries (GDP/capita was in a stable increasing trend). Figure A1 (b) presents that the correlation between DMC/capita (real data) and GDP/capita (economic prosperity, real data) was high for Bangladesh and India, but relatively low for Pakistan. Figure A1 (c) shows that the correlation between DMC/capita (predicted data) and GDP/capita (real data) is very high for both Bangladesh and India but relatively low for Pakistan, similar to what we found in the analysis of real data. Hence, we highlight that in general, more attention should be given to data uncertainty in countries which face economic fluctuations such as Pakistan. According to this investigation, in general, the projected data can be recognized as solid.

a. GDP/capita change from 1978-2017



b. Correlation of real material data with real economic data for 1978-2012

c. Correlation of predicted material data with real economic data for 2013-2017

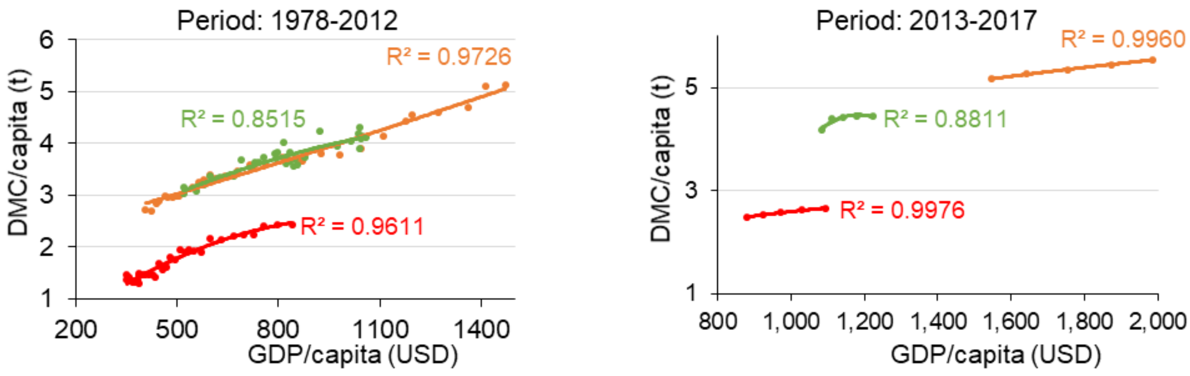


Figure A1. Correlation of material and socio-economic data

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Characterization of resource consumption and efficiency trends in Bangladesh, India and Pakistan: Economy-wide biotic and abiotic material flow accounting from 1978 to 2017

Highlights:

1. Resource metabolism features were analyzed in Bangladesh, India and Pakistan in a regional supply chain context from 1978-2017;
2. Driving forces of resource consumption in various periods were identified and compared to uncover policy insights from a transitional perspective;
3. Resource intensive production in bilateral trade resulted in lower resource productivity;
4. Macro-policies analysis highlighted lower economic development hindered integrated environmental management;
5. Future pathway towards resource efficiency scenarios in the three countries were proposed and discussed.

Author contributions

Use this form to specify the contribution of each author of your manuscript. A distinction is made between five types of contributions: Conceived and designed the analysis; Collected the data; Contributed data or analysis tools; Performed the analysis; Wrote the paper.

For each author of your manuscript, please indicate the types of contributions the author has made. An author may have made more than one type of contribution. Optionally, for each contribution type, you may specify the contribution of an author in more detail by providing a one-sentence statement in which the contribution is summarized. In the case of an author who contributed to performing the analysis, the author's contribution for instance could be specified in more detail as 'Performed the computer simulations', 'Performed the statistical analysis', or 'Performed the text mining analysis'.

If an author has made a contribution that is not covered by the five pre-defined contribution types, then please choose 'Other contribution' and provide a one-sentence statement summarizing the author's contribution.

Manuscript title: Characterization of resource consumption and efficiency trends in Bangladesh, India and Pakistan: Economy-wide biotic and abiotic material flow accounting from 1978 to 2017

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