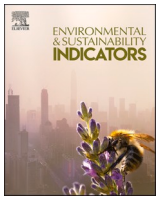
Environmental and Sustainability Indicators 31 (2026) 101314

Contents lists available at ScienceDirect

Environmental and Sustainability Indicators

journal homepage: www.sciencedirect.com/journal/environmental-and-sustainability-indicators



Economic and environmental factors influencing beef production in high-income countries: Panel evidence

Himaya Susan, Kalana Mendis, Nisal Perera, Yasodara Silva, Ruwan Jayathilaka *

SLIIT Business School, Sri Lanka Institute of Information Technology, New Kandy Road, Malabe, Sri Lanka

ARTICLE INFO

Keywords:
Beef production
Trade openness
Greenhouse gas emission
Beef consumption
Gross domestic product
Panel regression analysis

ABSTRACT

As the global population grows, dietary patterns are shifting towards protein-rich foods, with beef production playing a critical role in balancing food security, economic growth, and environmental sustainability. Among income groups, high-income countries exhibit relatively stable, yet elevated levels of beef production compared to others, warranting focused investigation. This study evaluates the causal effects of beef consumption, greenhouse gas emissions, gross domestic product, and trade openness on beef production across 42 high-income countries from 1993 to 2022. A panel regression model with country-specific fixed effects is employed to control for unobserved heterogeneity, as supported by panel specification tests. Additionally, a simple moving average method is used to forecast short-term trends in beef production for 2023–2026. The findings reveal that there is no significant evidence to claim that there is an effect of beef consumption and gross domestic product on beef production. In contrast, trade openness negatively influences production, while greenhouse gas emissions exhibit a positive effect. Forecast results indicate increasing beef production in countries such as Uruguay, New Zealand, Ireland, Australia, Canada, and the United States. The study offers policy-relevant insights for governments and international organisations in aligning livestock production strategies with Sustainable Development Goals.

1. Introduction

The growing population increases the demand for meat, which in turn leads to a need for more animal-based protein, increasing animal production (del Campo et al., 2025). Meat serves as a source of protein, vitamins and minerals for millions of people, as well as for poor people (Salzano et al., 2025). Beef meat is in demand in the world, as it has high-quality nutritional ingredients (Singh et al., 2023; Peel, 2025). Meat is a most essential nutrient because of premium protein, poly-unsaturated fatty acids, carbohydrates, vitamins and minerals (Almusawi et al., 2025; Wu et al., 2025). Therefore, meat helps a person to maintain a perfectly healthy body.

Since the beginning of human habitation, beef has been consumed, and it has been developed in all countries worldwide (Hocquette et al., 2018). Approximately 45% of total protein intake for humans comes from both the meat and milk of cattle and bison (Singh et al., 2023). Therefore, beef has been a lead meat due to its flavour, culture, significance and nutritional level (Bothare, 2025). Moreover, meat production has increased significantly over the past 50 years, and today it produces more than 340 million tons of beef per year (Sousa, 2025). In addition, demand for meat will increase 75% in 2050 and be a nutritious food that contains all essential amino acids with micronutrients (Salzano et al., 2025). Accordingly, meat plays a significant role in achieving global food and nutrition security in future. Therefore, for the growing population, the agriculture sector should be improved in terms of efficiency while maintaining sustainable patterns (Bettini et al., 2025; Rahman et al., 2025).

In contrast, cattle husbandry plays a significant role that supports food security and also increases the income of households (Syastiawan et al., 2025). Increasing household incomes means improving the rural livelihoods, which helps reduce poverty, increases food security, and also finds solutions for increasing the nutritional (Acosta et al., 2024). Not only is importing and exporting beef a significant advantage for the beef-producing countries (Greenwood et al., 2018), but it is also a significant advantage for beef-deficient countries to meet their consumers' needs (Peel, 2025) …

Livestock farming has been impacts on the environment (Salzano et al., 2025). Therefore, meat production causes a higher risk for the

* Corresponding author. Department of Information Management, SLIIT Business School, Sri Lanka Institute of Information Technology, New Kandy Road, Malabe, Sri Lanka.

E-mail addresses: himaya20012000@gmail.com (H. Susan), kalanamanusha2000@gmail.com (K. Mendis), nisalmenura01@gmail.com (N. Perera), yashodararadika500@gmail.com (Y. Silva), ruwan.j@sliit.lk (R. Jayathilaka).

https://doi.org/10.1016/j.indic.2026.101314
Received 22 December 2025; Received in revised form 12 April 2026; Accepted 9 May 2026
Available online 12 May 2026

environment, animal welfare, as well as for public health, of which approximately 14 per cent to 15 per cent is greenhouse gas emission and others are from animal diseases, antibiotic resistance, bacterial infections and climate change (Iram et al., 2025). These environmental causes also happen due to human activities (Berton et al., 2025), and it is necessary to reduce greenhouse gas emissions to address climate change (Pishgar-Komleh and Beldman, 2022). Due to the environment concerns, people shift towards poultry meat (OECD Food and Agriculture Organization of the United Nations, 2025), as red meat emits more greenhouse gases, because poultry meat is sustainable.

In Europe, North America and Oceania, which have the highest beef consumption, are expected to see a significant reduction in the beef consumption per capita by raising the price of beef meat over substitutes to consider the greenhouse gas emissions (OECD Food and Agriculture Organization of the United Nations, 2025). But greenhouse gas emissions are more prevalent in high-income countries, which include beef in their diet. Therefore, we are considering the high-income group in this study. In this study, further analysis of income level trend patterns for beef production, according to Fig. 1, the high-income trend line shows a slight fluctuation compared to other income groups. Also, the high-income trend line remains at the highest level, at a level of 25 to 30 beef production kilograms per capita.

In contrast, other income groups remain stable with minimal changes, which indicates that those income groups have a limited beef meat production capacity. Therefore, focusing on the high-income group, we can examine those slight fluctuations with the study variables, beef consumption, trade openness, gross domestic product and greenhouse gas emission to identify how those variables impact those fluctuations and the growth of the high-income group.

This study aims to evaluate the causal impact of beef consumption, greenhouse gas emissions, gross domestic product, and trade openness on beef production across the high-income group. This study's contribution to the existing body of literature is primarily in six ways.

First, in this study, we examine how the previously mentioned variables affect beef production. In the past, studies mainly focused on the individual variables' impacts separately. However, by adding the aforementioned variables together, we can provide comprehensive information and highlight the insights of how beef meat production affects consumption, environmental impact, and a country's economic growth.

Second, this study utilises novel visualisation to provide the descriptive statistics comprehensively. This visualisation simply interprets the data of the variables to understand better how those variables change over the period.

Third, in this paper, we utilise standard analytical techniques for analysing the Panel data set, which includes panel regression analyses to examine the impact of the mentioned variables on beef production for the overall high-income group. Panel regression and other econometric statistical analysis were widely used in empirical research whereas, for beef production studies comparatively limited in using panel regression analysis as for standard analytical techniques, but in this study, we uniquely introduce this analytical technique for empirical investigates dynamics of beef production.

Fourth, beef production was forecast for 2023, 2024, 2025 and 2026, to provide insights on how the trend pattern of beef production will be changing, and to get an idea about the future beef production in the individual countries of the high-income group.

Fifth, in addition to the empirical contribution, this study also provides methodological valve by integrating multiple econometric procedures with in a unified analytical framework. Specifically, the study combines cross sectional dependency testing's, second generation panel root testing, panel specification test, and fixed effect panel regression to ensure the robustness of the empirical results. Furthermore, forecasting component is based on simple moving average technique is incorporate to project future beef production trends. This combines approach enables both causal interpretation and forward-looking policy insights which remain limited in the existing literature on beef production determinates.

Finally, this study provides policy implications for policymakers, international and domestic organisations, and the governments related to beef production. These policies were aligned with the Sustainability Development Goals (SDGs) which introduced by the United Nations specifically to SDG 01: No Poverty, SDG 02: Zero Hunger, SDG 03: Good Health and Well-Being, SDG 08: Decent Work and Economic Growth, SDG 09: Industry, Innovation and Infrastructure, SDG 12: Responsible Consumption and Production, SDG 13: Climate Action and SDG 17: Partnerships for the Goals.

The remaining section of this research sis structured as follows: literature review from past studies, data and methodology, which provide the information regarding the variables and the analytical techniques, results and the discussion of the findings, conclusion, policy implications and the limitations and opportunities for future research.

2. Literature review

In literature review, we examined past studies related to the countries in the high-income group and for the variables beef consumption, gross domestic product, trade openness, greenhouse gas emission and beef production. Research articles were gathered from primary sources like Science Direct, Springer, and Taylor & Francis. Using these databases, 33 research articles were selected for the literature review.

