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Abstract

India's transition towards circular economy is pivotal in achieving sustainable development goals-12, decent economic growth and reducing greenhouse gas emissions. This study investigates the role of circular economy in facilitating responsible behavior towards consumption and production, managing and reducing all types of waste generations in rural and urban area in India, focusing on its integration into industrial processes and the broader economic and environmental impacts. The research explores the future aspects of GHG and GDP after including circular practices in the industries through implication of policies such as extended producer responsibility(EPR). The study analyzes data from the UNEP-International Resource Panel, and World Bank. The dissertation reveals the importance of combining circularity in the major industries to increase the productivity and increase the material efficiency. The concept of a circular economy, which emphasizes waste prevention, product life extension, resource recovery, and closed-loop systems, offers a transformative approach to decouple economic growth from resource consumption and environmental harm. The findings underscore the importance of supportive policies, investment incentives, and technological innovations in scaling circular economic model adoption. The forecasted GHG and GDP for 2070 is 14560.88 $MtCO_2e$ and Rs. 3,050 lakh crore respectively after taking DMC at 2% annual growth rate, Co2 from waste at 3% and Material Productivity at 3% based on historical trend. But after taking these independent variables at different annual growth assuming circularity in India we have slightly different forecasted values of GHG and GDP then before, indicating circular economy has positive impact on both dependent variables.

Keywords: Circular economy, Domestic Material Consumption, Material Productivity, Gross Domestic Product, Green House Gas emissions, and Decoupling.

Introduction

As we are moving to 2030, many sustainable development goals are yet to complete to make India stand out in the global environment advocacy. Since many years we are observing the repercussions of uncontrollable and anthropogenic overconsumption and production in developing and developed countries. These overconsumptions and productions lead to environmental degradation such as careless management of waste, climate change, air pollution, contamination of water resources, loss of biodiversity, existence of wildlife and land use etc.

Human life and economic activities are fundamentally dependent on the natural environment, which provides essential resources for survival and growth. At the same time, these activities continually influence and modify the environment, and cannot be fully understood without considering their connection to natural systems. One of the most significant consequences of human actions is climate change, primarily driven by activities such as the burning of fossil fuels, industrial operations, and waste production. These processes have led to an increased concentration of greenhouse gases like carbon dioxide (CO_2) and methane (CH_4) in the atmosphere, intensifying the greenhouse effect and contributing to rising global temperatures and environmental instability (M. Balasubramanian et al., 2012). Anthropogenic activities have intensified the concentration of greenhouse gases in the atmosphere, resulting in a rise in the Earth's average temperature (Sridevi et al.,2014). Consumption of unnecessary goods and services by human is the main source of greenhouse gases.

As of now, just 55% of the world's greenhouse gas-emitting nations have declared concrete goals for enhancing carbon emission reductions by 2030, while the majority of countries maintain their net-zero emission commitments for the period between 2050 and 2070. (Chen et al. 2022). At the same time, developing nations continue to rely heavily on fossil fuel-based energy systems, where significant consumption of coal and oil in industrial and transport sectors exacerbates climate change and environmental degradation (Su and Urban 2021). Furthermore, with the continuous growth of the world population and improvements in living standards, the rise of manufacturing automation and AI has driven mass production and consumption. This, in turn, has create to a substantial rise in solid waste generation. The escalating quantity and complexity of this waste now present serious risks to both the environment and human health (Chioatto and Sospiro 2022; Kurniawan et al. 2022).

India produces approximately 68.8 million tons of solid waste per day, and improper waste disposal has become as a serious problem for urban areas and their surrounding regions. Municipal Solid Waste (MSW) in the country is composed of about 51% organic matter, while 17.5% consists of recyclable materials such as paper, plastic, metal, and glass (Williams et al., 2016).

The implementation of taxes, pollution control measures, emission trading systems, along with fines and charges for polluters, can help internalize environmental externalities through the **"polluter pays" principle** (GARCÍA-MADURGA et al. 2022). These mechanisms would raise the operational costs for polluting or inefficient firms, thereby encouraging them to invest in cleaner, more environmentally sustainable practices (Masi et al., 2017).

Adopting a circular economy model is considered a powerful strategy for advancing policy frameworks while simultaneously reducing environmental pollution and curbing greenhouse gas emissions (De Pascale et al. 2021; Durán-Romero et al. 2020).

43 The top 10 emitters such as China, the USA, the EU, India, the Russia, Japan, Brazil, Indonesia, Iran, and Canada are responsible for over 68% of global greenhouse gas emissions. In contrast, less than one hundred countries account for 3% of global greenhouse gas emissions (Yang et al., 2022).

Energy and materials circularity acts such as using scrap steel, recycling and reusing plastics, papers and cement can reduce energy consumption and dependence on expensive technologies like carbon capture (Fragkos 2022).

As per world economic forum the framework such as circular economy (CE) outlook can save over 1 trillion dollars per year globally because of lower carbon emission, lower costs and reduction in supply chain risk and about half trillion dollars of India's GDP value can be protected by circular economy (Fiksel, 2021).

7 So what do mean by a Circular Economy?

A circular economy is an economic system aim at removing waste and the continual use of natural resources. It focuses on reuse, sharing, repair, refurbishment, remanufacturing, and recycling to create a closed-loop system, minimizing the use of resource inputs and the generation of waste, pollution, and carbon emissions (Geissdoerfer et al., 2017).

15 In a circular economy (CE), the main aim is to

1. Increase the value of products, materials and natural resources

2. Use waste as a resource; and minimize waste generation (Bressanelli et al., 2019).

CE is a strategy(few decades old) or a path for achieving SDG-12 (Responsible Consumption and Production), reducing environmental harm, and facing the challenge of resource scarcity. (Madurga et al , 2022)

3 The traditional culture of repair and reuse has gradually declined, giving way to linear business models. As a result, underlying issues such as:

- reduction in resource efficiency dragging the economic growth of the country,

- rampant waste generation,
- negative externalities at the cost of socio-economic welfare attributable to environmental degradation,
- extreme poverty due to unemployment and
- low quality dangerous working environments (Bherwani et al., 2022).

As outlined by the Ellen MacArthur Foundation (2023), the circular economy aims to separate economic growth from the use of limited natural resources. It is built upon three core principles:

8

1. Preventing waste and pollution,
2. Keeping products and materials in use at their highest possible value, and
3. Restoring and enhancing natural systems.

Currently, just 7.2% of the world's economy operates under circular principles (Circle Economy, 2023)

With a global population of 8 billion, over 100 million tons of materials are consumed annually. According to Circle Economy (2023), this material consumption is expected to double by 2050 compared to 2015 levels, posing a significant risk to the sustainability of natural resource limits.

CE will enable us to ''fulfill people's needs with only 70% of the materials we now extract and use—moving human activity back within the safe limits of the planet'' (Circle Economy, 2023).

Material productivity is an important measure of a circular economy and has been widely applied in various studies (Busu &Trica, 2019) It is calculated as the GDP divided by domestic material consumption (DMC) which measures the total amount of materials directly used by an economy and expressed in the purchasing power standard (PPS) per kilogram (Eurostat, 2023).

47 This indicator provides an effective measure of advancement toward a circular economy, since economies that are more circular tend to use fewer natural resources and exert less pressure on the environment (Robaina et al., 2020). Therefore, it is expected that material productivity is positively correlated with economic growth.

32 In recent decades, numerous countries have aimed to achieve net-zero emissions by 2050. In OECD nations, materials management activities contribute substantially to greenhouse gas emissions, both directly and indirectly. Total GHG emissions are expected to reach 75 gigatons of CO_2-equivalent by 2060, with materials management accounting for approximately two-thirds (50 gigatons CO_2-eq) of this total (OECD, 2020). Similarly, the Ellen MacArthur Foundation (2021) reports that nearly 45% of current emissions are linked to product manufacturing

processes, highlighting the importance of reducing energy and resource use in alignment with the circular economy's core principles.

Consistent with this, the Ellen MacArthur Foundation (2021) highlights that the circular economy can significantly contribute to reaching net-zero emissions by potentially reducing greenhouse gas emissions by 9.3 billion tonnes. This can be achieved through strategies such as keeping materials in circulation, removing waste, and restoring green space. This reduction is estimated to be comparable to the total current global emissions from all transportation sources (Ellen MacArthur Foundation, 2021).

