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SPECIAL FEATURE: ORIGINAL ARTICLE

Lessons learned from non-state and subnational climate action

Past trends, alternative futures, and energy demand scenarios for Bangladesh

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Abstract

In developing countries like Bangladesh, demand for energy services is expected to grow with the expansion of economic activity and population. Reliance on fossil fuels with a less diversified fuel mix poses challenges to sustainable energy sector growth. Studies indicate that there are feasible options for increasing the share of clean fuel in the energy mix if efforts are started without delay. Energy intensity is very slowly declining. Expediting access to efficient, modern technologies in all sectors can reduce wasteful energy use in service provision. There is a need for absolute growth in energy consumption to achieve a decent living standard (DLS) for all, and to support the aspiration level of the people of Bangladesh for a good life with higher wellbeing, urbanization, and access to modern appliances and infrastructure. This paper examines how alternative future scenarios, shaped by structural and demographic change, shifts in the fuel mix, technological innovation, and, above all, GDP growth aimed at enhancing human wellbeing, could influence energy demand pathways over time. We developed the SPINE (Service Provision Imagined with No Emissions) model, based on a decomposition approach for energy use, and applied it to generate alternative pathways to achieve Bangladesh's nationally determined contributions (NDC) and energy demand consistent with the IPCC's low energy demand (LED) scenario.

Keywords Development aspiration · Energy for high wellbeing · Rural-urban population distribution · Climate mitigation · Energy security · Developing country · Climate justice

Introduction

Over the last 2 decades (2000–2020), Bangladesh experienced an average annual 7–10% GDP growth rate to graduate from least developed nation status to the lower middle-income nation status (Mahmud and Roy 2024). Energy input demand from productive economic sectors like industry, transport, services, and agriculture increased with activity growth (Raihan et al. 2024). Household demand for energy also increased with the increasing urbanization and economic prosperity of the people (Haq et al. 2024). The country experienced structural shifts over this period, from agricultural dominance to energy-intensive manufacturing sector dominance. The annual average growth rate of energy demand was 6% between 2020 and 2022 (Hydrocarbon Unit 2023). The high economic growth rate of 8.15% (BBS 2025a) in the pre-pandemic period, optimism raised the national aspiration to attain the status of the developed nations by 2041 (GED 2020). The energy sector, including electrification, is expected to play a critical role in restoring, stabilizing, and maintaining economic growth while complying with multiple sustainable development goals and national pledges under the carbon-constrained world (Mahmud and Roy 2020; Roy 2024).

Fast-developing economies like Bangladesh, to attain aspired developed country status in the next two to three

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decades, with global carbon constraints, need to plan now strategically their economic growth pattern and pathways by avoiding unintended commitment to long-term cost burden and injustices in transition. Global GHGs mitigation objectives require human society of today to imagine, innovate, and invest in development models that are consistent with climate change adaptation solutions, and energy sources that do not lead to additional carbon and other greenhouse gas emissions to be taken out later through the deployment of negative emission technologies, e.g., direct-air capture (DAC) and bioenergy with carbon capture and storage (BECCS) (Grubler et al. 2018). The plan can be for a growth path that addresses multiple goals of sustainable development that are consistent with human wellbeing dimensions including energy security and sustainability, resilience to growing threats from climate change simultaneously and provide at the minimum a decent living standard (DLS) to all in the near term (Rose and Casler 1996; Lima et al. 2017; Rao and Min 2018; Li et al. 2021). Insights into future plausible structural shifts in the economy, fuel mix flexibility, income growth of people, and rural-urban population composition will help in developing future pathways for energy and emissions growth. How the future will unfold depends not only on past trajectory but also on possible future imaginaries. Strategic planning will require the development of context-specific alternative future scenarios and consistent pathways to determine how the past and current economic structure, fuel mix, technology access, and activity growth will need to be imagined, adjusted, or, if needed, reconfigured through policy measures by taking various opportunities that are emerging in the global context both in technology innovation and service provision systems (Nahid et al. 2025). Literature on climate justice and equity argues in favor of allocating sufficient room for economic development of the least developed and developing economies in the world while addressing climate change (Kartha et al. 2018). With global carbon constraint but within the climate justice paradigm, how Bangladesh can plan in the near-term for a sustainable low emission pathway while meeting energy needs for basic human wellbeing 'decent living standards' (DLS) (Rao and Min 2018; Rao et al. 2019) for all, and providing enough energy for productive economic sectors is a major research question. Answering such research questions can contribute to decision-making and policy framing for shifting development pathways (Kartha et al. 2018) with an attempt to create a new long-term sustainable path dependency for the country. Publication of the LED scenario and pathway in the 2018 IPCC report (Masson-Delmotte et al. 2018) created a new enthusiasm among researchers to find the new development pathways, energy demand, energy policy for equity, climate equity and justice, mitigation, that are consistent with developing countries' growth and ambitious global climate mitigation (Carbon Tracker 2017; Rao and Min 2018; Rao et al. 2019; Millward-Hopkins et al. 2020; Roy et al. 2021; Wilson et al. 2023). There is a major research gap in the context of Bangladesh, both in terms of DLS study and for future LED consistent pathways. For South Africa, India, and Brazil (Rao et al. 2019), DLS estimates and alternative DLS achievement scenarios are developed. The IPCC 1.5 report (Masson-Delmotte et al. 2018) provided a global scenario, so there is an intensified effort going on among researchers and a call for action (Sugiyama et al. 2024) to develop these specific scenario-based pathways. The objective of this paper is to address this research question for Bangladesh. The paper specifically addresses:

1. What has driven the past trend in energy use and mix, which can explain the status of economic activity growth and energy sector growth?
2. How can the country plan to grow differently in the near term if the high wellbeing of people and decent living standards (DLS) for all are to be provided by the turn of this decade?
3. What will be the energy demand growth and corresponding emission trajectories under alternative development scenarios, and what policy levers can be effective to achieve alternative scenarios to create a new path dependency?

In the sections below, we cover a short review of past literature in "Past literature". "Method" presents the methods we are applying for answering the questions mentioned above, and the sources of data. Results with main findings and discussion on implications in the context of national pledges reflected in Nationally Determined Contributions (NDCs) are included in "Results and discussion" and "Future scenarios: SPINE model results and analysis". "Conclusion" presents concluding remarks and summary of the reserach.

Past literature

Many researchers have approached answering the drivers of change in energy use and resultant emissions through factor decomposition analysis (Yoichi 1989; Su and Ang 2012; Liao et al. 2013). Structural Decomposition Analysis (SDA) is also used, but data limitations and an additive type of decomposition have led to less widespread application (Ang and Zhang 2000). Because of its comparatively low data requirements, a straightforward model that can be set up in spreadsheets, ease of operation, and visibility of assumptions, alternate decomposition forms (additive or multiplicative), the Index Decomposition Analysis (IDA) is most frequently applied by researchers for understanding drivers of energy consumption and emissions (Wang and Feng 2018). Literature (detailed in the supplementary material at Table S1) from various countries is rich (Ediger and Huvaz 2006; Olanrewaju et al. 2012; O'Mahony 2013; Wang et al. 2014; Shahiduzzaman and Layton 2017; Lima et al. 2017; Chong et al. 2017; Wang and Feng 2018; Zhang and Bai 2018; Dong et al. 2019; Gupta 2019; Zhang et al. 2019; Fatima et al. 2019; Trotta 2020; Hossain and Chen 2020; Das and Roy 2020; Zhao et al. 2020; Hasan and Chongbo 2020; Hossain et al. 2021; Li et al. 2021) in application of the Logarithmic Mean Divisia Index (LMDI), as it provides more reliable sectoral aggregation competing methods. Ang et al. (Ang and Liu 2001; Ang 2004, 2005, 2015) provide a summary of the evolution of the use of IDA methods and suggest LMDI for its reliability and usefulness in a variety of applications. The decomposition method helps in providing a clear understanding of the contribution of structural change, fuel mix pattern, product service ratio, income growth, population growth, and rural-urban distribution to growth in energy use and emissions. For developing future scenarios for emissions and energy, a variety of methods have been suggested and adopted, starting from Integrated Assessment Models (IAMC 2025), mixed methods through stakeholder engagement (Wester et al. 2019; Barua et al. 2024) to the decomposition method combined with scenario analysis (Ang and Zhang 2000; Agnolucci et al. 2009; O'Mahony et al. 2012). For developing countries, future trajectories of energy and emissions can be expected to start from relative decoupling towards absolute decoupling in the longer term. Relative decoupling in developing countries at the sectoral scale (Dasgupta and Roy 2017; Huzaifa Butt et al. 2024) and sometimes at the economy-wide scale (Das and Roy 2020) is already happening in many countries. Some are driven by fuel mix change, energy intensity change (Arent et al. 2014). So, for developing countries to understand drivers of change in the past and how these drivers might unfold or can be enabled to change to emerge in a low-carbon way will be an interesting exercise to conduct, as the agility of these economies exists, given the stage of their development in terms of structure design, technology adoption and fuel choice to meet new expanding demand.