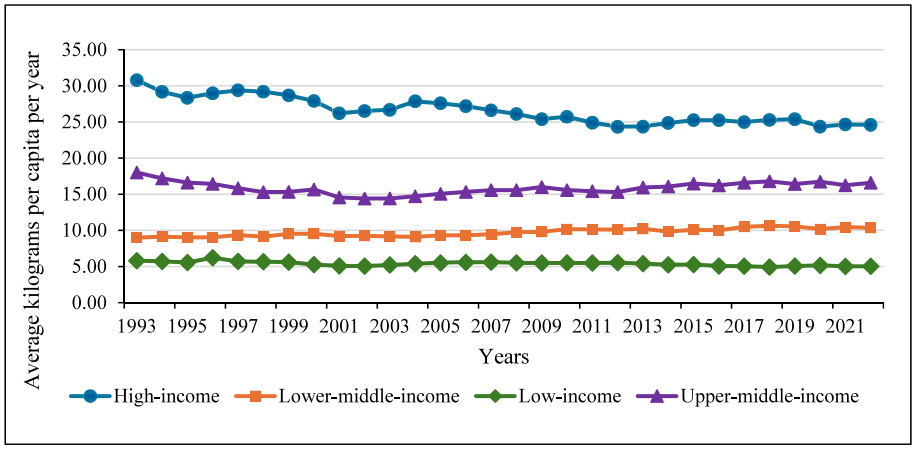


Fig. 1. Income group wise trend pattern for beef production.
Source: Authors' illustration based on Food and Agriculture Organisation Statistical data (Food and Agriculture Organization Statistics and Crops and livestock products, 2025).

According to Fig. 2, the number of research articles gathered and published in the period from 2000 to 2025 was categorised according to the study's variables. This stack bar chart includes only articles that were written in the literature review, and articles that were collected in this period were used to get an idea about the beef production, beef consumption, gross domestic product, trade openness and greenhouse gas emission. Further, this chart was generated through Canva and Origin Lab.

2.1. Beef consumption and beef production

Beef consumption plays a significant role than other variables, because of there should be a demand for consuming beef to produce beef meat it has been seen that in the last two-decades, beef consumption has been rising and being positive which reaching to the highest level in the past and beef meat being the third consuming meat after the pigmeat and chicken meat (Mansky et al., 2024). Meat consumption has increased in both developed and developing countries since the last century (Weibel et al., 2019). However, in high-income countries, beef consumption has decreased, and most consumers in these countries have been motivated by health and ethical concerns (Mansky et al., 2024) which being a negative effect for the beef production. Since 1970 meat consumption has been reduced, but beef is taking an essential place in the United States' diet (Barnhill et al., 2022). However, while consumers tend to reduce meat consumption, the consumption of plant-based food increased between 2018 and 2020 (Peschel and Grebitus, 2023). In addition, there is a decline in European beef consumption (Santinello et al., 2024), due to a lack of feedback from consumers to the beef producer regarding the taste of the beef.

However, Germany is the second largest beef manufacturer in Europe after France, which is known for its high-quality beef (Oliver et al., 2006). Meat consumption per capita has tripled during the last 50 years. Even in the traditional Mediterranean and industrialised diets, there is a high consumption of animal products (Farchi et al., 2017). Furthermore, consumption of beef has been increased due to the quality of the meat, tenderness, juiciness, and its flavour (Fu et al., 2024). In European countries, consumers are more towards to the animal welfare (Schnettler et al., 2009), they are willing to eat animal friendly food because of high quality and the health (Merlino et al., 2018). Countries like Spain, Ireland and Italy are more willing to purchase beef with safety, animal welfare information and organic (Schnettler et al., 2009).

In these past literature studies, the focus has mainly highlighted that the beef consumption has been increases due to consumer preferences and the nutrients in contrast it has been reducing due to the willingness to reduce meat consumption due to health issues and environmental impacts related to beef consumption.

2.2. Gross domestic product and beef production

Gross domestic product has a positive impact on the beef production; in some cases, gross domestic product is commonly used as an indicator of a country's beef market size and a larger gross domestic product is expected to have a positive effect on the volume of beef meat exports to that country (Kibona et al., 2022). Beef demand changes over time and has been rising in many countries as people's incomes grow (Schierhorn et al., 2016). An increase in beef meat exports leads to greater growth in gross domestic product and household income compared to a similar rise in live cattle exports, considering the potential macroeconomic and employment impact (Kibona et al., 2022). When having high-income households, they tend to buy beef more often than households with lower incomes (Koizumi et al., 2001). Rising income levels generally contribute to an increase in beef meat imports (Hadi and Chung, 2022), whereas greater domestic production typically leads to a reduction in import volumes.

Countries produce high-quality beef for export or local use, have different ways of making and selling beef; these differences come from factors such as available resources, climate, population size, cultural habits, and their economy and technology (Smith et al., 2018). In 1990, the Soviet Union spent almost 12 per cent of its gross domestic product on agricultural subsidies, mainly for livestock, which helped to raise meat consumption high at 71.2 kg per capita (Schierhorn et al., 2016), and had twice their average income from meat consumption, which is 72 kg.

Similarly, in a research has shown that growth in real gross domestic product has a positive impact on the amount of meat the country imports (Hadi and Chung, 2022). With fast economic growth, beef consumption has increased significantly as gross domestic product per capita has risen; however, domestic beef production has not matched this growth in demand, making China a net importer of beef from other countries (Smith et al., 2018). But consumer demand for meat is expected to rise in the future (Ortega et al., 2016) due to projected gross domestic product growth.

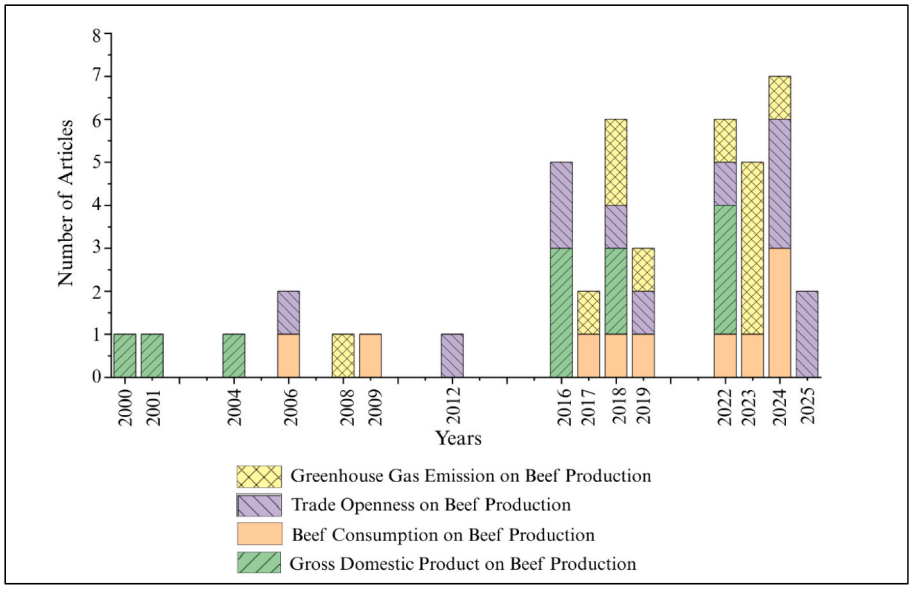


Fig. 2. Number of publications from 2000 to 2025.
Source: Authors' compilation.

The demand for high-quality beef is more sensitive to income changes than the demand for low-quality beef. The higher real gross domestic product leads to greater demand for high-quality beef, lower-quality beef, and hides, according to their estimated income elasticity (Van Eenoo et al., 2000). Over the past decade, the growth of Canada's beef cattle sector has been driven by exports of both live animals and meat products, every 100 million dollar in cattle sector exports contributes 80 million dollar to gross domestic product (Mitura and di Pietro, 2004). However, when discovered the disease of bovine spongiform encephalopathy in May 2000 led to an international trade ban that had a significant impact on beef cattle farm families and in 2003, cattle and calves dropped around by 2.5 billion dollars to 5.2 billion dollars compared to 2002 (Mitura and di Pietro, 2004).

These studies show that beef production has a positive or negative impact on gross domestic product. As demand for beef production increases, the economic, employment, domestic incomes and gross domestic product also increase (Saniyyah and Istiandari, 2024). Moreover, when the beef export and import increase, their gross domestic product increases, but decreases due to the demand for beef production because of pathogens.

2.3. Trade openness and beef production

Trade openness has a significant impact on beef production, as beef is a key commodity in international agricultural trade and has been extensively studied to analyse import demand and global market dynamics. Japan is the world's third biggest importer of beef which being a positive effect for the beef production. In recent years, the amount of agricultural goods being traded has grown faster than ever before (Schmitz et al., 2012). In 2015, the United Kingdom accounted for over 5 per cent of global meat imports, ranking it as the world's fifth-largest meat market (Gu et al., 2025). In recent years, beef consumption in China has grown quickly but even though China produces a lot of beef, it still can't meet all the demand, so much of the beef imported from other countries (Chen et al., 2019) and Chinese consumers prefer Australian beef more, therefore Australia is a major supplier of beef to China.