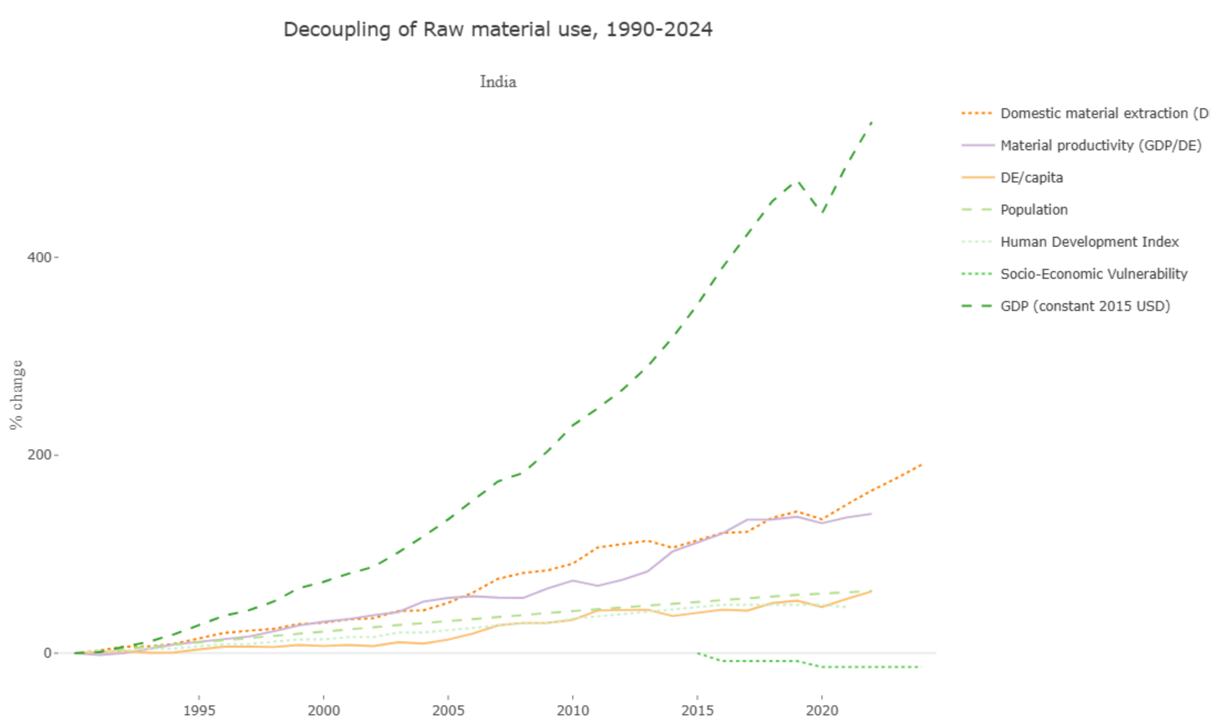
Literature Review

Modern economies heavily rely on the extraction and use of raw materials, which support both industrial production and societal development. However, the continuous rise in resource extraction has resulted in serious environmental consequences and social inequalities, pushing the planet beyond its safe ecological limits. The ever-increasing demand for natural resources intensifies ecological pressures and poses significant challenges to achieving global sustainability. (SCP-HAT Standard Report)

4

To address these issues, international frameworks such as Sustainable Development Goal (SDG) 8, which promotes Decent Work and Economic Growth, and SDG 12, focusing on Responsible Consumption and Production, encourage the adoption of more efficient and responsible resource use practices. One of the key approaches recommended within these frameworks is enhancing material efficiency — producing more economic value while using fewer raw materials, thereby improving material productivity.

Figure 1: Trend of raw material consumption.



Source – International Resource Panel, SCP-HAT, Module 2

A crucial step toward achieving sustainable resource use involves the concept of decoupling, where a country's economic output grows at a faster pace than its material consumption. In practical terms, this means decreasing the amount of natural resources required to sustain economic growth, typically measured through the material footprint. Decoupling economic performance from material use is fundamental to the transition towards a circular economy, which prioritizes resource efficiency, waste minimization, and the continual reuse of materials within production cycles.

Between 1990 and 2022, India experienced a significant rise in domestic raw material consumption, which increased by approximately 164.4%, from **2**.9 gigatonnes (Gt) or (2.9 billion **tonnes**) in 1990 to **7.7** Gt or **7.7** billion tonnes in 2022. Among the various material categories, non-metallic minerals accounted for the largest share in 2022, with consumption reaching 3497.2 million tonnes (Mt**)**, followed by biomass (2987.0 Mt**)**, fossil fuels (905.8 Mt**)**, and metallic minerals (281.7 Mt**)**.

India's economic development has increasingly relied on resources sourced both domestically and internationally, reflecting the complex interdependencies created by globalization and integrated global supply chains. This growing global interconnectedness has led to a geographical separation between where environmental pressures occur and where the benefits of production, trade, and consumption are experienced. The **material footprint** of a country — representing the total global extraction of resources driven by a nation's final consumption — illustrates this dynamic. For India, the material footprint grew by **167.2%** during the same period, reaching **7.2 Gt in 2022**. Here again, **non-metallic minerals** contributed the most (**2947.9 Mt**), followed by biomass (2567.8 Mt), fossil fuels (1124.4 Mt), and metallic minerals (511.7 Mt**)**.

Simultaneously, India's **Gross Domestic Product (GDP)** increased by a significant **536.6%** between 1990 and 2022. This considerable economic growth led to an improvement in **material productivity** defined as GDP generated per unit of material footprint, showing more economic output was achieved for each tonne of materials consumed.

A comparative analysis of trends in India's **material footprint**, **economic growth (GDP)**, and **human development** reveals important insights. Between **1990 and 2022**, India succeeded in achieving **relative decoupling** of material footprint from GDP growth. In other words, while both GDP and material consumption increased, the rate of economic growth consistently outpaced the rise in material use across domestic and global supply chains. However, when assessed in relation to human development outcomes, India did not achieve decoupling between **1990 and 2021**. This suggests that while economic gains were made more resource-efficient, improvements in human well-being and social progress, as captured by HDI, did not correspondingly decouple from material consumption trends. (UNEP, 2024)

Sustainable Development Goal (SDG) 13 (Climate Action) highlights the universal threat of climate change, which disrupts economies and jeopardizes long-term development. To tackle this, nations must lower their **greenhouse gas (GHG) emissions** while continuing to pursue socio-economic progress, measured through indicators such as **GDP** and **HDI**.

Beyond domestic emissions, it's important to account for **the emissions embedded along global supply chains**, known as a country's **carbon footprint**—the total GHG emissions globally attributable to the final consumption within a country. Progress in mitigating emissions relative to economic growth can be assessed using **carbon productivity**, calculated as GDP divided by the carbon footprint.

In India, GHG emissions rose by **181.1%** between 1990 and 2022, increasing from **1.3 Gt CO2 equivalent (CO2e)** to **3.6 Gt CO2e**. The primary contributor in 2022 was **carbon dioxide (2463.7 Mt CO2e)**, followed by **methane (833.0 Mt CO2e)**, **nitrous oxide (246.2 Mt CO2e)**, and other greenhouse gases (76.3 Mt CO2e). India's extensive global trade links mean its consumption patterns indirectly contribute to emissions worldwide, intensifying the global disconnect between the location of environmental pressures and consumption demands.

Over the same period, India's **carbon footprint** grew by **174.6%**, reaching **3.3 Gt CO2e** in 2022. The distribution of this footprint was dominated by **carbon dioxide (2239.2 Mt CO2e)**, followed by **methane (801.6 Mt CO2e)**, **nitrous oxide (219.0 Mt CO2e)**, and other gases (85.3 Mt CO2e). Notably, **GDP expanded by 536.6%**, leading to an increase in **carbon productivity**.

A comparative analysis of **carbon footprint**, economic growth (GDP), and **human development (HDI)** reveals that India achieved **relative decoupling** of GHG emissions from GDP between 1990 and 2022, meaning GDP growth outpaced the rise in emissions. However, this decoupling was not achieved in relation to HDI improvements over the same period, highlighting the ongoing challenge of aligning environmental sustainability with inclusive human development (UNEP, 2024).

Figure 2: Trend of domestic GHG emissions.

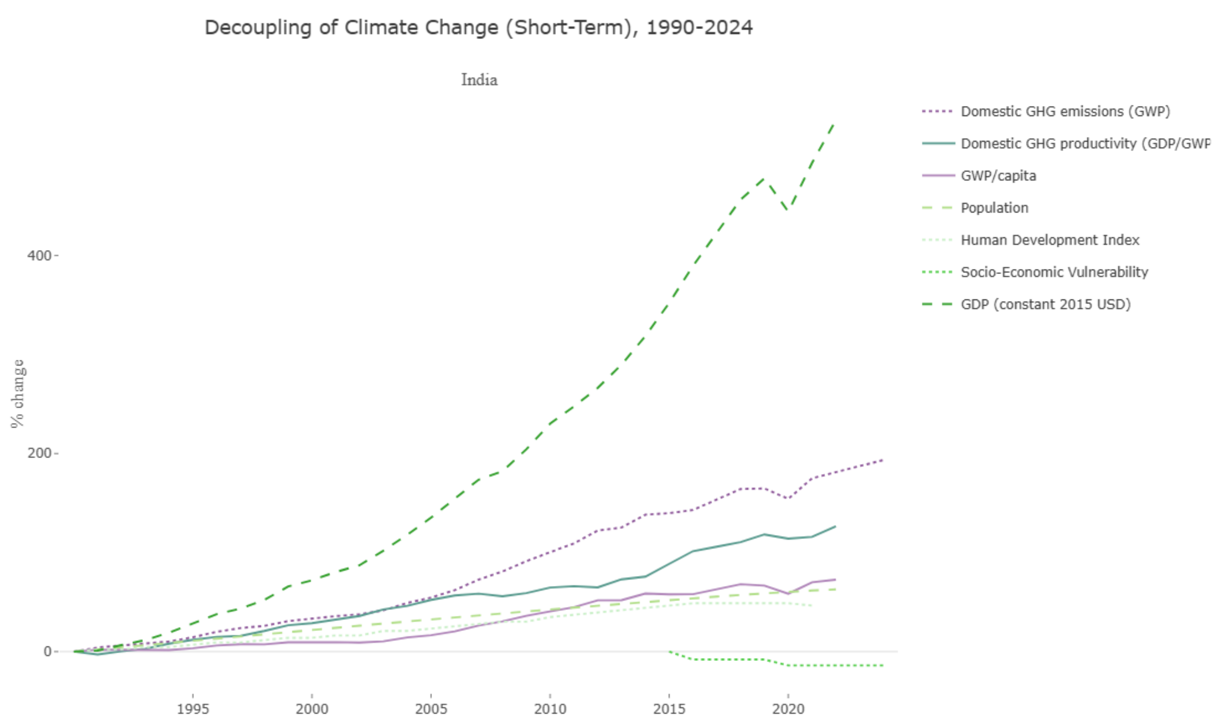


Figure 3: Trend of CO2 from waste collection, treatment, and disposal.