Method

SPINE (service provision imagined with no emissions)

We developed the SPINE (Service Provision Imagined with No Emissions) model to apply for Bangladesh using basic principles of the decomposition approach (Y. 1989) that specifies the key drivers of energy use/emissions. A combination of decomposition analysis and scenario analysis is not new in the literature, but the type and level of decomposition and tool applied vary and are context dependent and developed for individual countries (Farber 1986; Sun 2001; Barrett and Scott 2012; O'Mahony et al. 2012). It helps in tracking in a national context past emissions, as well as helps in understanding various future energy/emissions levels depending on assumptions about how these basic drivers can evolve in the future with socio-economic development/policy changes/technology innovation, and population growth and distribution. For building the SPINE model, we start from the definition of a scenario, which represents a plausible description of how the future may develop based on a coherent and internally consistent set of assumptions about key driving forces and relationships. Scenarios are used to provide a view of the implications of developments and actions (IPCC 2022).

To decompose the energy consumption in Bangladesh, we use two basic identities represented by 1 and 2. For Productive sectors: Industry, Agriculture, Transport, and Services, this study uses the same identity (1) but with sector representation adjusted appropriately.

$$E_{Industry} \equiv \left[(E_{Coal} + E_{Gas} + E_{Oil} + E_{Electricity}) \times \frac{1}{E_{industry}} \times \frac{E_{industry}}{GDP_{industry}} \times \frac{GDP_{industry}}{GDP_T} \times \frac{GDP_T}{Pop} \times Pop \right] \quad (1)$$

Decomposition of the total sector-level energy use in the various components in ratio form allows us to explain the drivers of energy use change. First component help us to understand how fuel mix (coal, oil products, natural gas, and electricity)—in total energy use is changing and can be imagined to change in the long run, second term reflects energy intensity representing technological advancement in energy input use efficiency, third component captures the structure of the economy represented by sectoral share in GDP, fourth component shows changing affluence of the people of Bangladesh represented by per capita GDP and the last component shows how total demand change with absolute size of the population.

For the Residential sector, energy use for various energy service needs, such as illumination, cooking, thermal comfort, etc., this study uses the identity (2) appropriately adjusted for the rural and urban sectors. Here, the first and the last components have similar significance as above. The second component shows the share of expenditure on energy by rural households in total household expenditure, and the third component represents the affluence of rural (urban) people by taking per capita expenditure by rural (urban) households. The fourth component shows population distribution between rural and urban areas through the share of the respective population share in the total population.

$$E_{Rural} \equiv \left[(E_{Coal} + E_{Gas} + E_{Oil} + E_{Electricity}) \times \frac{1}{E_{Rural}}\right] \times \frac{E_{Rural}}{TEX_{Rural}} \times \frac{TEX_{Rural}}{Pop_{Rural}} \times \frac{Pop_{Rural}}{Pop} \times Pop \quad (2)$$

Detailed breakdown by component for estimation purposes is given in Appendix 2.

In the first step, we use past data to understand how the energy service demand is evolving in Bangladesh. In the next step, we consider how these drivers in identity 1 and 2 can evolve, driven by policy choice, technology selection, national targets, population growth, and rural-urban distribution to construct the future alternative scenarios (Table 1). However, we demonstrate in this paper future pathways until 2030 to understand what should be the near-term actions that can be created without any further delay, a development path dependency towards a sustainable future, going beyond 2030. Nevertheless, they can be extended to any period beyond 2030 as well with plausible assumptions; however, the scope of this paper is limited to 2030. The need for near-term actions is emphasized in the literature(Calvin et al. 2023) to avoid unintended locking in on an unsustainable/high-emission future pathway and to avoid high stranded asset costs in the future. We use five alternative future scenarios with high wellbeing and low energy demand(Wilson et al. 2023), consistent with the LED scenario of IPCC (Zhai et al. 2018; Creutzig et al. 2022; Wilson et al. 2023; Sugiyama et al. 2024; Bento et al. 2024). The reason being that the LED scenario provides scope for economic growth for developing economies, addresses higher human well-being needs, consistent with the Paris goal of well below 2 °C stabilization goal, and avoids any deployment need for engineered negative emission technologies except for nature-based solutions like afforestation and reforestation (Masson-Delmotte et al. 2018).