Food imports, especially animal products like beef, are essential for the European Union, which is the world's biggest food importer (Rinn et al., 2024). In 2004, exported most of its beef to the United States, but since Europe has a similar population and countries like Germany and the United Kingdom already imported Uruguayan beef, Europe is seen as an essential market where beef exports could grow even more (Oliver et al., 2006). In 2021, the European Union brought in about 283,729 tons of beef and all imported meat must follow the same strict European Union food safety and hygiene rules (Rinn et al., 2024). The Soviet Union bought much beef because could not produce enough meat (Schierhorn et al., 2016), but after the Soviet Union disbanded, beef production dropped, so it started importing even more and became the third largest beef importer between 1992 and 1998.

In contrast it being a negative effect due to the growth of global trade in animal products (Gondauri, 2025), there is a bigger risk of spreading harmful germs worldwide, and some studies have shown that imported meat can carry dangerous bacteria like Salmonella, Shiga toxin-producing *E. coli*, and *Listeria monocytogenes* (Rinn et al., 2024; Kenny et al., 2024; Shen et al., 2022; Kim et al., 2018). As the global food trade grows, it can spread easily through food around the world, posing a significant risk to food safety and public health. When the bovine spongiform encephalopathy outbreak occurred in the United States in 2003, beef imports declined significantly from 2004 to 2008 (Ortega et al., 2016). However, after 2008, people wanted more imported beef than before. Between 2012 and 2013, beef imports grew 4.5 times.

In past studies, it has been emphasised that there is a positive impact to the beef production when there are more countries with high-quality beef production, because they are willing to import beef and increase the trade agreements. Additionally, there is a negative effect of the reduction in beef imports and exports due to bacterial diseases affecting beef cattle.

2.4. Greenhouse gas emissions and beef production

Greenhouse gas emissions hurt beef production because climate change has been a significant challenge in the food supply chain, which has adverse effects on the environment; therefore, changes must be made for the food systems (Peschel and Grebitus, 2023). Environmental impact has mainly come from the meat industry (Weibel et al., 2019). The beef industry is a major contributor to greenhouse gas emissions (Bragaglio et al., 2018) which being a negative effect for the beef production. Out of all meat, beef has the most significant effect on the emission of carbon dioxide from the production process, methane from the enteric fermentation and nitrous oxide from the manure management (Farchi et al., 2017). In the agriculture sector, cattle husbandry accounts for 65 per cent of emissions (Kearney et al., 2023), and beef production emits 54 per cent of enteric methane and 41 per cent of manure ammonia.

Environmental impact resulting from beef production is an emerging topic, which is why people are reducing beef consumption (Mansky et al., 2024). Today, it has been a challenge to provide food for the growing population while reducing the environmental impact, which means greenhouse gas emissions (Sandström et al., 2018). However, if the livestock production is reduced by 50 per cent, it will reduce greenhouse gas emissions by 24 to 40 per cent (Weibel et al., 2019). When comparing developed and developing countries, developed countries are decreasing their greenhouse gas emissions by 23 per cent (Kearney et al., 2023). Additionally, the beef industry has reduced greenhouse gas emissions by 1 per cent over the overall period.

Australian agriculture is facing a challenge to mitigate global warming by reducing greenhouse gas emissions (Sandström et al., 2018). In China, meat consumption is rising, as are greenhouse gas emissions; therefore, they also need strategies to reduce greenhouse gas emissions (Wei et al., 2023). In Canada, their beef production also accounts for larger greenhouse gas emissions than dairy in their agriculture (Vergé et al., 2008). But in Europe, citizens are supposed to consume sustainable food to reduce greenhouse gas emissions (Peschel and Grebitus, 2023). Reducing the intake and eating plant-based foods will be an advantage in reducing climate change, which means reducing greenhouse gas emissions (Weibel et al., 2019). Moreover, reducing red meat also reduces the health issues (Porto Costa et al., 2023). A study (Barnhill et al., 2022)reveals says that if avoiding the temperature rises above the 1.5 Celsius will be a great full advantage to reduce the emission in half of 2030 and able to go for zero emission in 2050.

In addition, greenhouse gas emission being a threat to the world globalisation, it also effects to the beef production. Whereas, when people are tend to reducing the greenhouse gas emissions will lead to a negative impact for the beef production because of reducing the beef consumption.

2.5. Hypothesis development and Conceptual Framework

Based on the theoretical arguments and empirical evidence presented in the literature review the following hypothesis are proposed to examine the relationship between the exponential variables and beef production in high income countries. In Fig. 3 it clearly presents the relationship of the beef consumption, gross domestic product, trade openness and greenhouse gas emissions to beef production.

H1. Beef consumption has a significant effect on beef production

Consumer demand is one of the primary drivers of livestock production, higher beef consumption generally stimulate the domestic production as procedure respond to market demand. The several studies indicate that the changes in dietary preferences and meat consumption patterns can directly influence livestock production levels. Therefore, beef consumption is expected to influence the beef production across

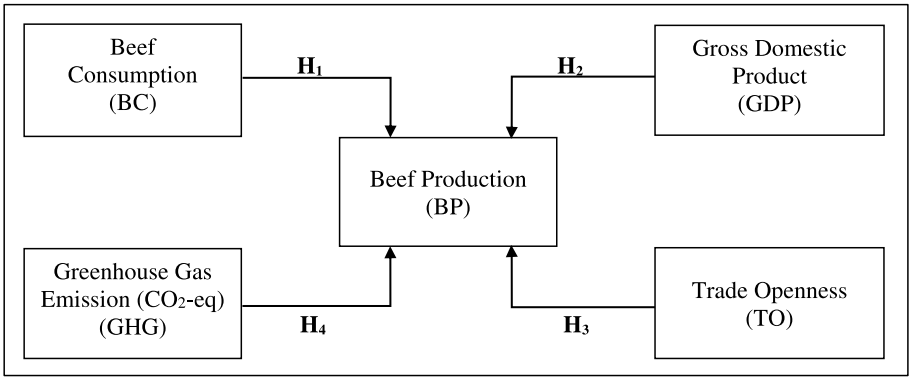


Fig. 3. Conceptual framework.

high income countries.

H2. Gross domestic product has a significant effect on beef production

Economic growth increases household income and purchasing power, which may lead to higher demand for animals-based proteins, as GDP increases countries tend to expand agricultural and livestock production to meet rising demand. Thus, GDP may influence beef production levels in high income economies.

H3. Trade openness has a significant effect on beef production

Trade openness has influence agriculture markets through export opportunities and imports competitions. Countries with higher trade openness may experience changes in domestic production depending on global demand, international competitiveness, and trade policies. Therefore, trade openness is expected to effect beef production.

H4. Greenhouse gas emissions have a significant effect on beef production

Livestock production is closely associated with greenhouse gas emissions particularly with methane emissions from cattle production. Changes in environment policies and climate mitigation strategies may influence livestock production systems. Therefore, greenhouse gas emissions are expected to be associated with the beef production dynamics.

3. Material and method

This section provides detailed information about the measuring units and the sources of variable data, as well as providing details of the analytical statistics that were used to analyse the data obtained in this study.

3.1. Data sources and sample selection

For this research study, panel data set consist of 42 high income countries was employed over a 30-year data period from 1993 to 2022. The selection of the countries follows the world bank indicated classification, which identified countries with high gross national income per capita as high income economy. The final sample of 42 countries was determine based on data availability for all study variables (Beef Production, Beef Consumption, Gross Domestic Product, Trade Openness and Greenhouse Gas Emission) across the entire study period. And the collected data were presented in Appendix 1.

The dataset using this study is a balance panel, were observation is available for all 42 countries across the full time period. This results in a total of 1260 observations (42 countries * 30 years). The balanced structure of the panel improves the reliability of the econometric estimations and facilitate consistence comparison across countries and time.

In Table 1, the variables measuring units and the sources that were taken from are detailed, and the variables like beef production, beef consumption and greenhouse gas emission (CO_2 equivalent) were measured in kilograms per capita. And gross domestic product also measured as per capita and trade openness are taken as percentage of total trade relative to GDP.

Table 1
Data source for variables.

Variables	Measurement	Source
Beef Production (BP)	Kilograms per capita	Food and Agriculture Organization Statistics and Crops and livestock products (2025)
Beef Consumption (BC)	Kilograms per capita	Food and Agriculture Organization Statistics et al. (2025)
Gross Domestic Product (GDP)	Per capita (current US$)	World Bank (2025)
Trade Openness (TO)	Percentage of GDP	World Bank (2025)
Green House Gas Emission -CO_2eq (GHG)	Kilograms per capita	Food and Agriculture Organization Statistics and Emissions totals (2025)

Source: Authors' compilation.

$$\text{Trade Openness per capita} = \text{Total Trade (Imports} + \text{Exports)/GDP *100} \quad (1)$$

In addition, there is no direct sources to obtain data for Trade Openness variable, therefore we have collected macroeconomic data which are Imports, Exports and GDP valves and calculate trade openness using Equation (1) for this study. Those data were gathered through World Bank and for the other variables used Food and Agriculture Organisation Statistics source which were reliable to collect data.