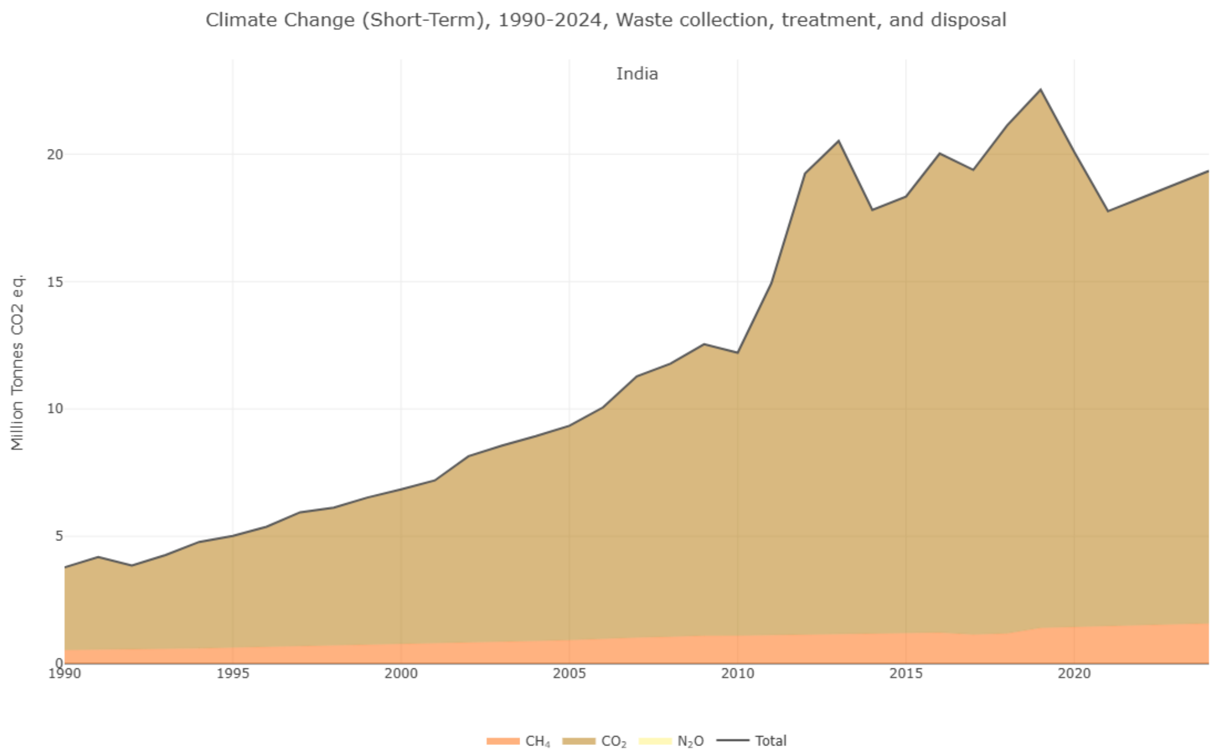
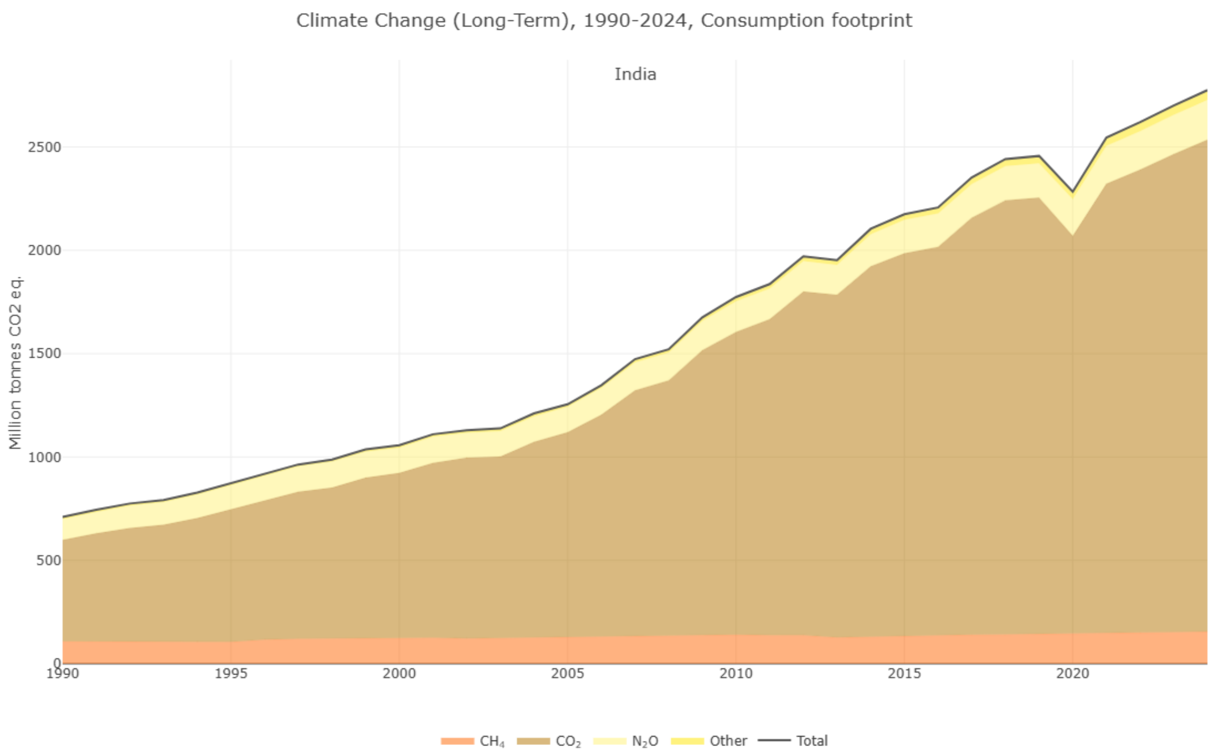
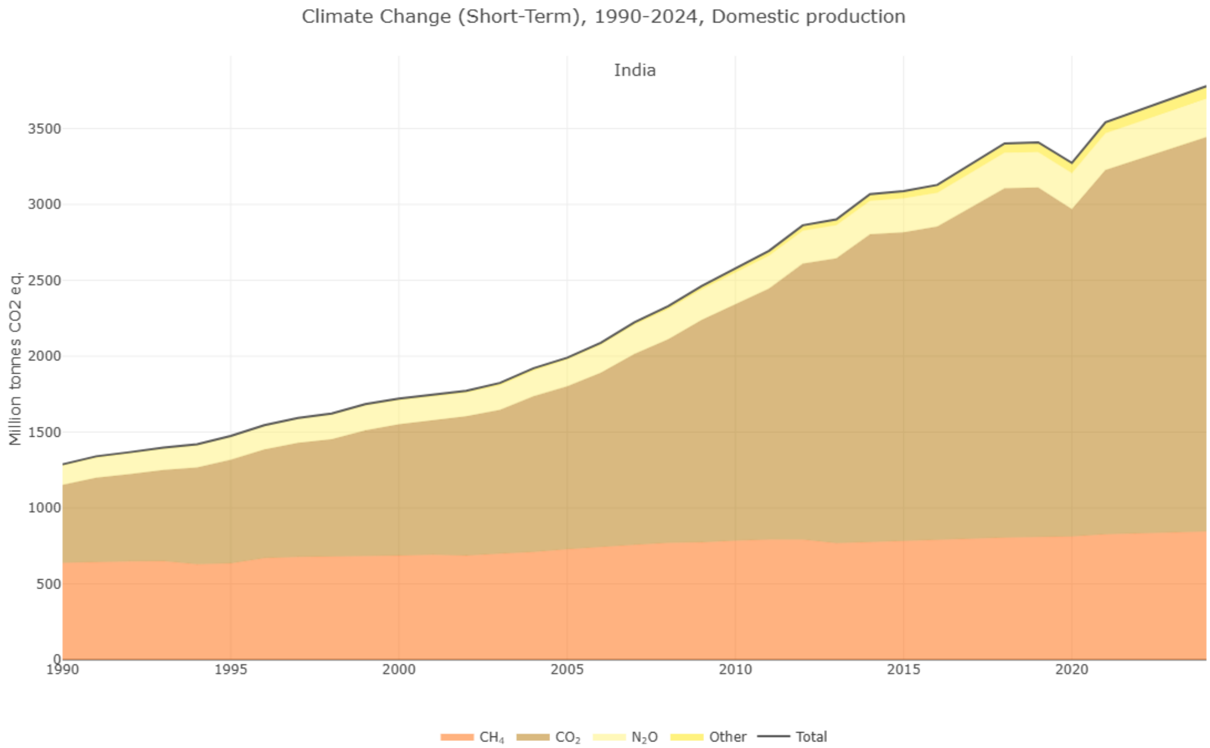


Figure 4: Trend and classification of GHG emissions from consumption.



Source- International Resource Panel, SCP-HAT, Module 2

Figure 5: Trend and classification of GHG emissions from domestic production.



Gaps in Literature Review

- **Gap 1**: Few studies quantitatively demonstrate how CE policies achieve **absolute decoupling** (GDP↑ + GHG↓) in India.
- **Contribution**: ARIMAX models can fill this by showing:

1. Relationship between material consumption and GHG
2. Use of MP as a **continuous variable** in time-series models provides replicable metrics for policy evaluation.