Through the five alternative future scenarios, this study quantifies the role of drivers in the future energy demand growth trajectories, considering, but not limited to, decent living standards-led (Rao and Min 2018) energy demand growth for Bangladesh by 2030.

Historical trend analysis

This study employs the Logarithmic Mean Divisia Index (LMDI) to estimate the identities to evaluate past trends in energy use growth in Bangladesh. Given a clear theoretical foundation, versatility across diverse contexts, and capacity for perfect decomposition with zero residual LMDI is used (O'Mahony et al. 2012). The mathematical details of the energy consumption identity, decomposition method, and related equations are provided in Appendix 1.

Table 1 Scenario descriptions for SPINE model

Scenario name	Scenario description	Description translated for SPINE model
Default Demand, No Policy (Defdem_noPol)	Model energy demand based on historical trends, assuming no new climate or energy policies are implemented	Sectoral economic structure follows historical patterns Energy intensity (EI) aligns with historical trends GDP growth follows historical trends
High Wellbeing, Low Demand, No Policy (Hwl_noPol)	Represents a scenario with enhanced societal wellbeing than in the past, but with low energy demand, without new climate policy interventions	GDP growth adjusted by reported national aspirations Lower demand is due to Energy intensity improvements, as national projections Sectoral energy mix is estimated using historical trend extrapolation based on national energy statistics
Default Demand, 1.5 °C Pathway (Defdem_1.5)	Projects energy demand under a pathway aligned with limiting global warming to 1.5 °C, maintaining historical economic structures	No structural change in the economy, the past structure continues Energy intensity improves as per NDC 2.0[a] energy efficiency (EE) targets set consistent with the 1.5 °C scenario GDP growth follows sector-specific historical trends
High Wellbeing, Low Demand, 1.5 °C Pathway (Hwl_1.5)	Combines high wellbeing and low energy demand with policies targeting a 1.5 °C warming limit	Energy intensity aligns with NDC 2.0 projections Sectoral energy mix is estimated using historical trend extrapolation based on national energy statistics GDP growth adjusted based on national reports
Decent Living Standard, High Wellbeing, Low Demand, 1.5 °C Pathway (Hwl_1.5_DLS)	Combines a decent living standard, high wellbeing, and low energy demand with policies targeting a 1.5 °C warming limit	Energy intensity aligns with NDC projections − 12.35 GJ per capita energy requirement for a decent living standard in Bangladesh Sectoral energy mix shifts per NDC 2.0 and national reports GDP growth adjusted with national aspirations reflected in national reports

[a]Authors acknowledge that a new NDC 3.0 has been announced, but we keep NDC2.0 assumptions here as our goal is to find a near-term solution for 2030, and also, the work started much earlier than the publication of NDC3.0. An additional note is added in a later section comparing the two NDCs for the relevant parameters used in this paper

Data

The study utilizes yearly time-series data on end-use energy consumption, population, sectoral value added, and per capita household expenditure in 2001–2018, as we use the baseline scenario interchangeably for the no policy scenario or reference scenario as per the IPCC glossary. So, we take 2018 as the reference year with the assumption that climate policy manifestations start for Bangladesh after 2018, since the submission of the 2015 first NDC. The energy consumption data are extracted from the IEA Energy Balance Table developed for Bangladesh (IEA 2025a). This study excludes biomass energy use in the residential sector in Bangladesh. We also exclude energy consumption by non-energy use, as they do not go through the combustion process directly, and it constitutes less than 1% of total energy consumption in our study period. As mentioned above, we consider coal, oil products, natural gas, and electricity. Oil products include refinery gas, LPG, gasoline, kerosene, diesel oil, fuel oil, lubricants, bitumen, paraffin waxes, and other petroleum products (IEA). Due to the unavailability of rural-urban regional level energy consumption data, we split aggregate level residential energy use by a constant ratio of urban-rural energy use obtained in Miah et al. (2011) and assume that this ratio is 1:3.25 for electricity and 1:3.22 for oil products and is constant for the whole study period. Like the survey result by Miah et al. (2011), we also assume that natural gas is used by urban residents only.