3.2. Method

The overall research flow and the methodologies were presented in Fig. 4. As for the main methodology, panel regression with country specific was utilised to estimate the determinants of beef production while controlling for unobserved country specific heterogeneity in this study. Panel data analysis used information from both time series and cross-sectional data, which helped to get accurate results than using one type of data (Wei and Bandara, 2009).

In addition, panel data econometric techniques adapted in this study because they allow the analysis of both cross sectional and time series variations simultaneously, compared with pure cross sectional or time series approaches, panel model provides greater degrees of freedom, reduce multicollinearity and allow the control of unobserved country specific heterogeneity. In the context of the high-income countries the structural differences such as agriculture policies, climate conditions and production technologies may influence beef production. Therefore, panel regression with a country specific fixed effect is appropriate for capturing these unobserved characteristics while estimating the effects

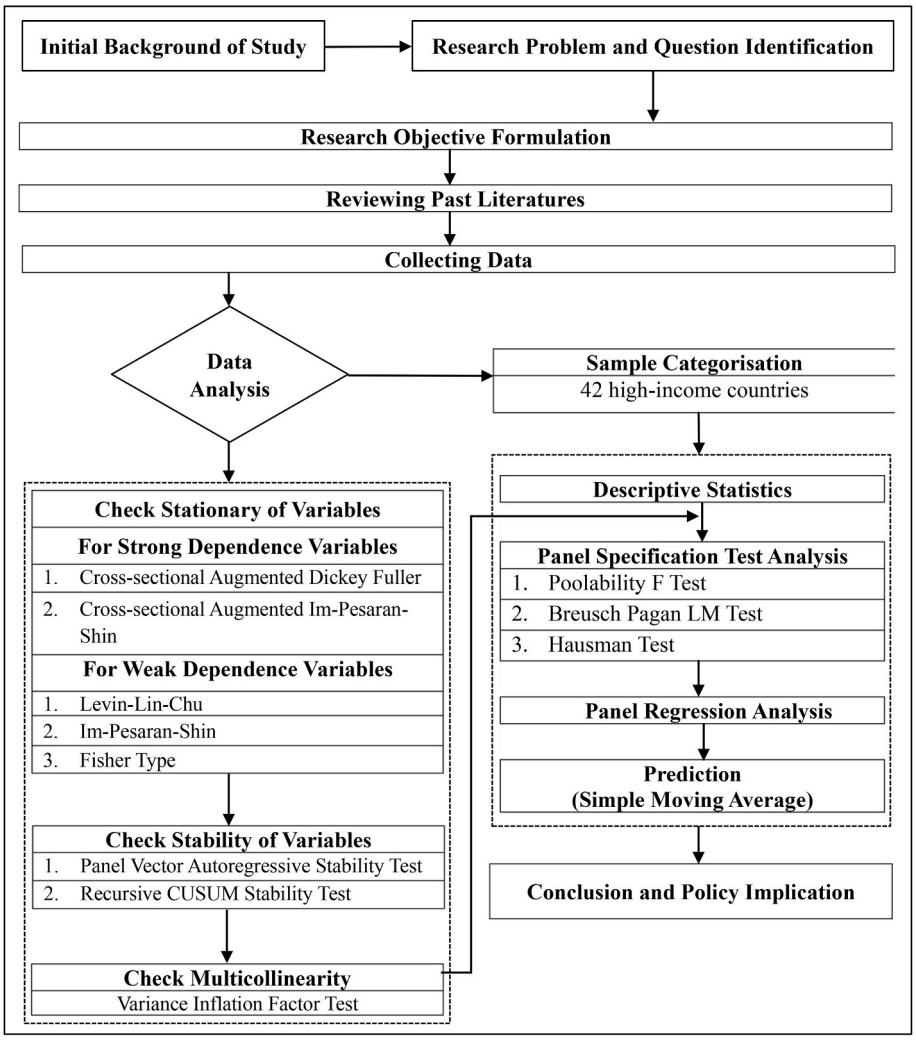


Fig. 4. Methodology flow diagram.
Source: Authors' compilation.

of the exponential variables. Following shows the panel regression equation,

$$BP_{it} = \beta_0 + \beta_1\, BC_{it} + \beta_2\, GDP_{it} + \beta_3\, TO_{it} + \beta_4\, GHG + \varepsilon_{it} \quad (2)$$

In this statistical equation (2), BP is Beef Production, BC is Beef Consumption, GDP is Gross Domestic Product, TO is Trade Openness, and GHG is Greenhouse Gas emission. The (β_0) denotes the base value of the beef production, and (β_1, β_2, β_3, β_4) are the coefficients of BC, GDP, TO and GHG, which show how the changes of these variables affect beef production. All these variables are estimated in level forms because they are already express in comparable per capita unit, it facilitates direct interpretation of the effects of beef production. In addition, some variables contain very small values across countries and periods which may create distortions under the logarithmic transformation. Nevertheless, logarithm specification is commonly used in empirical economics to interpret coefficients as elasticities. Therefore, log-log specification was considered as robustness framework and the levels was retained to maintain consistency with the measurement unit and the interpretation of production changes.

Moreover, the coefficients represent the marginal effects of the exponential variables on beef production measured in kilograms per capita. In addition, (i) represents the countries in the high-income group, (t) is the period that is considered and (ε_{it}) is the other factors which impact to the beef production, and which are not included in the study model. This model is used to test the proposed hypothesis $H_1 - H_4$ regarding the determinants of beef production.

Prior to estimation of the regression model several diagnostic procedures were conducted to ensure the reliability of the results. These includes cross sectional dependency test, panel unit root test for stationary, stability test reduces the panel vector autoregression framework and multicollinearity diagnostics based on the Variance Inflation Factor. Conducting these preliminary tests ensure that the estimated panel regression results are statistically consistence and not affected by common econometric issues.

Further, in this study performed simple moving averages method to forecast beef production for 2023, 2024, 2025 and 2026. The moving average method has an advantage because it removed short-term fluctuations. In this method, it takes the average of a fixed number set in a time series, which moved in the series by dropped the oldest value and added the next in each time (Molugaram and Rao, 2017). Therefore, by predicting, it can identify the potential short-term fluctuations and the growth patterns of the beef production in each country in the high-income group which provided insights for policy makers and stakeholders that support informed decision-making. Following shows the simple moving average equation,

$$\widehat{BP}_{t+1} = \frac{BP_t + BP_{t-1} + BP_{t-2}}{3} \quad (3)$$

In this equation (3), BP is Beef Production, (t), (t+1), (t-1) and (t-2) denote the current year, next year after current year, previous year (year before current year), and two years ago (two years before current year), respectively.

In this study, utilising a balance panel structure improves estimation efficiently and reduce the bias caused by missing observation and using a simple moving average, able to predict the behaviour of beef production since many environmental issues and economic policies are formulated in high-income countries therefore, this facilitated to provide insights on how beef production will behave in the future.

3.3. Endogeneity consideration

One potential concerning estimating the relationship between beef consumption and beef production being a possibility of reversed causality. Higher level of beef production may increase the supply and availability in the market which in terms can influence consumption patterns this bidirectional relationship may introduce endogeneity biased in the regression estimations.

To mitigate this, concern the study added two approaches, first the fixed effect panel model controls for the time invariant country specific characteristics that may influences both beef production and consumption. Second, as for the robustness consideration the independent variables were interpretated in a framework were production decision response to consumption patterns observed in prior periods. This help reduce potential simultaneous bias between beef consumption and beef production.