- **Gap 2**: Lack of datasets for circularity indicators in India such recycling rate, environmental tax, and Green jobs.
- **Contribution**: Use comprehensive datasets to show circularity in India such as Domestic Material Consumption and CO2 from waste collection and treatment.

Research Objectives

Research Question

1. Can an ARIMAX model incorporating material consumption (DMC) and waste-CO_2 trends accurately forecast future GHG emissions under business-as-usual conditions, and what policy interventions could alter this trajectory?

2. Can India decouple its economic growth from environmental crises based on resource efficiency and waste management before 2070 ?

Objectives

36 1. Measure Domestics Material Consumption(DMC) and Co2 Emissions from Waste's impact on GHG over the period of time till 2030, 2047, 2070. By doing this study aims to express the importance of circular economy implication in India to reduce wastage and GHG.

2. Analyze the impact of Material Productivity on GDP .

3. Analyze the trend of decoupling of economic growth from environment degradation.

Hypothesis Setting

Primary Hypothesis (Model Validation)

Null Hypothesis: The ARIMA(0,0,1) model do not **significantly** explains GHG emissions trends, with DMC and waste-CO_2 as predictors ($\beta_1 \neq 0$, $\beta_2 \neq 0$).

Alternative Hypothesis : The ARIMA(0,0,1) model **significantly** explains GHG emissions trends, with DMC and waste-CO_2 as predictors ($\beta_1 \neq 0$, $\beta_2 \neq 0$).

Data and Methodology

This study investigates the impact of the circular economy on greenhouse gas (GHG) emissions and Gross Domestic Product (GDP) in India over the period 2019 to 2024, with projections till 2030, 2047, and 2070. The analysis draws upon secondary time-series data sourced from reputable national and international databases.

The key variables considered in this study are:

- **Gross Domestic Product (GDP):** Measured at constant prices (PPP 2017 LCU), sourced from the World Bank.

- **Greenhouse Gas (GHG) Emissions:** Measured in million metric tons of CO_2 equivalent, aggregated from carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O) emissions, sourced from the World Bank.

- **Domestic Material Consumption (DMC):** It is an indicator to show resource use, indicating the total amount of material directly used in an economy. Data sourced from the United Nations Environment Program (UNEP), International Resource Panel. It is measured in million metric tons.

- **Material Productivity (MP):** is a key indicator of a circular economy and it has been used in numerous studies (Busu &Trica, 2019). It is calculated as the GDP divided by domestic material consumption (DMC) which measures the total amount of materials directly used by an economy and expressed in the purchasing power standard (PPS) per kilogram (Eurostat, 2023). Data obtained from UNEP's Global Material Flows Database.

- **CO_2 Emissions from Waste collection, treatment, and disposal:** Represents emissions resulting specifically from waste management processes in India. Data sourced from International Resource Panel's SCP HAT. It is measured in Mt

Econometric Modeling

- **Elasticity Estimation:**
  GHG elasticity with respect to GDP is estimated before including circular economy variables to observe whether the economy's emissions intensity.

  Figure 6: Elasticity of GHG over GDP as per 2023

. reg ln_ghg ln_gdp

Source	SS	df	MS			
				Number of obs	=	34
				F(1, 32)	=	4067.20
Model	3.86235859	1	3.86235859	Prob > F	=	0.0000
Residual	.030388331	32	.000949635	R-squared	=	0.9922
				Adj R-squared	=	0.9919
Total	3.89274692	33	.117962028	Root MSE	=	.03082

ln_ghg	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
ln_gdp	.5606162	.0087906	63.77	0.000	.5427103	.578522
_cons	-10.06568	.2796724	-35.99	0.000	-10.63535	-9.496002

- The model ln_GHG = -10.07 + 0.56*ln_GDP is a log-log regression
- Coefficient of ln_GDP(0.56) represents the **elasticity of GHG emissions with respect to GDP**.
- Interpretation: A **1% rise in GDP** is associated with a **0.56% rise in GHG emissions,** holding other factors constant.
- This indicates **inelastic demand for emissions relative to economic growth** (elasticity < 1).
- Decoupling occurs when GHG emissions grow **slower than GDP**.
- **Elasticity < 1 (0.56)**: Emissions grow at **~56% the rate of GDP growth**.
- Example: If India's GDP grows by 10%, emissions rise by only 5.6%.
- **Statistical Significance**: The coefficient is highly significant (p = 0.000), confirming this relationship.

Descriptive Statistics

21 The preliminary analysis involves summarizing the data through descriptive statistics (mean, standard deviation, maximum, and minimum values) to examine the strength and direction of linear relationships between variables.

Figure 7: Descriptive Analysis of all variables.

. summarize ghg

Variable	Obs	Mean	Std. Dev.	Min	Max
ghg	34	2499.642	848.8416	1383.064	4133.554

. summarize gdp

Variable	Obs	Mean	Std. Dev.	Min	Max
gdp	34	7.76e+13	4.52e+13	2.51e+13	1.74e+14

. summarize mp

Variable	Obs	Mean	Std. Dev.	Min	Max
mp	34	15502.43	4596.573	9378.264	23345.78

. summarize Co2waste

Variable	Obs	Mean	Std. Dev.	Min	Max
Co2waste	106	29.78248	18.66669	3.24725	71.87061

. summarize dmc if year <= 2023

Variable	Obs	Mean	Std. Dev.	Min	Max
dmc	34	5361.765	1769.269	3000	8900

Unit Root and Stationarity Tests

Time-series data often exhibit trends, and it is essential to check for stationarity before proceeding with regression analysis. The study applies the following tests:

- Augmented Dickey-Fuller (ADF) Test

The test ascertains whether the series are stationary at levels or after differencing.

Figure 8: Output of stationary test of all variables.

```
. dfuller d_ln_gdp, lags(1)   // Check stationarity after differencing

Augmented Dickey-Fuller test for unit root         Number of obs   =        31

                               ---------- Interpolated Dickey-Fuller ---------
                  Test         1% Critical       5% Critical      10% Critical
               Statistic           Value             Value             Value
------------------------------------------------------------------------------
 Z(t)             -4.195            -3.709            -2.983            -2.623
------------------------------------------------------------------------------
. do "C:\Users\PC\AppData\Local\Temp\STD01000000.tmp"

. dfuller d_ghg

Dickey-Fuller test for unit root                   Number of obs   =        32

                               ---------- Interpolated Dickey-Fuller ---------
                  Test         1% Critical       5% Critical      10% Critical
               Statistic           Value             Value             Value
------------------------------------------------------------------------------
 Z(t)             -4.275            -3.702            -2.980            -2.622
------------------------------------------------------------------------------
MacKinnon approximate p-value for Z(t) = 0.0005
```

- **ARIMAX Models:**
  The Autoregressive Integrated Moving Average with exogenous variables (ARIMAX) model is used to incorporate circular economy indicators (DMC and MP) as explanatory variables to assess their influence on GHG emissions. A Dickey-Fuller test with trend confirmed stationarity of the first-differenced DMC series. GHG and Co2 waste became stationary after first-differenced without trend.

Figure 9: ARIMAX model, arima d_ghg d_dmc d_Co2waste epr_policy if year <= 2023, arima(0,0,1)

```
ARIMA regression

Sample:  1991 - 2023                            Number of obs     =         33
                                                Wald chi2(4)      =      91.34
Log likelihood = -187.1518                      Prob > chi2       =     0.0000

------------------------------------------------------------------------------
             |                 OPG
       d_ghg |      Coef.   Std. Err.      z    P>|z|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
d_ghg        |
       d_dmc |    .348301   .0688308     5.06   0.000     .2133951     .483207
  d_Co2waste |   42.40345   8.273787     5.13   0.000     26.18712    58.61977
  epr_policy |    18.7656   9.997504     1.88   0.061    -.8291445    38.36035
       _cons |  -4.430852   12.76685    -0.35   0.729    -29.45341    20.59171
-------------+----------------------------------------------------------------
ARMA         |
          ma |
         L1. |  -1.000001   .2545298    -3.93   0.000     -1.49887   -.5011316
-------------+----------------------------------------------------------------
      /sigma |   66.61464          .        .       .            .           .
------------------------------------------------------------------------------
Note: The test of the variance against zero is one sided, and the two-sided
      confidence interval is truncated at zero.
```

$$\Delta GHGt = -4.43 + 0.3483 \times \Delta DMCt + 42.40 \times \Delta\ CO2Wastet + 18.77 \times EPRPolicyt - 1.000 \times et-1+et$$

Table 1**:** Details of the variables.

Variable	Coefficient	P-value	Significance
d-dmc	0.34830	0.000	Significant at 1%
d_Co2waste	42.4034	0.000	Significant at 1%
Constant	-4.4308	0.729	Not significant
EPR policy	18.7656	0.061	Significant at 10%
Moving Average	-1.0000	0.000	Significant at 1%

In this study, an **(ARIMAX) with Exogenous Variables** model has been used to forecast **Greenhouse Gas (GHG) emissions in India** under the influence of circular economy indicators. It includes external predictor variables (also called regressors) that may influence the dependent variable beyond its own lagged values and past errors.

Model Specification

The selected model for the study is **ARIMAX (0,0,1)**, meaning:

- **AR (p) = 0**: No autoregressive terms.
- **I (d) = 0**: The series is stationary at level (after differencing GHG once to remove non-stationarity).
- **MA (q) = 1**: One lag of the error term is included.
- **Exogenous variables (X)**:
    - **Differenced Domestic Material Consumption (d_dmc)**
    - **Differenced CO_2 Emissions from Waste (d_Co2waste)**
    - **EPR Policy Dummy Variable (epr_policy)** — indicating presence of EPR policy intervention from 2016 onwards.