The GDP value and sectoral value-added data were collected from the Statistical Yearbook of Bangladesh 2011 and 2018. These data are converted to millions of USD in constant 2010 prices. The household expenditure in constant 2010 USD and the number of populations are collected from the World Bank Open Data source (World Bank 2025a). The ratios of per capita rural and urban household expenditure for the years 2000, 2005, 2010, and 2016 are extracted from the preliminary report of the Household Income and Expenditure Survey 2016 (BBS 2025b). The ratios for the remaining years in the study period were simulated by linear interpolation. These ratios were used to split the aggregated value of household expenditure into urban and rural levels.

For maintaining consistency, all data is considered in calendar years; for example, data for the 2002–03 economic year is considered for the year 2002. In addition, to tackle zero value, we adopted the "small value strategy" introduced by Ang (Ang and Liu 2007). Using this technique, we replaced zero with 0.00001 for the base year and 0.000013 for the following year (with a very minimal positive fraction), without infringing the relationships among the variables, such that the natural log does not face any undefined values. The calculations are carried out in spreadsheets.

Imagining the future trend

Future alternative scenarios can be built by varying the values assumed for the components in identity 1 and 2, such as economic structure, energy intensity reflecting the technology choice, fuel mix (modern and traditional), and level of urbanisation. We assume that for less developed and developing countries, GDP growth is the major indicator reflecting human wellbeing, as income growth is the primary determinant of the capability to attain better living standards (Gundimeda and Atkinson 2024). In Table 1, five alternative future scenarios for Bangladesh are consistent with the reference case and LED (Low Energy Demand) scenarios in the literature (Mondal et al. 2018; Rao and Min 2018; Wilson et al. 2023; Sugiyama et al. 2024). All LED scenarios will have similar characterisation, but national circumstances will determine their exact values and implementation mechanisms.

The five scenarios considered in this study represent alternative pathways for Bangladesh's future energy demand. The Default Demand, No Policy (Defdem_noPol) scenario extends historical patterns of growth without introducing new energy or climate policies. The High Wellbeing, Low Demand, No Policy (Hwl_noPol) scenario reflects national aspirations for higher wellbeing but assumes efficiency gains are achieved without explicit climate policy interventions. The Default Demand, 1.5 °C Pathway (Defdem_1.5) scenario aligns with global climate objectives while retaining Bangladesh's historical economic structure. The High Wellbeing, Low Demand, 1.5 °C Pathway (Hwl_1.5) combines strong efficiency and structural change policies with higher income growth consistent with national reports. Finally, the Decent Living Standard, High Wellbeing, Low Demand, 1.5 °C Pathway (Hwl_1.5_DLS) builds on the 1.5 °C scenario but additionally ensures that per capita energy use reaches the minimum threshold required for a Decent Living Standard (DLS) in Bangladesh. These scenarios were developed to capture the range of possible development and policy futures, balancing national aspirations with climate mitigation commitments. The naming convention is adopted from the EDITS community's model intercomparison exercise (IIASA 2024; RITE Systems Analysis Group 2025), which ensures consistency across global and national modeling exercises. While the acronyms are uniform for comparability, the numerical values are tailored to Bangladesh's specific socio-economic and policy context.

Data

The quantitative data consistent with scenario descriptions for the SPINE model need data for various assumptions made for the structure of the economy, how it is imagined evolving along alternative paths, low energy demand, and how it can be achieved in a country like Bangladesh. Fuel mix change is provided in Appendix Table 6. Then we follow the LMDI method to derive future alternative pathways for energy and emissions growth.