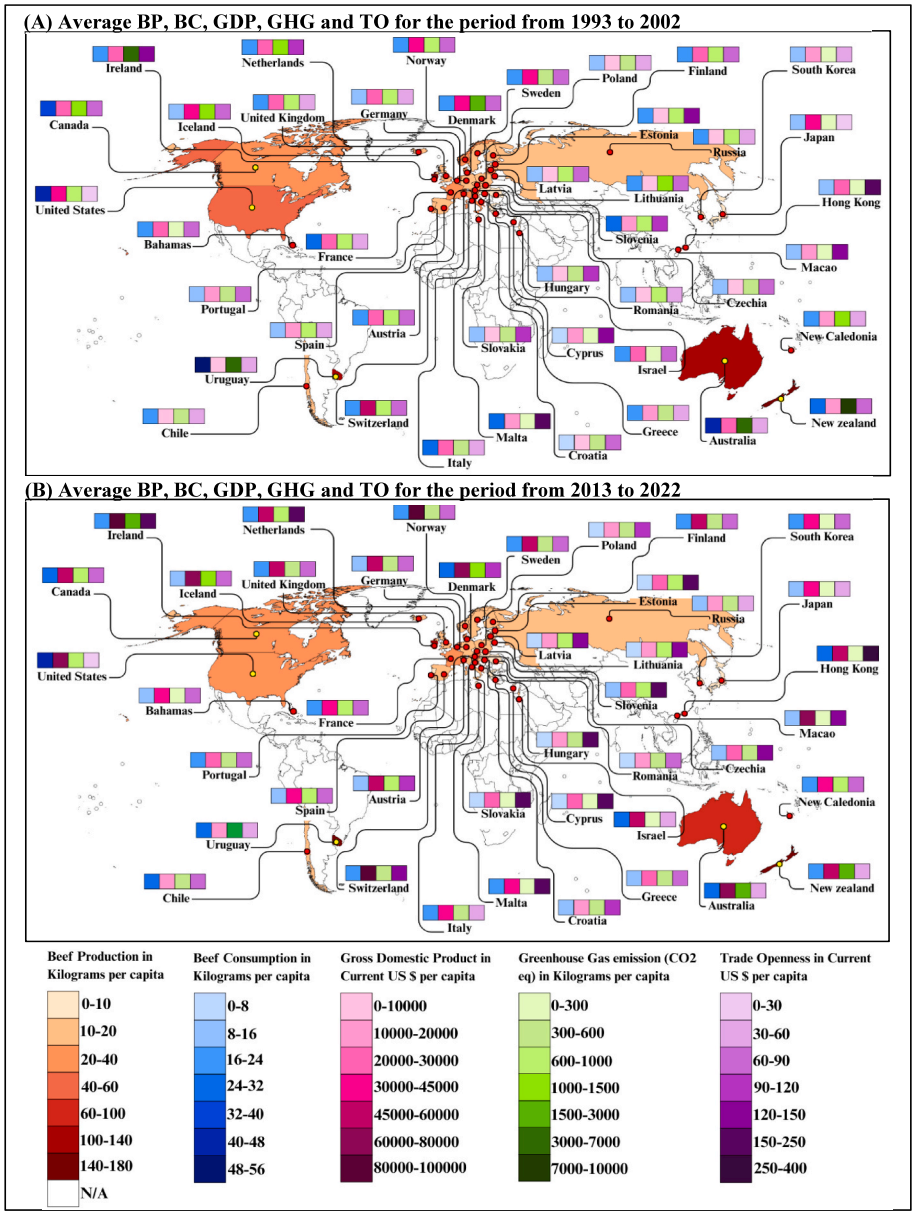


Fig. 5. Average of beef production, beef consumption, gross domestic product, greenhouse gas emissions, and trade openness for two periods: 1993 to 2002 and 2013 to 2022.

Source: Authors' illustration based on Food and Agriculture Organisation Statistics (Food and Agriculture Organization Statistics and Crops and livestock products, 2025; Food and Agriculture Organization Statistics et al., 2025; Food and Agriculture Organization Statistics and Emissions totals, 2025) and World Bank (World Bank, 2025) data. Note: A map of beef production in high-income countries shows a range of brown colours (from light to dark) with light colours indicating low values and dark colours indicating high values, while the independent variables beef consumption (blue), gross domestic product (pink), greenhouse gas emissions (green), and trade openness (purple) are also shown as boxes on the map, with light colours indicating low values and dark colours indicating high values

4. Results and discussion

This section provides the findings obtained from the descriptive statistics and panel regression analysis, and a comprehensive discussion of the findings.

4.1. Descriptive statistics

Descriptive statistics are used to condense large amounts of data into a few meaningful numbers and to gain a basic understanding of the data set. To get a better understanding of the variables (beef production, beef consumption, trade openness, greenhouse gas emissions and gross domestic product) and statistics for the high-income group. According to the summary of the descriptive statistics presented in Appendix 2, for each variable, the number of observations, mean, standard deviation, minimum and maximum values are observed. To get a more detailed understanding of these statistics, a two-time-period map visualisation was presented from 1993 to 2002 and from 2013 to 2022.

According to Fig. 5, the top beef producers over the past 30 years from 1993 to 2022 were Australia, New Zealand, Ireland, and Uruguay, which produced more than 100 kg per capita in both the 1993 to 2002 and 2013 to 2022 time periods. In addition, countries such as the Bahamas, Macau, Hong Kong, Japan, and Malta show very low beef production during two period.

Furthermore, beef consumption in high-income countries shows high values in Australia, Hong Kong, Israel, and the United States, with values above 30 kg per capita in period 2, while values below 10 kg per capita in period 2 are shown in Croatia, Cyprus, Poland and Romania.

Greenhouse gas emissions also show large variations between countries over the same period. Australia's peak of 4655 kg per capita between 1993 and 2003 has declined significantly from 2908 kg per capita between 2013 and 2022, while Ireland, New Zealand and Uruguay have seen large increases in greenhouse gas levels to over 3500 kg per capita. In addition, countries with small economies and limited industrial activity, such as Hong Kong and Macao, report very low greenhouse gas emissions levels of less than 10 kg per capita.

4.2. Preliminary test analysis

Preliminary tests were performed before regression analysis, first checking the cross-sectional of the variables through the Pesaran Cross-sectional Dependence test. According to the Cross-sectional Dependence test, beef production and beef consumption show weak cross-sectional dependency. In contrast, gross domestic product, trade openness, and greenhouse gas emissions show strong cross-sectional dependency. Due to the cross-sectional nature of the data, unit root tests were chosen to check the stationarity of the variables. In this study, for weak cross-selection dependence variables, use Levin–Lin–Chu, Im–Pesaran–Shin and Fisher Type tests and for strong cross-selection dependence, use Cross-Sectionally Augmented Im-Pesaran-Shin and Cross-Sectionally Augmented Dickey Fuller tests.

Results of the unit root tests were presented in Appendix 3. According to the Levin–Lin–Chu, Im–Pesaran–Shin and Fisher type unit root test results, beef production and beef consumption are stationary at 1% significance level. And according to the Cross-Sectionally Augmented Im-Pesaran-Shin and Cross-Sectionally Augmented Dickey-Fuller tests, greenhouse gas emissions are stationary at 1% significance level. In contrast, gross domestic product and trade openness are stationary at first difference with 1% significance level.

To further reliability of the empirical model additional diagnostic checks were conducted to evaluate stability of the variables over the sample period, in this context eigen valves stability condition of the Panel Vector Autoregressive (pVAR) framework and the Recursive CUSUM test were used as supplementary robustness checks. These procedures have varied that the dynamics behaviour of the variables remain stable overtime and tat the estimated relationships are not given by structural instability in the dataset. The results indicate that all eigen valves lie within the unit circle and that the CUSUM statistics remain within the critical boundaries confirming the stability of the empirical model. These stability diagnostics complement the panel regression analysis and provide additional confidence in the reliability of the empirical results. The results of the stability analysis were presented in Appendix 4.

Third, perform a multicollinearity test using the variance inflation factor test to check for multicollinearity among the independent variables. As the results were presented in Appendix 5, VIF results for all the variables are lower than 5 (VIF <5) and, the tolerance values (1/VIF) are high, which ensures that there is no multicollinearity between independent variables.

4.3. Panel regression results

Panel Regression analysis is utilised to determine the impact of beef consumption, greenhouse gas emission, gross domestic product, and trade openness on beef production in the high-income group, with a best model to control the variables' heteroskedasticity. To choose an appropriate model, perform panel specification tests, which were the Poolability F test, the Breusch-Pagan LM test and the Hausman test. According to the results presented in Table 2, the null hypothesis was rejected at 1% significance level, as were the Pooled Ordinary Least Squares tests in both the F test and the LM test, which accept both random effect and fixed effect models for this study. But Hausman tests were performed to choose the better model from the fixed-effect model and the random-effect model. According to the Hausman test, it rejects the null hypothesis, which was a random effect model at a 1% significance level, and based on the hypothesis testing of the Hausman test it declares that the fixed effect model is being the best model for this study.

The fixed-effect model helps to identify time-varying variables that may impact beef production and controls the unobserved heterogeneity variables throughout the data period. According to the results of the fixed effect estimation, which were presented in Table 3, the coefficients of beef consumption and gross domestic product negatively affect beef production. However, this impact is not statistically significant, indicating there is no evidence to claim that there are no direct effects from beef consumption and gross domestic product on beef production. Trade openness has a statistically significant negative impact on beef production which means when the one percent (1%) of the trade openness increases, beef production reduces by 0.0338 kg per capita. When considering greenhouse gas emissions, it has a statistically significant positive effects on beef production, where one percent (1%) of the greenhouse gas emission increases, the beef production increases by 0.0129 kg per capita.