Interpretation:

- **Both explanatory variables, DMC and Co2 from waste are statistically significant** at the 1% level and 5% respectively.
- A 1-unit increase in the change in DMC leads to a **0.35-unit increase in GHG emissions**.
- A 1-unit increase in the change in CO_2 emissions from waste causes a **42.4 unit increase in GHG emissions**.
- **EPR Policy Dummy** is statistically significant at **10% level (marginally)**. This positive sign is a bit counterintuitive, as EPR is expected to lower GHG emissions.

  This suggests:

- Either EPR's measurable effect on reducing emissions hasn't materialized in the short term.
- Or that implementation lag and coverage gaps have limited its immediate impact.
- **MA (1) term is significant**, indicating residual autocorrelation at lag 1 is captured well.
- The overall model is statistically significant (**Wald chi2(3) = 60.77, p = 0.0000**).
- Coefficient is not statistically significant, indicating no fixed intercept effect in explaining changes in GHG emissions.

Wald Chi-squared (4) = 91.34, p = 0.0000
→ Jointly, all predictors in the model are highly significant.

• **Material consumption (DMC)** and **CO_2 emissions from waste** have statistically significant, positive short-run impacts on changes in GHG emissions in India.

• The inclusion of **EPR Policy as a dummy variable** shows a **positive but marginally significant effect**, indicating complexities or lagging outcomes in the short-run, which might improve with stronger implementation over time.

• The **moving average term successfully captures residual autocorrelation**, ensuring robust error term management.

• Overall, the model is statistically sound and reliable for short-run policy-oriented environmental forecasting

The ARIMAX (0,0,1) model confirms that both material consumption and waste-related CO2 emissions have a statistically significant and positive impact on the change in India's GHG emissions. The model effectively captures the moving average component in the residuals and offers a reliable short-run dynamic forecasting framework. Residual diagnostics indicate robustness, making this model suitable for policy-oriented environmental forecasting.

The selected following model for forecasting GDP is ARIMAX (1,0,1):

Figure 10: Output of ARIMAX model of GDP based on material productivity.

ARIMA regression

Sample: 1991 - 2023 Number of obs = 33
Wald chi2(2) = 9.12
Log likelihood = 76.58963 Prob > chi2 = 0.0105

d_ln_gdp	Coef.	OPG Std. Err.	z	P>|z|	[95% Conf.	Interval]
d_ln_gdp						
d_ln_mp	.4593516	.1912521	2.40	0.016	.0845043	.8341988
_cons	.0470664	.0057347	8.21	0.000	.0358266	.0583063
ARMA						
ar						
L1.	.6663812	.2712187	2.46	0.014	.1348022	1.19796
ma						
L1.	-.9999995	.	.	.	.	.
/sigma	.0230387	.0031625	7.29	0.000	.0168404	.029237

Model equation:

d(lnGDP)t = 0.0471 + 0.4594×d(lnMP)t + 0.6664×(lnGDP)t−1 – 0.9999×et−1+et

- Its own lag AR (1), that is past value of previous period of GDP.
- A lagged error term MA (1), that is past error term et-1.
- **Material productivity (d_ln_mp)** as an exogenous variable.

Wald chi square which is 9.12 ($p = 0.0105$), means the joint significance test of predictors is statistically significant ($p < 0.05$), meaning the included variables have explanatory power over GDP growth.

Log Likelihood is 76.58963, which means model is good for comparison.

Variable d_ln_gdp (lag) has coefficient of 0.4594 with P-value of 0.016, means the first lag of GDP growth (log-difference) has a positive and significant effect on current GDP growth. A 1% increase in last period's GDP growth is associated with a **0.459% increase** in this period's GDP growth.

Variable d_ln_mp has coefficient of 0.0471 with P-value of 0.000, means Material productivity growth has a **positive and highly significant** effect. A 1% increase in material productivity growth leads to a **0.047% increase in GDP growth**.

AR (L1) Autoregressive term with lag 1 has coefficient of 0.6664 with Significant p-value ($p < 0.05$), indicating positive autocorrelation in GDP growth, meaning last year's growth positively affects this year's.

MA(L1) Moving Average with lag 1 has coefficient of -0.9999(Approximate value of -1, suggesting a strong correction for shocks in GDP growth, i.e., errors from the previous period almost fully offset in the current period.

The standard deviation of residuals (model's error term). Lower is better — and this is fairly low for log-differenced GDP growth.

The ARIMA model suggests that GDP growth in India is significantly influenced by both its past values and material productivity growth. Past GDP growth has a strong positive impact on current growth. Additionally, material productivity growth contributes positively and significantly to economic growth. The model also reveals significant autoregressive (AR) and moving average (MA) dynamics, indicating the presence of persistent trends and correction mechanisms in the time series of GDP growth.

17 These are the forecasted value of GHG from 2024 - 2070 based on exogenous variables (Projected DMC at 3% annual growth based on historical trend) and (Projected CO2waste at 2% annual growth based on historical trend).

On the right side there is forecasted value of GDP from 2024 – 2070 based on material productivity which is projected at 3% annual growth based on historical trend.

Figure 11: Forecasted value of GHG(Left) and GDP(Right).

year	ghg	ghg_fo~t	lower	upper
2020	3433.62	4133.554	3991.615	4275.494
2021	3679.86	4133.554	3991.615	4275.494
2022	3897.21	4133.554	3991.615	4275.494
2023	4133.55	4133.554	3991.615	4275.494
2024	.	4157.955	4016.015	4299.894
2025	.	4269.404	4095.865	4442.943
2026	.	4383.924	4210.385	4557.463
2027	.	4501.603	4328.064	4675.142
2028	.	4622.534	4448.995	4796.073
2029	.	4746.813	4573.273	4920.352
2030	.	4874.537	4700.998	5048.076
2031	.	5005.807	4832.268	5179.346
2032	.	5140.727	4967.188	5314.266
2033	.	5279.404	5105.865	5452.943
2034	.	5421.948	5248.409	5595.487
2035	.	5568.473	5394.934	5742.012
2036	.	5719.095	5545.556	5892.634
2037	.	5873.935	5700.396	6047.474
2038	.	6033.115	5859.576	6206.654
2039	.	6196.763	6023.224	6370.302
2040	.	6365.011	6191.472	6538.55
2041	.	6537.994	6364.455	6711.533
2042	.	6715.849	6542.31	6889.388
2043	.	6898.721	6725.182	7072.26
2044	.	7086.757	6913.218	7260.296
2045	.	7280.108	7106.569	7453.647
2046	.	7478.931	7305.392	7652.47
2047	.	7683.386	7509.847	7856.925
2048	.	7893.639	7720.1	8067.178
2049	.	8109.86	7936.321	8283.399
2050	.	8332.226	8158.687	8505.765
2051	.	8560.915	8387.376	8734.454
2052	.	8796.114	8622.575	8969.653
2053	.	9038.016	8864.477	9211.555
2054	.	9286.815	9113.276	9460.354
2055	.	9542.718	9369.179	9716.257
2056	.	9805.931	9632.392	9979.47
2057	.	10076.67	9903.131	10250.21
2058	.	10355.16	10181.62	10528.7
2059	.	10641.62	10468.08	10815.16
2060	.	10936.29	10762.75	11109.83
2061	.	11239.42	11065.88	11412.96
2062	.	11551.25	11377.71	11724.79
2063	.	11872.04	11698.5	12045.57
2064	.	12202.04	12028.5	12375.58
2065	.	12541.54	12368.01	12715.08
2066	.	12890.82	12717.28	13064.36
2067	.	13250.16	13076.62	13423.7
2068	.	13619.86	13446.32	13793.39
2069	.	14000.22	13826.68	14173.76
2070	.	14391.56	14218.02	14565.1

year	gdp	gdp_fo~t	lower	upper
2020	1.4e+14	1.74e+14	1.66e+14	1.82e+14
2021	1.5e+14	1.74e+14	1.66e+14	1.82e+14
2022	1.6e+14	1.74e+14	1.66e+14	1.82e+14
2023	1.7e+14	1.74e+14	1.66e+14	1.82e+14
2024	.	1.85e+14	1.77e+14	1.94e+14
2025	.	1.97e+14	1.88e+14	2.07e+14
2026	.	2.09e+14	1.99e+14	2.20e+14
2027	.	2.23e+14	2.12e+14	2.34e+14
2028	.	2.37e+14	2.25e+14	2.49e+14
2029	.	2.52e+14	2.39e+14	2.64e+14
2030	.	2.67e+14	2.54e+14	2.81e+14
2031	.	2.84e+14	2.70e+14	2.98e+14
2032	.	3.02e+14	2.87e+14	3.17e+14
2033	.	3.21e+14	3.05e+14	3.37e+14
2034	.	3.41e+14	3.24e+14	3.58e+14
2035	.	3.62e+14	3.45e+14	3.80e+14
2036	.	3.85e+14	3.66e+14	4.04e+14
2037	.	4.09e+14	3.89e+14	4.30e+14
2038	.	4.34e+14	4.13e+14	4.56e+14
2039	.	4.62e+14	4.39e+14	4.85e+14
2040	.	4.90e+14	4.67e+14	5.15e+14
2041	.	5.21e+14	4.96e+14	5.47e+14
2042	.	5.54e+14	5.27e+14	5.82e+14
2043	.	5.88e+14	5.60e+14	6.18e+14
2044	.	6.25e+14	5.95e+14	6.57e+14
2045	.	6.64e+14	6.32e+14	6.98e+14
2046	.	7.06e+14	6.72e+14	7.41e+14
2047	.	7.50e+14	7.14e+14	7.88e+14
2048	.	7.97e+14	7.58e+14	8.37e+14
2049	.	8.46e+14	8.06e+14	8.89e+14
2050	.	8.99e+14	8.56e+14	9.45e+14
2051	.	9.55e+14	9.09e+14	1.00e+15
2052	.	1.02e+15	9.66e+14	1.07e+15
2053	.	1.08e+15	1.03e+15	1.13e+15
2054	.	1.15e+15	1.09e+15	1.20e+15
2055	.	1.22e+15	1.16e+15	1.28e+15
2056	.	1.29e+15	1.23e+15	1.36e+15
2057	.	1.37e+15	1.31e+15	1.44e+15
2058	.	1.46e+15	1.39e+15	1.53e+15
2059	.	1.55e+15	1.48e+15	1.63e+15
2060	.	1.65e+15	1.57e+15	1.73e+15
2061	.	1.75e+15	1.67e+15	1.84e+15
2062	.	1.86e+15	1.77e+15	1.96e+15
2063	.	1.98e+15	1.88e+15	2.08e+15
2064	.	2.10e+15	2.00e+15	2.21e+15
2065	.	2.23e+15	2.13e+15	2.35e+15
2066	.	2.37e+15	2.26e+15	2.49e+15
2067	.	2.52e+15	2.40e+15	2.65e+15
2068	.	2.68e+15	2.55e+15	2.81e+15
2069	.	2.85e+15	2.71e+15	2.99e+15
2070	.	3.02e+15	2.88e+15	3.18e+15

