

# Modelling the Economic Impact of Climate Change Using Differential Equations

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## Abstract

Climate change has become one of the greatest threats to global economic stability and sustainability. Its effects ripple across every sector from agriculture and industry to labour productivity and overall growth. In this study, we explore the economic consequences of climate change using differential equations, a powerful tool for modelling dynamic systems over time. By combining key economic factors such as output, capital accumulation, and environmental damage with climate variables like rising temperatures and extreme weather events, we develop a mathematical framework to analyse how economies and the environment interact.

Our model shows that differential equations can effectively track the evolving ties between climate shifts and economic performance. The results are clear without intervention, climate change will drive long-term economic decline. However, policies like carbon taxes, green investments, and technological advances can soften these blows. This research adds a quantitative perspective to climate economics, equipping policymakers with data-driven insights for smarter decision-making.

**Keywords:** Climate Change, Economic Growth, Differential Equations, Mathematical Framework, Environmental Damage

## 1. Introduction

Climate change has shifted from a distant environmental issue to an urgent economic challenge affecting both developed and developing countries. Rising temperatures, more frequent natural disasters, and unpredictable weather patterns deeply impact economic systems. These disruptions harm agricultural output, damage infrastructure, and lower labour productivity, ultimately stalling economic growth.

Traditional economic analyses often depend on static models, which struggle to reflect the dynamic and long-term nature of climate change. In contrast, mathematical modelling with differential equations offers a robust way to examine how economic variables evolve under shifting environmental conditions. Differential equations enable researchers to analyse rates of change and interactions between variables, making them ideal for modelling complex systems like climate and the economy.

This paper develops and explains a mathematical framework using differential equations to model the economic impact of climate change. It addresses three key questions:

- How does climate change affect economic growth over time?
- How can differential equations model this relationship?
- What policy insights can these models provide?

## 2. Literature Review

The connection between climate change and economic performance has been a central focus in environmental economics. Early research leaned heavily on qualitative approaches, but in recent years, studies have shifted toward more quantitative and mathematical methods.

Economic frameworks like the Solow Growth Model have been adapted to include environmental factors. By integrating climate variables into production functions, researchers have demonstrated how environmental degradation can stifle economic output. Integrated Assessment Models (IAMs) go a step further, merging economic and climate systems to assess long-term impacts and explore policy solutions.

Differential equations have become a cornerstone of modelling dynamic systems. In climate economics, they are particularly useful for capturing:

- How temperatures evolve over time
- The build-up of carbon in the atmosphere
- Economic growth within ecological limits

Recent work underscores the value of dynamic modelling in unravelling the feedback loops between the economy and the environment. A prime example is how economic expansion drives emissions, which in turn worsen climate change and hamper future growth.

Despite these advances, there's still a pressing need for simpler, more practical models that can be easily understood and applied, particularly in developing nations. This paper addresses that gap by offering a clear and structured mathematical framework.

## 3. Objectives of the Study

The main objectives of this study are:

1. To analyse the economic impact of climate change using a mathematical framework
2. To develop a differential equation-based model linking climate variables and economic growth
3. To understand the dynamic relationship between environmental degradation and economic output
4. To suggest policy measures based on model outcomes

## 4. Methodology

This research takes a theoretical and analytical approach, using mathematical modelling to uncover connections between different factors. Our process unfolds in four key steps:

- First, we pinpoint the most important economic and climate-related variables.
- Next, we develop differential equations to capture how these elements interact.
- We then examine how the system evolves through time.
- Finally, we translate these mathematical findings into meaningful economic insights.

### **Key Variables Used**

- $Y(t)$ : Economic output (GDP)
- $K(t)$ : Capital stock
- $T(t)$ : Temperature level
- $E(t)$ : Carbon emissions

## **5. Model Development**

### **5.1 Economic Growth Equation**

Economic growth can be represented as:

$$\frac{dY}{dt} = \alpha Y - \beta T Y$$

Where:

- $\alpha$  = natural growth rate
- $\beta$  = impact of temperature on output

#### **Interpretation:**

Economic output grows naturally but is negatively affected by rising temperature.

### **5.2 Climate Change Equation**

Temperature change is influenced by emissions:

$$\frac{dT}{dt} = \gamma E - \delta T$$

Where:

- $\gamma$  = effect of emissions on temperature
- $\delta$  = natural cooling rate

### **5.3 Emissions Equation**

Emissions depend on economic activity:

$$\frac{dE}{dt} = \theta Y - \lambda E$$

Where:

- $\theta$  = emissions generated per unit of output
- $\lambda$  = reduction due to policies

## 6. Analysis of the Model

The system of equations shows a **feedback loop**:

1. Economic growth increases emissions
2. Emissions increase temperature
3. Higher temperature reduces economic output

This creates a cycle where economic growth initially increases but eventually slows down due to environmental damage.

### 6.1 Without Policy Intervention

- Emissions rise continuously
- Temperature increases
- Economic growth declines in the long run

### 6.2 With Policy Intervention

If policies reduce emissions (increase  $\lambda$ ):

- Temperature rise slows
- Economic damage reduces
- Sustainable growth is achieved

## 7. Graphical Interpretation

The model can be represented graphically:

- GDP initially rises, then declines
- Temperature continuously increases without control
- Emissions grow rapidly unless regulated

This highlights the importance of early intervention.

## 8. Discussion

The model clearly demonstrates that climate change has a long-term negative impact on economic growth. While short-term growth may benefit from increased industrial activity, the resulting environmental damage eventually outweighs these benefits.

Differential equations help capture this dynamic interaction effectively. They allow us to:

- Predict future trends
- Analyse stability of the system
- Evaluate policy effectiveness

The model also emphasizes the importance of sustainable development. Economic growth should not come at the cost of environmental degradation.

## 9. Policy Implications

Based on the model, the following policies are recommended:

### 9.1 Carbon Taxation

Reducing emissions by imposing taxes on carbon-intensive activities.

### 9.2 Investment in Green Technology

Promoting renewable energy and sustainable practices.

### 9.3 Regulation of Industrial Emissions

Setting limits on pollution levels.

### 9.4 Climate Resilient Infrastructure

Reducing economic losses from natural disasters.

## 10. Limitations

- The model is simplified and does not include all variables
- Real-world data is not incorporated
- Assumes linear relationships

Future studies can improve accuracy by including:

- Non-linear models
- Empirical data
- Regional analysis (e.g., Kerala, India)

## 11. Conclusion

This study highlights the importance of using mathematical tools such as differential equations to understand the economic impact of climate change. The model developed in this paper demonstrates the dynamic relationship between economic growth, emissions, and temperature.

The findings suggest that without intervention, climate change will significantly hinder economic progress. However, appropriate policies can mitigate these effects and promote sustainable growth.

Mathematical modelling provides valuable insights for policymakers and helps in designing effective strategies to combat climate change while ensuring economic stability.

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