To gain a clear understanding of beef production for the 42 high-income countries for the next four years, this study forecasts short

Table 2
Panel specification test results for high-income group.

Region	Tests		
	F Test	LM Test	Hausman Test (Sigmamore)
	H_0: POLS	H_0: POLS	H_0: Random Effect
	H_1: Fixed Effect	H_1: Random Effect	H_1: Fixed Effect
High-income group	96.51***	7632.16***	98.13***

Note: The symbol *** represents 1% significance level. Source: Authors' calculation based on data from Food and Agriculture Organisation Statistics (Food and Agriculture Organization Statistics and Crops and livestock products, 2025; Food and Agriculture Organization Statistics et al., 2025; Food and Agriculture Organization Statistics and Emissions totals, 2025) and World Bank (World Bank, 2025) data.

Table 3
Fixed effect and Random effect estimation results for high-income group.

Variables	Beef production (Fixed Effect)	Beef production (Random Effect)
Beef consumption	−0.187	−0.207
	(0.327)	(0.316)
GDP	−8.28e-06	4.73e-05
	(2.55e-05)	(3.27e-05)
Trade Openness	−0.0338**	−0.0345**
	(0.0163)	(0.0173)
GHG	0.0129***	0.0179***
	(0.00253)	(0.00276)
Constant	19.89***	13.40**
	(5.240)	(5.795)
N	1260	1260
R^2 Within	0.2598	0.2518
R^2 Between	0.9081	0.9218
R^2 Overall	0.8898	0.9045

Note: The symbol *** represents 1% significance level and ** represents 5% significance level. Parentheses represent the robust standard error. N represents several observations. Source: Authors' calculation based on data from Food and Agriculture Organisation Statistics (Food and Agriculture Organization Statistics and Crops and livestock products, 2025; Food and Agriculture Organization Statistics et al., 2025; Food and Agriculture Organization Statistics and Emissions totals, 2025) and World Bank (World Bank, 2025) data.

term trend patterns of the beef production of the individual countries for 2023, 2024, 2025 and 2026. To predict the trend in beef production, the simple moving average method, a widely used time-series forecasting technique that estimates the future based on values for previous periods, was used. The forecast values of the beef production were visualised in a line chart. According to Fig. 6, Uruguay will be the country with the highest beef production and will increase due to its focus on beef exports. In addition, New Zealand, Ireland, Australia, Canada, and the United States will also be increasing their beef production in future.

The line graph shows the negative impact on Australian beef production since 2019 due to lower demand for beef (Burton and Bolton, 2025). Because COVID-19 has affected domestic and international markets, Australian beef production has fallen by 23% compared to the previous year (Meat & Livestock Australia Limited, 2025). Moreover, there were droughts in 2013 and 2015, which again were a turning point, and also the number of male cattle slaughtered fell sharply in 2014 and 2015; therefore, beef production was reduced by 50% (Atkinson, 2025). In 2022, a drought reduced the cattle herd by 25 million (Morris, 2025), which could lead to a decrease in beef production from 2022 to 2026 compared to Uruguay.

The COVID-19 outbreak experienced a sharp drop in beef prices in November and December 2019, which also affected Uruguayan beef production (Joseph, 2020); therefore, in Uruguay, the forecast period does not show significant fluctuations from 2022 to 2026. The outbreaks of bovine spongiform encephalopathy in 2003 and 2005 led to a decline in beef production in the United States (Davis and Lin, 2005). In 2003, Canada also faced the bovine spongiform encephalopathy disease from beef cattle, which led to a decline in Canadian beef production. But forecast value in Canada and the United States (Schroeder et al., 2005) increased annually.

According to Fig. 7, Hong Kong is the seventh largest carbon emitter out of 113 regions globally. This is mainly due to the increase in imported meat consumption. However, in 2030, they are willing to reduce their carbon emissions by 36% (Ho, 2025); therefore, the beef production is decreasing and will continue to decrease in the forecast period. And in Israel, they consume only 8% of their beef domestically, which is a significant reason why the domestic industry is reduced (Luz, 2023) because they import most of it and have almost doubled in a decade. In the Bahamas, which is a tiny beef-producing country, accounting for 0.8% of its country land area (Shik et al.PerezDarrel, 2018), for beef production. Bahamas imports 80 per cent of its food (Caribbean Community, 2025), and only 0.7 per cent of its gross domestic product (Shik et al.PerezDarrel, 2018) comes from the agriculture sector.

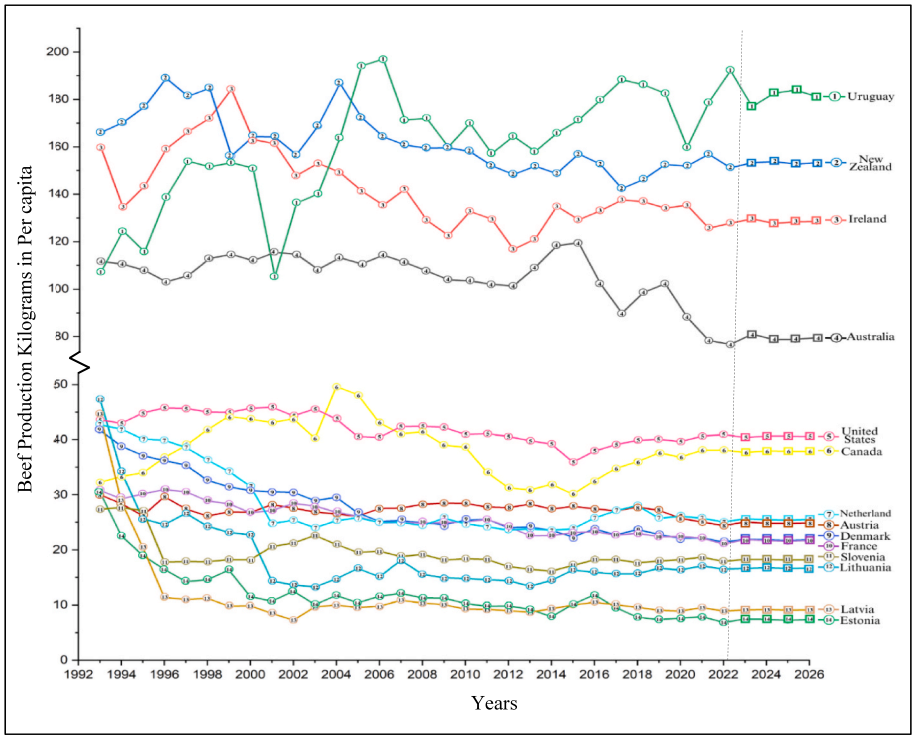


Fig. 6. Forecast beef production from 2022 to 2026 (14 countries).
Source: Authors' illustration based on Food and Agriculture Organisation Statistics (Food and Agriculture Organization Statistics and Crops and livestock products, 2025).

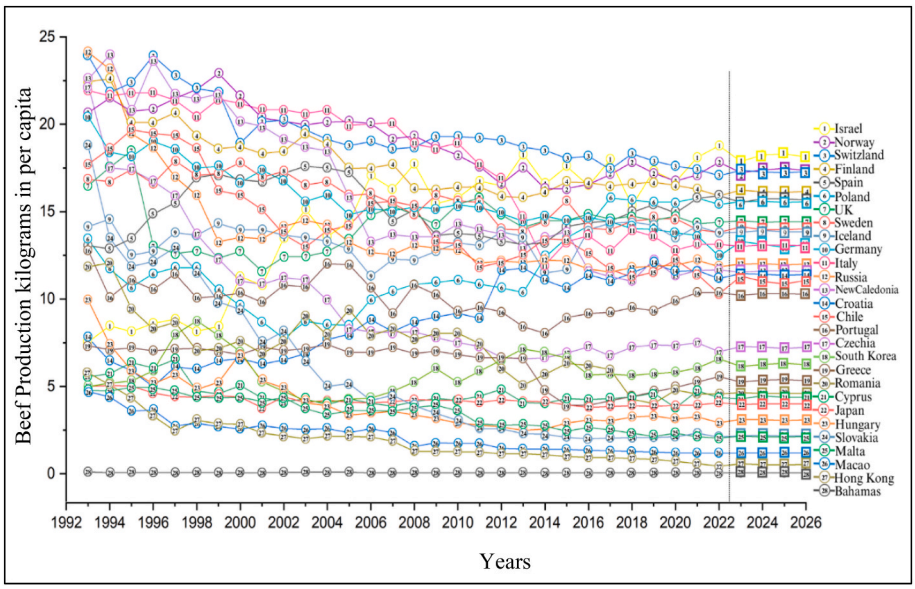


Fig. 7. Forecast beef production from 2022 to 2026 (28 countries).
Source: Authors' illustration based on Food and Agriculture Organisation Statistics (Food and Agriculture Organization Statistics and Crops and livestock products, 2025).