Table 2: Key Highlights of forecasted values of variables.

Year	GHG ($MtCO_2e$)	GDP(Constant) (Rupees)	DMC (Tons)	CO_2 from Waste (Mt)	MP (Rs/Tones)
2030	4875	₹267.3 Lakh Crore	10946	19.84	28712
2047	7683	₹749.7 Lakh Crore	18092	27.78	47457
2070	14,391	₹3,020 Lakh Crore	35706	43.81	93660

Trend of GHG: Steady and significant increase from **1,383 Mt in 1990** to **14,391 Mt in 2070** (~10.7x growth).

- Growth accelerates post-2020(covid-19), suggesting rising industrial activity, energy demand, or insufficient de-carbonization policies.
- No peak or decline observed—contrary to global climate goals (e.g., net-zero by 2050).
- **Policy Implication**: Without aggressive mitigation (e.g., renewables, carbon capture), emissions will continue rising dangerously.

Trend of DMC: Grows from **3000 Million tonnes (1990)** to **35706 Million tonnes (2070)** (~12x increase).

- Linear growth, indicating no decoupling from economic/population expansion.
- **Policy Implication**: Circular strategies (recycling, efficiency) are needed to flatten the curve.

Trend of Co2 from waste: Rises from **3.25 Mt (1990)** to **43.81 Mt (2070)** (~13.5x increase).

- Tracks closely with DMC, suggesting waste generation is tied to material consumption.
- No significant waste reduction or advanced treatment (e.g., zero-landfill policies) is modeled.
- **Policy Implication**: Waste-to-energy, composting, and stricter landfill regulations could curb this trend.

Model Diagnostic and Validation Tests

To ensure the robustness of the estimated models, the following diagnostic tests are conducted:

Forecast after assuming circularity in the country:

These are the forecasted value of GHG from 2024 - 2070 based on exogenous variables (When projected DMC at 2% annual growth), (Projected CO2waste at 1% annual growth) and introduction EPR (Extended Producer Responsibility) policy from 2016 after assuming some circularity in the country through policy implementation.

On the right side there is forecasted value of GDP from 2024 – 2070 based on material productivity which is projected at 5% annual growth after some circularity in the country.

Figure 12: Forecasted value of GHG(Left) and GDP(Right).

year	ghg	ghg_f~t2	lower2	upper2
2023	4133.55	4133.554	3991.615	4275.494
2024	.	4140.75	3979.772	4263.651
2025	.	4225.72	4021.679	4368.757
2026	.	4312.028	4096.493	4443.571
2027	.	4399.701	4172.639	4519.717
2028	.	4488.765	4250.145	4597.223
2029	.	4579.247	4329.035	4676.113
2030	.	4671.176	4409.338	4756.417
2031	.	4764.579	4491.082	4838.16
2032	.	4859.484	4574.294	4921.373
2033	.	4955.921	4659.004	5006.082
2034	.	5053.921	4745.24	5092.318
2035	.	5153.513	4833.033	5180.111
2036	.	5254.728	4922.413	5269.491
2037	.	5357.599	5013.411	5360.489
2038	.	5462.156	5106.059	5453.137
2039	.	5568.435	5200.389	5547.467
2040	.	5676.466	5296.434	5643.512
2041	.	5786.286	5394.229	5741.307
2042	.	5897.929	5493.806	5840.884
2043	.	6011.431	5595.202	5942.28
2044	.	6126.827	5698.452	6045.53
2045	.	6244.155	5803.592	6150.67
2046	.	6363.453	5910.66	6257.738
2047	.	6484.759	6019.693	6366.771
2048	.	6608.113	6130.73	6477.809
2049	.	6733.554	6243.811	6590.889

year	gdp	gdp_f~t1	lower	upper
2020	1.4e+14	1.74e+14	1.66e+14	1.82e+14
2021	1.5e+14	1.74e+14	1.66e+14	1.82e+14
2022	1.6e+14	1.74e+14	1.66e+14	1.82e+14
2023	1.7e+14	1.74e+14	1.66e+14	1.82e+14
2024	.	1.87e+14	1.77e+14	1.94e+14
2025	.	1.99e+14	1.88e+14	2.07e+14
2026	.	2.11e+14	1.99e+14	2.20e+14
2027	.	2.25e+14	2.12e+14	2.34e+14
2028	.	2.39e+14	2.25e+14	2.49e+14
2029	.	2.54e+14	2.39e+14	2.64e+14
2030	.	2.70e+14	2.54e+14	2.81e+14
2031	.	2.87e+14	2.70e+14	2.98e+14
2032	.	3.04e+14	2.87e+14	3.17e+14
2033	.	3.24e+14	3.05e+14	3.37e+14
2034	.	3.44e+14	3.24e+14	3.58e+14
2035	.	3.65e+14	3.45e+14	3.80e+14
2036	.	3.88e+14	3.66e+14	4.04e+14
2037	.	4.12e+14	3.89e+14	4.30e+14
2038	.	4.38e+14	4.13e+14	4.56e+14
2039	.	4.66e+14	4.39e+14	4.85e+14
2040	.	4.95e+14	4.67e+14	5.15e+14
2041	.	5.26e+14	4.96e+14	5.47e+14
2042	.	5.59e+14	5.27e+14	5.82e+14
2043	.	5.93e+14	5.60e+14	6.18e+14
2044	.	6.31e+14	5.95e+14	6.57e+14
2045	.	6.70e+14	6.32e+14	6.98e+14
2046	.	7.12e+14	6.72e+14	7.41e+14

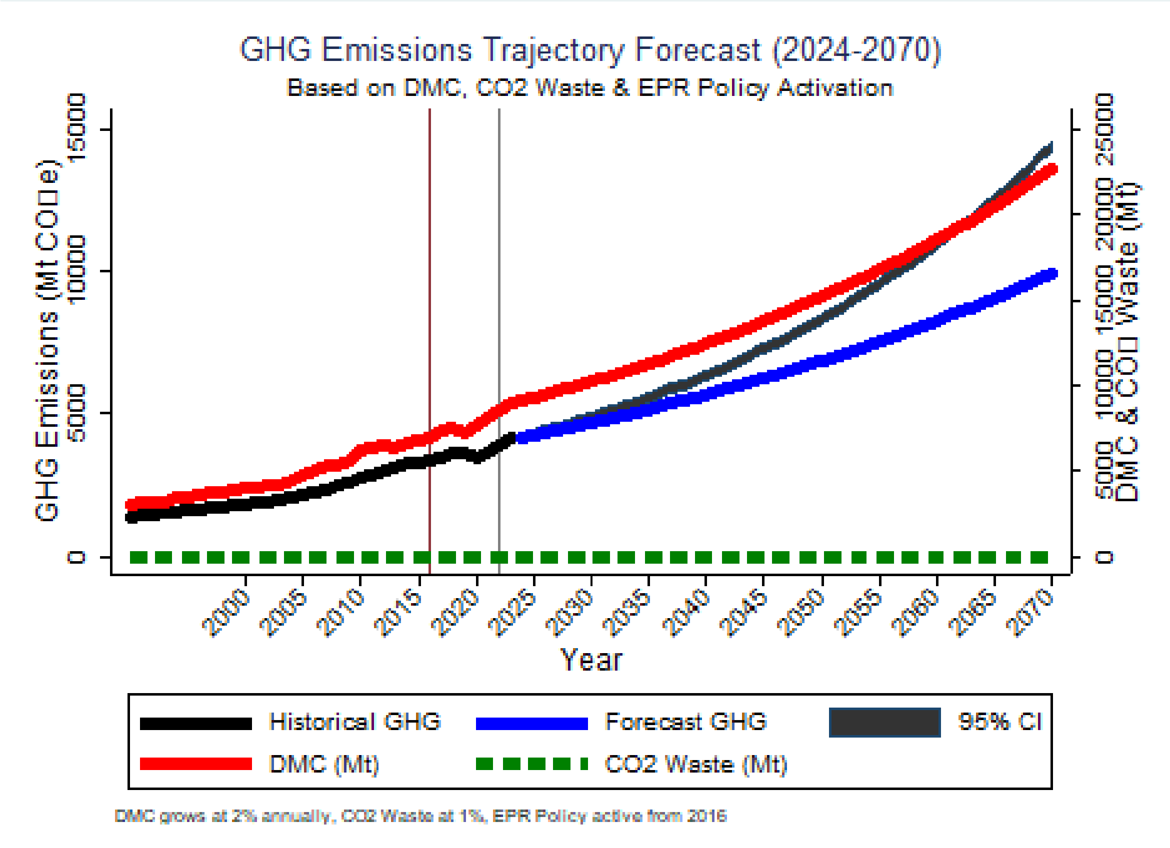
2050	.	6861.123	6358.975	6706.053
2051	.	6990.861	6476.264	6823.342
2052	.	7122.813	6595.718	6942.796
2053	.	7257.019	6717.382	7064.46
2054	.	7393.525	6841.298	7188.376
2055	.	7532.376	6967.51	7314.588
2056	.	7673.618	7096.064	7443.143
2057	.	7817.297	7227.006	7574.084
2058	.	7963.461	7360.383	7707.461
2059	.	8112.16	7496.243	7843.321
2060	.	8263.441	7634.634	7981.712
2061	.	8417.357	7775.607	8122.685
2062	.	8573.959	7919.212	8266.29
2063	.	8733.299	8065.501	8412.579
2064	.	8895.431	8214.527	8561.605
2065	.	9060.41	8366.345	8713.423
2066	.	9228.292	8521.008	8868.086
2067	.	9399.134	8678.572	9025.65
2068	.	9572.993	8839.097	9186.175
2069	.	9749.93	9002.638	9349.716
2070	.	9930.003	9169.256	9516.334