As illustrated in Table 6, GDP growth is projected either along historical trends (average 5.55% annually) or based on national planning documents such as the Integrated Energy and Power Master Plan (IEPMP 2023). For the Hwl_noPol and related scenarios, GDP follows the "in-between" or steady development case from IEPMP, with annual growth rates of 8.2% in 2019, 3.4% in 2020 (reflecting pandemic-related slowdown), and 7.2% from 2021 to 2030. Sector-specific GDP growth rates are then applied to agriculture, industry, transport, and services to reflect structural variations across scenarios. Energy intensity is assumed to evolve either along historical linear trends or according to efficiency improvement targets outlined in the Energy Efficiency and Conservation Master Plan (EECMP 2016) and Bangladesh's INDC commitments (e.g., 21% reduction in industry, 28.8% in residential, 20% in agriculture, and 15% in transport by 2030 relative to 2013 levels). Sectoral energy mixes are derived from linear or polynomial extrapolation of historical shares, adjusted using national policy reports where applicable, while household expenditure and energy expenditure ratios are based on World Bank and BBS data sources. Population growth follows UN and national projections, with urbanization assumed to accelerate toward the Vision 2041 target of 80% urban population. Finally, the Hwl_1.5_DLS scenario incorporates a Decent Living Standard benchmark by setting a minimum per capita total energy use of 12.35 GJ/year, consistent with literature on energy requirements for basic decent material wellbeing.

Results and discussion

Energy usage in Bangladesh: past trend and drivers

Energy consumption for the years 2001–2018 shows a rising trend in Bangladesh (Fig. 1) with an average annual growth rate of 7.66%. In 2001, oil was the dominant source, while natural gas started to dominate in 2009 (Fig. 2). More detailed data on energy sector trends and drivers with sectoral details are presented in Appendix 1 through Figs. 13, 14, 15, 16, 17 and 18 and in supplementary materials through Tables S2 to S8.

During 2001-09, the annual increase in energy usage in the productive sectors was 8.45% while the residential energy consumption increased by 5.58%. Residential energy consumption growth increased to 8.33% during 2009-18. The energy consumption mix was dominated by oil, 46.63%, and 32.38% of natural gas in 2001. The share of oil declined to 25.32% in 2009 and then remained nearly constant and reached 22.43% in 2018, whereas the share of gas rose to 41.76% in 2018. The share of electricity has increased from 19.28% in 2001 to 27.5% in 2018. In contrast, the share of coal decreased slightly from 5.70% in 2001 to 4.49% in 2009 but then increased to 8.31% in 2018.

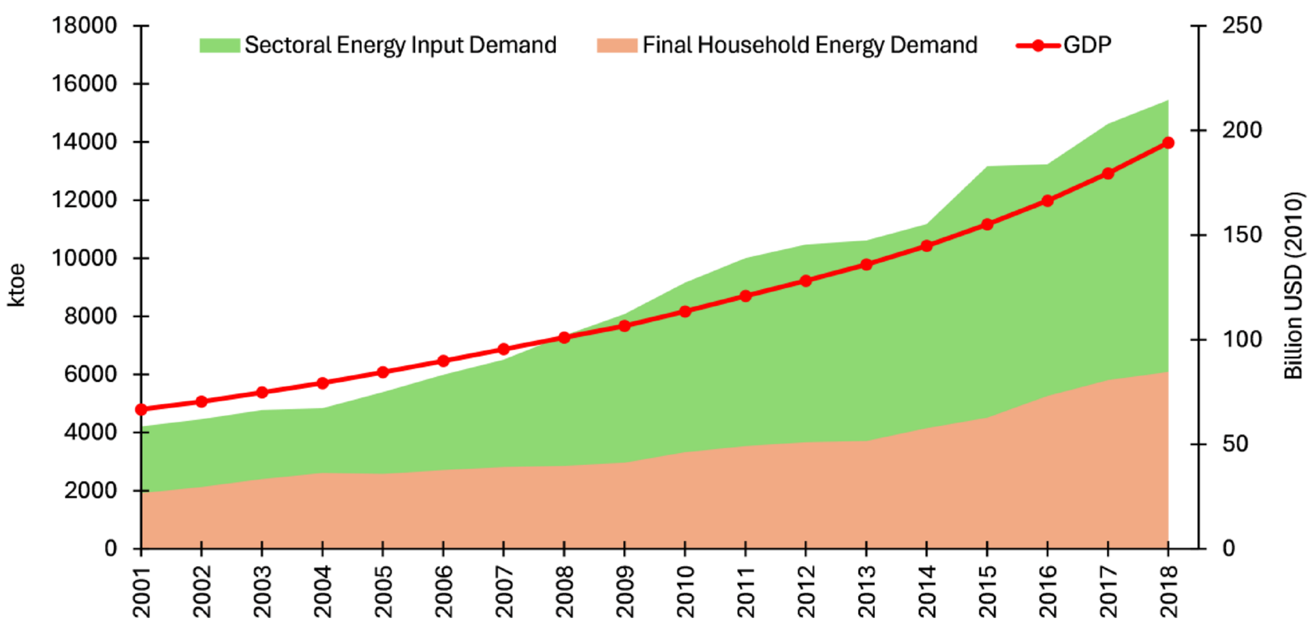

Fig. 1 Bangladesh National context from 2001 to 2018: Total energy input demand for industries, mobility service, agricultural production, and residential demand for illumination, hygiene, cooking, and thermal comfort, GDP, and Population growth