5. Conclusion

This study uses panel regression analysis with a panel data set of 42 high income countries over a 30-year period from 1993 to 2022 to investigate the relationship between beef consumption, trade openness, GDP, and greenhouse gas emissions from beef production in high-income countries according to the findings of panel regression analysis, revealed that there is no statistical evidence shows that beef consumption and GDP significant effect on beef production. In contrast, trade openness shows a negative effect and greenhouse gas emissions show a positive significant effect on beef production.

The results of descriptive analysis, show that there is an increasement in GDP after 2013, which, has been driven by the advent of new technology (Magoutas et al., 2024; Appiah-Otoo and Song, 2021; Niebel, 2018). The decline in beef production, beef consumption and greenhouse gas emissions has been attributed to climate change (Chapman et al., 2025), lack of profit, the emergence of substitute meats and the Paris Agreement (Craymer, 2025). Further in this study employed simple moving average method to estimate the impact in the coming years. According to forecast results of beef production from 2022 to 2026, shows that countries such as Uruguay, New Zealand, Ireland, Australia, Canada and the United States are expected to be among the leading beef producing countries. They will increase their future beef production compared to other high-income countries.

6. Policy implications

This study provides insights for policymakers to improve the beef production industry by determining its key factors in line with some Sustainable Development Goals. Governments in Australia, Hong Kong, and Switzerland are considering reducing beef production due to rising greenhouse gas emissions. When the government and the private sector working together, with a focus on adopting environmentally friendly farming methods for beef production to reduce greenhouse gas emissions, thereby being able to align with SDG 12: Responsible Consumption and Production and SDG 13: Climate Action goals Meanwhile, the SDG 9 Industry, Innovation and Infrastructure goal will enable beef industry farmers to increase their beef production with generate many jobs in rural communities in the agricultural sector by using innovative devices to reduce greenhouse gas emissions and introducing new production methods. When expanding the beef production, which has many macronutrients and micronutrients, it will align with SDG 2: Zero Hunger goal.

In Australia, decreasing its beef production by introduced kangaroo meat as an alternative meat to reduce greenhouse gas emissions (Ratnasiri and Bandara, 2017). But if a government can improve beef production without adopting substitute meat by introducing new methods that align with SDG 9: Industry, Innovation and Infrastructure, and SDG 2: Zero Hunger. In addition, European citizens are also supposed to take sustainable foods (Peschel and Grebitus, 2023), which focuses on SDG 13: Climate Action goal.

Trade openness contributes significantly to beef production. Countries such as Uruguay (Amodio et al., 2025), Ireland (Fu et al., 2021), New Zealand (Hall, 2025), United States (Adu et al., 2023) and Australia The governments are focusing on reaching safe and stable trade agreements to prevent destructive imports and exports, which is consistent with SDG 17: Partnership for the Goals.

7. Limitations and opportunities for future research

There are several limitations to this research. The high-income group was selected for this research, and it may not be possible to cover all the income groups. Also, there are 83 countries in the high-income group, and only 42 countries were taken for this research paper, based on data availability, as the variable did not have data for every high-income country. In addition, the period of this research is from 1993 to 2022, so although a data forecast for 2023, 2024, 2025, and 2026 was made, the lack of accurate data is a limitation.

Furthermore, other variables affect beef production, such as land use and water use, but secondary data for these variables cannot be obtained for the individual countries; it is only available at the global level. But this will be an opportunity for future researchers when gathering data on those variables in primary research. Also, there is an opportunity to compare the variables in this study to other income groups, which are lower-income, lower-middle-income, and upper-middle-income groups.

Funding

The authors did not receive support from any organization for the submitted work.

CRediT authorship contribution statement

Himaya Susan: Conceptualization, Data curation, Formal analysis, Methodology, Software, Validation, Visualization, Writing – original draft, Writing – review & editing. **Kalana Mendis:** Conceptualization, Data curation, Formal analysis, Methodology, Software, Validation, Visualization, Writing – original draft, Writing – review & editing. **Nisal Perera:** Data curation, Formal analysis, Methodology, Validation, Visualization, Writing – original draft, Writing – review & editing. **Yasodara Silva:** Data curation, Methodology, Validation, Visualization, Writing – original draft, Writing – review & editing. **Ruwan Jayathilaka:** Conceptualization, Funding acquisition, Investigation, Project administration, Supervision, Validation, Visualization, Writing – original draft, Writing – review & editing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.indic.2026.101314.

Data availability

All data generated or analysed during this study are included in this published article and its supplementary information files.

References

Acosta, A., Nicolli, F., Tirkaso, W., 2024. Cattle ownership and households' welfare: evidence from Southern Africa. Global Food Secur. 42, 100772.

Adu, D.T., Li, W., Sawadgo, W.P.M., 2023. Estimating the unintended impact of the North American free trade agreement on U.S. public health. Soc. Sci. Med. 333, 116140.

Almusawi, H.A.I., et al., 2025. Nutritional properties, lipid oxidation, microbial growth, and sensory evaluation of beef burgers enriched with garden cress seeds powder. Cogent Food Agric. 11 (1), 2452342.

Amodio, F., Chiovelli, G., Frache, S., 2025. How Uruguay's beef exports to China reshaped its economy. https://voxdev.org/topic/trade/how-uruguays-beef-exports-china-reshaped-its-economy.

Appiah-Otoo, I., Song, N., 2021. The impact of ICT on economic growth-comparing rich and poor countries. Telecommun. Policy 45 (2), 102082.

Atkinson, R., 2025. How the 2013–2015 Drought Reshaped Australia's Beef Industry. https://pulse.auctionsplus.com.au/aplus-news/insights/a-turning-point-that-transformed-the-beef-industry-and-its-supply-chain.

Barnhill, A., et al., 2022. Moral reasons for individuals in high-income countries to limit beef consumption. Food Ethics 7 (2), 11.

Berton, M., et al., 2025. Life cycle assessment in cattle farming systems: a review of approaches, goals and scopes. Ital. J. Anim. Sci. 24 (1), 1075–1091.

Bettini, S., et al., 2025. Assessing the impact of biotics on the ruminal microbiome to enhance sustainability, welfare, and performance in beef cattle: highlighting the omics approach. Ital. J. Anim. Sci. 24 (1), 660–676.

Bothare, V., 2025. Top Beef-Consuming Countries in the World. https://straitsresearch.com/statistic/countries-with-the-highest-beef-consumption-rates.

Bragaglio, A., et al., 2018. Environmental impacts of Italian beef production: a comparison between different systems. J. Clean. Prod. 172, 4033–4043.

Burton, L., Bolton, M., 2025. COVID-19 causes 'volatile' global beef market, reducing cattle on feed in Australia. https://www.abc.net.au/news/rural/2020-07-23/feedlot-numbers-decline-amid-volatile-beef-market/12473984.

Caribbean Community. *Bahamas*, 2025. Available from: https://agricarib.org/bahamas-2/.

Chapman, D.F., et al., 2025. Pasture productivity in New Zealand 1990–2020: trends, expectations, and key factors. N. Z. J. Agric. Res. 68 (6), 1221–1264.

Chen, X., et al., 2019. Shelf-life and microbial community dynamics of super-chilled beef imported from Australia to China. Food Res. Int. 120, 784–792.

Craymer, L., 2025. New Zealand targets cutting emissions by 51% to 55% by 2035. https://www.reuters.com/world/asia-pacific/new-zealand-targets-cutting-emissions-by-51-55-by-2035-2025-01-30/.

Davis, C.G., Lin, B.-H., 2005. Factors Affecting U.S. Beef Consumption.

del Campo, M., et al., 2025. Future cattle production: animal welfare as a critical component of sustainability and beef quality, a South American perspective. Meat Sci. 219, 109672.

Farchi, S., et al., 2017. Meat consumption reduction in Italian regions: health co-benefits and decreases in GHG emissions. PLoS One 12 (8), e0182960.

Food and Agriculture Organization Statistics, *Food Balances (2010)*, 2025. Food Agriculture Organization United Nations.

Food and Agriculture Organization Statistics, *Crops and livestock products*, 2025. Food Agriculture Organization United Nations.

Food and Agriculture Organization Statistics, *Emissions totals*, 2025. Food Agriculture Organization United Nations.

Fu, R., et al., 2024. Chinese consumer preference for beef with geographical indications and other attributes. Meat Sci. 212, 109475.

Fu, R., Li, C., Wang, L., 2021. Market power in the Irish beef processing industry. Sustainability 13 (11).

Gondauri, D.J.a.e.-p., 2025. The impact of artificial intelligence on gross domestic product: a global analysis. arXiv:2505, 11989. https://doi.org/10.48550/arXiv.2505.11989.

Greenwood, P.L., Gardner, G.E., Ferguson, D.M., 2018. Current situation and future prospects for the Australian beef industry — a review. Asian-Australas. J. Anim. Sci. 31 (7), 992–1006.