[illegible]	.	[illegible]	[illegible]	[illegible]
2047	.	7.56e+14	7.14e+14	7.88e+14
2048	.	8.04e+14	7.58e+14	8.37e+14
2049	.	8.54e+14	8.06e+14	8.89e+14
2050	.	9.07e+14	8.56e+14	9.45e+14
2051	.	9.64e+14	9.09e+14	1.00e+15
2052	.	1.02e+15	9.66e+14	1.07e+15
2053	.	1.09e+15	1.03e+15	1.13e+15
2054	.	1.16e+15	1.09e+15	1.20e+15
2055	.	1.23e+15	1.16e+15	1.28e+15
2056	.	1.31e+15	1.23e+15	1.36e+15
2057	.	1.39e+15	1.31e+15	1.44e+15
2058	.	1.47e+15	1.39e+15	1.53e+15
2059	.	1.57e+15	1.48e+15	1.63e+15
2060	.	1.66e+15	1.57e+15	1.73e+15
2061	.	1.77e+15	1.67e+15	1.84e+15
2062	.	1.88e+15	1.77e+15	1.96e+15
2063	.	2.00e+15	1.88e+15	2.08e+15
2064	.	2.12e+15	2.00e+15	2.21e+15
2065	.	2.25e+15	2.13e+15	2.35e+15
2066	.	2.39e+15	2.26e+15	2.49e+15
2067	.	2.54e+15	2.40e+15	2.65e+15
2068	.	2.70e+15	2.55e+15	2.81e+15
2069	.	2.87e+15	2.71e+15	2.99e+15
2070	.	3.05e+15	2.88e+15	3.18e+15

Table 3: key highlights from forecasted values

Year	**GHG ($MtCO_2e$)**	**GDP(Constant) (Rupees)**	**DMC (Mt)**	**CO_2 from Waste (Mt)**	**MP (Rs/Tons)**
2030	4671	270 Lakh Cr.	10223	18.3344	32850
2047	6484	756.3 Lakh Cr.	14315	21.9307	75293
2070	9930	3050 Lakh Cr.	22573	27.5704	231263

Figure 13: Trend of GHG based on independent variabbles.



After forecasting the GHG and the GDP, study examined the elasticity between both of them explaining the concept of decoupling in case of India, whether the GHG growth is less than that of GDP or GHG is Zero when GDP is rising (Absolute Decoupling).

Here the elasticity in all output is the coefficient of log of GDP:

Table 4: Elasticities of GHG over GDP on BAU.

Year	**Elasticity (η)**	**Decoupling Status**
2030	**0.544**	**Moderate Decoupling**
2047	**0.507**	**Decoupling**
2070	**0.4821**	**Insufficient Decoupling**

This is elasticity of GHG over GDP on business-as-usual (BAU) conditions, when DMC and Co2 is increasing based on historical trend.

Table 5: Elasticities of GHG over GDP after circularity.

Year	**Elasticity (η)**	**Decoupling Status**
2030	**0.535**	**Moderate Decoupling**
2047	**0.463**	**Decoupling**
2070	**0.402**	**Insufficient Decoupling**

Table shows the elasticity of GHG over GDP after implementing circularity in Indian industries through less domestic material use, Co2 from waste, high material productivity, and policies such as Extended Producer Responsibility

Hypothesis Testing

1. Primary Hypothesis Testing (Model Significance)

H_0: The ARIMA(0,0,1) model **does not** significantly explain GHG emissions trends when accounting for DMC and waste-CO_2 ($\beta_1 = \beta_2 = 0$).

Test Statistic (Likelihood Ratio Test (Full vs. Restricted Model)):

LR chi - square = 10.49, p-value: 0.0053, since $p = 0.0053 < 0.05$, we reject H_0.

We have statistically significant evidence that **DMC, CO_2 from waste, and EPR policy** improves the model's ability to explain changes in GHG emissions.

Hence, the ARIMAX model with DMC and CO_2 waste significantly improves GHG emissions prediction compared to a model without these predictors. Material consumption and waste management are statistically significant drivers of GHG emissions in India.

2. Predictor Significance Test

($H_0$1): The coefficients of d_dmc and d_Co2waste are individually and jointly zero.

Test Statistic: Wald $chi^2(2) = 24.36$

p-value: 0.0000, Strong rejection of H_0 ($p < 0.0001$). It means d_dmc and d_Co2waste are statistically significant predictors of d_ghg.

Joint Significance Test of Explanatory Variables

- Chi2(3) = 58.91 and Prob > chi2 = 0.0000. The p-value is **0.0000 (< 0.05)**. We reject the null hypothesis, means **all three variables together are jointly significant** predictors of the change in GHG emissions.

Breusch-Pagan Test for Heteroskedasticity

- Chi2(1) = 0.00 and Prob > chi2 = 0.9477

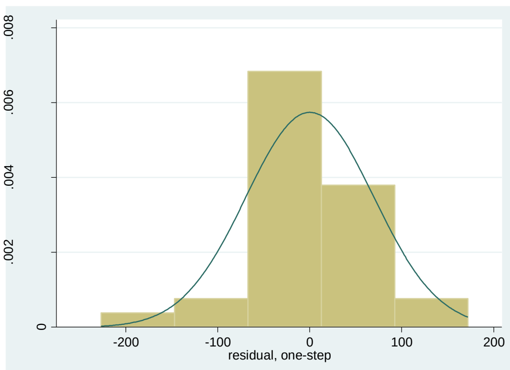
High p-value **(0.9477 > 0.05)** suggests **no evidence of heteroskedasticity** in the residuals when tested against fitted values.

```
. sktest res1

                   Skewness/Kurtosis tests for Normality
                                                     ------ joint ------
    Variable |        Obs  Pr(Skewness)  Pr(Kurtosis) adj chi2(2)   Prob>chi2
-------------+---------------------------------------------------------------
        res1 |         33     0.0595        0.0160        8.06         0.0178
```

Skewness is slightly marginal, borderline non-normal skew (typical cutoff is 0.05)

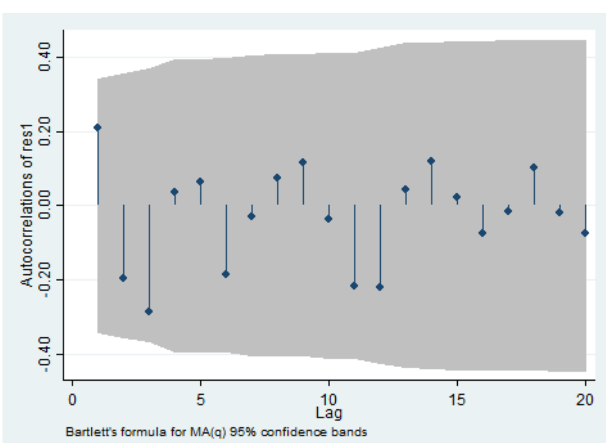
Kurtosis is significant — indicates kurtosis deviates from normal (more peaked or flat-tailed)



Source: Stata software

Autocorrelation Check: Portmanteau (Q) Test

• Q-stat = 8.8421 and Prob > chi2(10) = 0.5472, the p-value is **0.5472 (> 0.05)**, so we **fail to reject the null hypothesis of no autocorrelation**. **Residuals are not auto-correlated**, meaning your ARIMA model's MA (1) term is working well and has captured any autocorrelation structure.Only the **lag 1 autocorrelation is on the boundary (a bit high)**,which makes sense because the ARIMAX(0,0,1) model was specifically built to capture that MA(1) effect.