Gu, X., et al., 2025. The future of cultured meat: focusing on multidisciplinary, digitization, and nutritional customization. Food Res. Int. 219, 117005.

Hadi, S.N., Chung, R.H., 2022. Estimation of demand for beef imports in Indonesia: an autoregressive distributed lag (ARDL) approach. Agriculture 12 (8).

Hall, R., 2025. Livestock and Products Semi-annual, pp. 1–17. New Zealand.

Ho, S., 2025. OPINION: why Hong Kong needs A meat tax. https://www.greenqueen.com.hk/opinion-why-hong-kong-needs-a-meat-tax-covering-climate-now/.

Hocquette, J.-F., et al., 2018. Current situation and future prospects for beef production in Europe — a review. Asian-Australas. J. Anim. Sci. 31 (7), 1017–1035.

Iram, S., et al., 2025. Serum markers for beef meat quality: potential media supplement for cell-cultured meat production. Curr. Res. Food Sci. 10, 100943.

Joseph, K., 2020. Livestock and Products Annual.

Kearney, M., et al., 2023. Mitigation of greenhouse gas emissions in pasture-based dairy-beef production systems. Agric. Syst. 211, 103748.

Kenny, U., et al., 2024. Exploring perceptions of and attitudes towards bluetongue disease: a multi-stakeholder interview study in the beef and sheep farming sector in Ireland. Soc. Sci. Humanit. Open 9, 100799.

Kibona, C.A., Yuejie, Z., Tian, L., 2022. Towards developing a beef meat export oriented policy in Tanzania: -exploring the factors that influence beef meat exports. PLoS One 17 (6), e0270146.

Kim, Y.-J., et al., 2018. Genotypic characterization of ESBL-producing E. coli from imported meat in South Korea. Food Res. Int. 107, 158–164.

Koizumi, S., et al., 2001. Study on consumer behavior for meat consumption in the U.S. Nihon Chikusan Gakkaiho 72 (4), 329–343.

Luz, N., 2023. The treacherous road to sustainable agriculture: lessons from Israeli farmers and the need to upscale the debate. Sustainability 15 (16).

Magoutas, A.I., et al., 2024. Digital progression and economic growth: analyzing the impact of ICT advancements on the GDP of European Union countries. Economies 12 (3).

Mansky de la Fuente, V., et al., 2024. Citizen attitudes towards present and future beef consumption before and after the COVID-19 pandemic. Meat Sci. 212, 109467.

Meat & Livestock Australia Limited, 2025. COVID-19: impacts on markets. https://www.mla.com.au/news-and-events/industry-news/covid-19-impacts-on-markets14.

Merlino, V.M., et al., 2018. Beef meat preferences of consumers from northwest Italy: analysis of choice attributes. Meat Sci. 143, 119–128.

Mitura, V., di Pietro, L., 2004. Canada's beef cattle sector and the impact of BSE on farm family income 2000-2003. Statistics Canada Agriculture Division 1 (1), 38.

Molugaram, K., Rao, G.S., 2017. Chapter 12 - analysis of time series. In: Molugaram, K., Rao, G.S. (Eds.), Statistical Techniques for Transportation Engineering. Butterworth-Heinemann, pp. 463–489.

Morris, N., 2025. Cattle prices are down and the herd is growing, so why is steak still so expensive? https://www.abc.net.au/news/2023-07-30/why-is-steak-still-expensive/102630100.

Niebel, T., 2018. ICT and economic growth – comparing developing, emerging and developed countries. World Dev. 104, 197–211.

OECD Food and Agriculture Organization of the United Nations, 2025. OECD-FAO Agricultural Outlook 2025-2034. OECD Publishing, Paris/FAO, Rome.

Oliver, M.A., et al., 2006. Eating quality of beef, from different production systems, assessed by German, Spanish and British consumers. Meat Sci. 74 (3), 435–442.

Ortega, D.L., et al., 2016. Emerging markets for imported beef in China: results from a consumer choice experiment in Beijing. Meat Sci. 121, 317–323.

Peel, D.S., 2025. Global beef trade: key economic insights and trends. https://www.drovers.com/news/industry/global-beef-trade-key-economic-insights-and-trends.

Peschel, A.O., Grebitus, C., 2023. Flexitarians' and meat eaters' heterogeneous preferences for beef: gourmets and value seekers. Food Qual. Prefer. 104, 104756.

Pishgar-Komleh, S.H., Beldman, A., 2022. Literature Review of Beef Production Systems in Europe.

Porto Costa, M., et al., 2023. Environmental and land use consequences of replacing milk and beef with plant-based alternatives. J. Clean. Prod. 424, 138826.

Rahman, A.U., et al., 2025. Comparative analysis of antibiotic-administered vs. antibiotic-free farming in meat production: implications for health, environment, and antibiotic resistance. Food Microbiol., 104877

Ratnasiri, S., Bandara, J., 2017. Changing patterns of meat consumption and greenhouse gas emissions in Australia: will kangaroo meat make a difference? PLoS One 12 (2), e0170130.

Rinn, N., et al., 2024. Microbiological quality of raw beef imported into the European Union from third countries. Food Control 160, 110358.

Salzano, A., et al., 2025. Nutritional, environmental and social profiles of natural meat and food derived from cultured muscle cells: an overview. Meat Sci. 228, 109868.
Sandström, V., et al., 2018. The role of trade in the greenhouse gas footprints of EU diets. Global Food Secur. 19, 48–55.
Saniyyah, R.D., Istiandari, D.N., 2024. Analysis determinants of economic growth in Asian countries: an empirical study of middle-income and high-income countries. Int. J. Appl. Adv. Multidisciplinar. Res. 2 (5), 395–414.
Santinello, M., et al., 2024. The meat standards Australia carcass grading site affects assessment of marbling and prediction of meat-eating quality in growing European beef cattle. Meat Sci. 213, 109501.
Schierhorn, F., et al., 2016. The dynamics of beef trade between Brazil and Russia and their environmental implications. Global Food Secur. 11, 84–92.
Schmitz, C., et al., 2012. Trading more food: implications for land use, greenhouse gas emissions, and the food system. Glob. Environ. Change 22 (1), 189–209.
Schnettler, B., et al., 2009. Consumer willingness to pay for beef meat in a developing country: the effect of information regarding country of origin, price and animal handling prior to slaughter. Food Qual. Prefer. 20 (2), 156–165.
Schroeder, T., Mintert, J., Coffey, B., 2005. The Economic Impact of BSE on the U.S. Beef Industry: Product Value Losses, Regulatory Costs, and Consumer Reactions.
Shen, J., et al., 2022. Prevalence, antibiotic resistance, and molecular epidemiology of Listeria monocytogenes isolated from imported foods in China during 2018 to 2020. Int. J. Food Microbiol. 382, 109916.
Shik, O., et al., 2018. In: Perez, Darrel (Eds.), Analysis of Agricultural and Fisheries Policy in the Bahamas, pp. 1–83.
Singh, S., et al., 2023. Beef cattle production systems and constraints among subsistence farmers across the Fijian windward–leeward divide. Outlook Agric. 52 (2), 140–152.
Smith, S.B., Gotoh, T., Greenwood, P.L., 2018. Current situation and future prospects for global beef production: overview of special issue. Asian-Australas. J. Anim. Sci. 31 (7), 927–932.
Sousa, A.V.D., 2025. Top 10 beef producing countries worldwide. https://ruminants.ceva.pro/beef-producing-countries.
Syastiawan, A., et al., 2025. Income assessment of beef cattle farming and measurement of the customer satisfaction index (CSI) on farmer's satisfaction level. Agribusiness Dev. J. 5 (1), 30–40.
Van Eenoo Jr., E., Peterson, E.B., Purcell, W.D., 2000. Impact of exports on the U.S. beef industry. In: NCR-134 Conference on Applied Commodity Price Analysis, Forecasting, and Market Risk Management. Chicago, Illinois.
Vergé, X.P.C., et al., 2008. Greenhouse gas emissions from the Canadian beef industry. Agric. Syst. 98 (2), 126–134.
Wei, Y., et al., 2023. Greenhouse gas emissions of meat products in China: a provincial-level quantification. Resour. Conserv. Recycl. 190, 106843.
Wei, W., Bandara, Y.M.W.Y., 2009. Chapter 7 - FDI spillovers - the strategy for Chinese economic development. In: Basu, P.K., Bandara, Y.M.W.Y. (Eds.), WTO Accession and Socio-Economic Development in China. Chandos Publishing, pp. 111–134.
Weibel, C., et al., 2019. Reducing individual meat consumption: an integrated phase model approach. Food Qual. Prefer. 73, 8–18.
World Bank, 2025. World Development Indicators. World Bank Group.
Wu, Y., et al., 2025. Lotus fiber-derived scaffolds for enhanced cultured meat production: quality and sustainability. Bioact. Mater. 51, 807–824.