Regression Analysis of GDP on MP and EPR policy

```
. regress gdp mp epr_policy

      Source |       SS           df       MS      Number of obs   =        34
-------------+----------------------------------   F(2, 31)        =    823.03
       Model |  6.6263e+28         2  3.3132e+28   Prob > F        =    0.0000
    Residual |  1.2479e+27        31  4.0256e+25   R-squared       =    0.9815
-------------+----------------------------------   Adj R-squared   =    0.9803
       Total |  6.7511e+28        33  2.0458e+27   Root MSE        =    6.3e+12

------------------------------------------------------------------------------
         gdp |      Coef.   Std. Err.      t    P>|t|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
          mp |   8.74e+09   4.07e+08    21.46   0.000     7.91e+09    9.57e+09
  epr_policy |   1.30e+13   4.35e+12     2.98   0.006     4.10e+12    2.18e+13
       _cons |  -6.09e+13   5.63e+12   -10.82   0.000    -7.24e+13   -4.94e+13
------------------------------------------------------------------------------
```

98.15% of the change in GDP is interpreted by material productivity and EPR policy.

Adjusted for number of predictors — still very high, suggesting a strong model.

The overall regression is **highly statistically significant**.

For **every one-unit increase in material productivity**, GDP increases by **₹ 8.74 billion** (keeping EPR policy constant). This effect is highly significant ($p < 0.001$).

When the **EPR policy is active (dummy = 1)**, GDP increases by **₹ 13 trillion on average** compared to when it isn't active (keeping material productivity constant). Statistically significant at 1% ($p = 0.006$). **The execution of EPR mandate is also associated with a significant increase in GDP**, suggesting that environmental regulation, rather than harming growth, might have coexisted with or even contributed to economic expansion.

The regression analysis reveals that both material productivity and EPR policy implementation have statistically significant and positive effects on India's GDP between the observed years, explaining over 98% of the GDP variation.

Hypothesis Formulation for this regression analysis

Null Hypothesis (H_0):

Material productivity (MP) and EPR policy implementation have no statistically significant effect on India's GDP growth.

Alternative Hypothesis (H_1):

Both material productivity and EPR policy implementation have a positive and statistically significant effect on India's GDP growth.

Testing the hypothesis:

```
. test mp = 0  // Tests H□: β□ = 0

 ( 1)  mp = 0

       F(  1,    31) =  949.67
            Prob > F =    0.0000
```

Conclusion: Since **p** < **0.05**, we **reject the null hypothesis** (**H_0**). There is **strong, statistically significant evidence that Material Productivity has a significant effect on GDP** in our model.

```
. test epr_policy = 0  // Tests H□: β□ = 0

 ( 1)  epr_policy = 0

       F(  1,    31) =    9.35
            Prob > F =    0.0046
```

Conclusion:
Since **p = 0.0046** < **0.05**, we **reject the null hypothesis** (**H_0**). There's statistically significant evidence that **EPR policy has a significant effect on dependent variable (GDP).**

```
. test mp epr_policy  // Tests H□: β□ = β□ = 0

 ( 1)  mp = 0
 ( 2)  epr_policy = 0

       F(  2,    31) =  739.64
            Prob > F =    0.0000
```

Conclusion:

Since **p** < **0.05**, you **reject the null hypothesis** (**H_0**). There's very strong, statistically significant evidence that **both Material Productivity and EPR Policy significantly affects the dependent variable.**

Answer to the research question 1:

Yes — the ARIMAX model used in this study, integrating Domestic Material Consumption (DMC) and CO_2 emissions from waste as explanatory variables, demonstrated strong explanatory power in forecasting GHG emissions under business-as-usual (BAU) conditions. Under the BAU scenario, the forecasted GHG emissions for India by 2070 reached approximately **14,391 $MtCO_2e$** based on historical growth trends in DMC (2% annually), CO_2 from 3waste (3% annually).

However, when adjusting the growth rates of these independent variables to simulate circular economy adoption — through less material consumption (at 2% annual growth), Co2 from waste (at 1% annual growth) and EPR policy implication, the forecasted GHG emissions showed a noticeable moderation compared to the BAU trajectory which is **9,930 $MtCO_2e$.**

Answer to the research question 2:

The results of this dissertation suggest that **India can gradually decouple its economic growth from environmental degradation by enhancing resource efficiency and strengthening waste management frameworks before 2070**, provided that comprehensive circular economy strategies are adopted.

13 The regression analysis indicated a **significant positive relationship between Material Productivity and GDP**, supporting the notion that improving the efficiency of resource use can drive economic growth without proportionally increasing environmental burdens. Furthermore, the trend analysis of decoupling indicators reveals a potential pathway where economic growth can be maintained or accelerated while stabilizing or even reducing GHG emissions, particularly when coupled with policies such as EPR, waste segregation, material reuse, and recycling initiatives.

Under a scenario incorporating increased material productivity and improved waste management systems, **the forecasted GDP by 2070 reached ₹3,050 lakh crore**, with a relatively lower increment in GHG emissions compared to the BAU scenario, which was **3020 Lakh Crore**. This partial decoupling reflects the transformative potential of circular economy principles in aligning environmental sustainability with economic advancement.

The elasticity of GHG in 2070 was 0.482(insufficient decoupling) after assuming circularity in the country, which is slightly less than BAU scenario, which was 0.488.

In conclusion, while full decoupling may be challenging without aggressive policy and technological shifts, **a substantial reduction in the environmental intensity of economic growth appears achievable for India through systematic circular economy adoption, material efficiency improvements, and regulatory reforms in waste management**.

Conclusion

After assuming the DMC grow at the rate by 1%, Co2 waste by 2%, material productivity by 5% and EPR policy implication to promote circularity in the country, we have different forecasted value of GHG and GDP then before.

Using a simple regression on GDP with MP and EPR policy implication as predictors, we can state that both significantly affect GDP and promise productive economic growth in India.

The circular economy can actually help in reducing the GHG emissions and the same time increasing the GDP growth, if government focuses on material recovery facility, waste management through technological advancement, and enforcing laws with strict implementation of EPR mandates, Solid waste management rule, and environmental protection act 1986.

To encourage the adoption of a circular economy (CE) in India, the government has introduced several regulatory initiatives. One of the most significant among these is **Extended Producer Responsibility (EPR)**, a policy that places the accountability for the end-of-life management of products on the producers, manufacturers, importers, and brand owners. Under this system, companies are required to ensure proper waste collection, recycling, and safe disposal of their products.

In India, EPR obligations are legally mandated through various environmental regulations, particularly targeting industries that generate plastic packaging waste, electronic waste, battery waste, and waste tyres. The implementation and oversight of these regulations are carried out by the Ministry of Environment, Forest and Climate Change (MoEFCC) in coordination with the Central Pollution Control Board (CPCB).

The main regulatory frameworks for EPR in India comprise:

1. Plastic Waste Management (PWM) Rules, 2016 (Amended in 2022):
   These rules require producers, importers, and brand owners to adhere to EPR guidelines for plastic packaging. Businesses must recover and recycle a fixed percentage of the plastic waste they generate and can opt for a **Plastic Credit Mechanism** if direct recovery targets are not met.

2. E-Waste (Management) Rules, 2022:
   Applicable to manufacturers and importers of electronic and electrical equipment, these rules mandate the establishment of systems for collecting, recycling, and reporting e-waste.

3. Battery Waste Management Rules, 2022
   This framework requires producers of lead-acid, lithium-ion, and other battery types to develop recycling programs and ensure the safe disposal of battery waste.

4. EPR for Waste Tyres, 2022
   Forming a component of the Hazardous and Other Wastes (Management and Transboundary Movement) Amendment Rules, 2022, this regulation makes it obligatory for tyre producers and importers to responsibly collect, recycle, and dispose of used tyres to reduce environmental hazards and support circular practices.

Non-compliance with these EPR regulations can lead to financial penalties, fines, and potential cancellation of business licenses (Malu, 2025).

Policy suggestions

1. **Strengthen Enforcement Mechanisms for EPR Compliance**
   While EPR frameworks exist for plastics, e-waste, batteries, and tyres, implementation gaps at state and local levels remain significant. The government should invest in **digital monitoring platforms** and enforce stricter penalties for non-compliance to ensure accountability.

2. **Scale up Material Recovery Facilities (MRFs) and Waste Collection Infrastructure**
   Establish **state-of-the-art MRFs** at district and urban levels to process segregated waste efficiently. Incentivizing private sector participation through Public-Private Partnerships (PPPs) can expedite infrastructure development.

3. **Incentivize Circular Business Models**
   Provide **fiscal incentives, tax rebates, and subsidies** to businesses adopting circular practices, including models like product-as-a-service, material reuse innovations, and waste-to-resource startups.

4. **Integrate CE Education and Awareness Programs**
   Launch national campaigns to raise public awareness about waste segregation, recycling, and responsible consumption habits. Integrating **CE concepts into school and university curricula** can create a long-term behavioral shift.

5. **Mandate Decentralized Waste Management in Rural and Semi-Urban Regions**
   Circular economy practices must not remain confined to metropolitan cities. Promote **community-level composting units, biogas plants, and decentralized recycling systems** in rural areas to build a truly nationwide circular framework.

6. **Strengthen Data Collection and Impact Assessment Systems**
   A key challenge in formulating effective circular economy policies is the unavailability of accurate data regarding material flows and waste production. The government should prioritize establishing a **National Circular Economy Dashboard** to track performance metrics, policy outcomes, and carbon savings.

7. **Regularly Review and Update Regulatory Frameworks**
   Keep CE-related laws dynamic by conducting **biennial policy reviews** in consultation with industry players, civil society organizations, and environmental experts to address new waste streams, emerging industries, and global best practices.

The research confirms that a well-planned and rigorously implemented circular economy strategy in India is not just an environmental necessity but also an economic opportunity. **By closing material loops, improving resource efficiency, and mainstreaming circular business models**, India can carve a pathway towards a **climate-resilient, resource-secure, and prosperous future**.

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