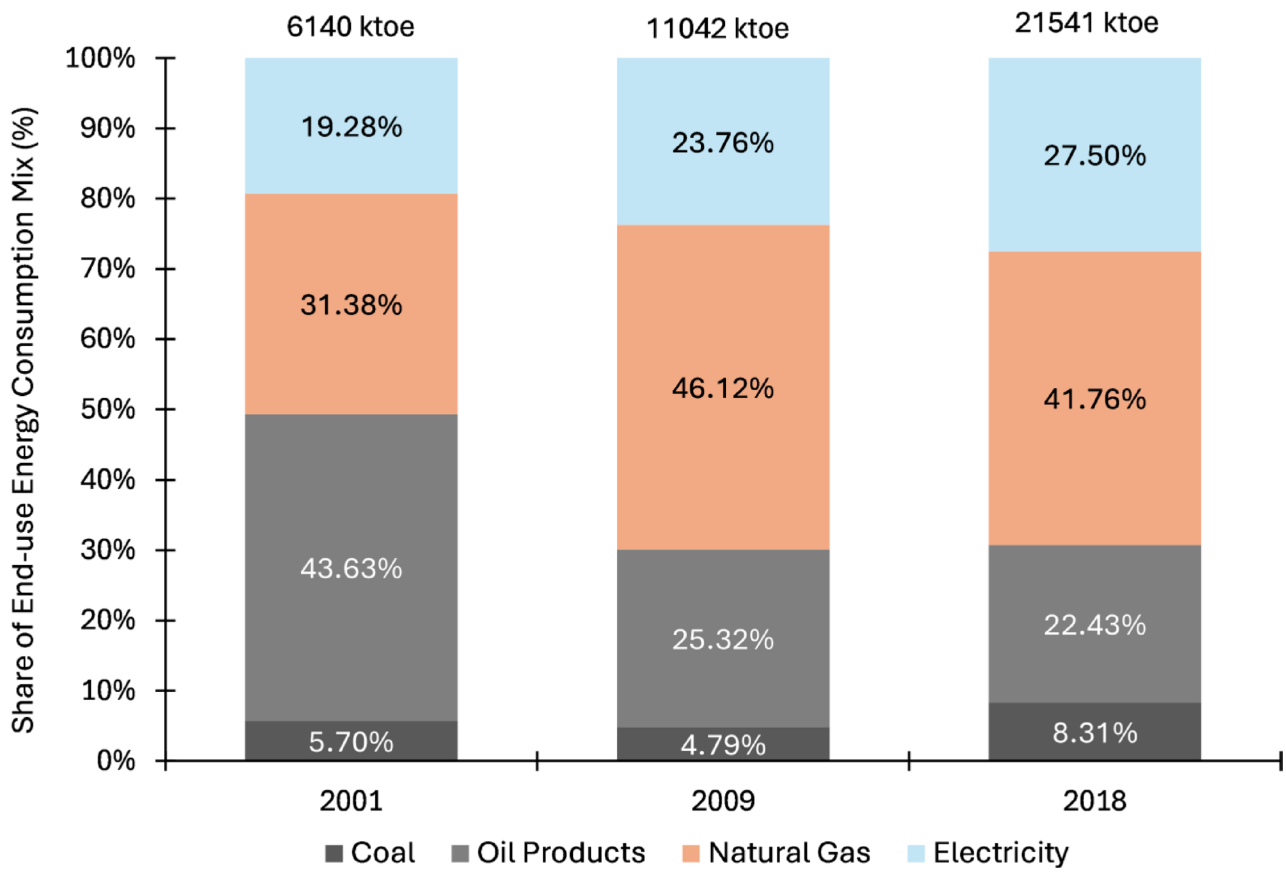

Fig. 2 Evolution of end-use energy consumption by fuel type in Bangladesh, 2001–2018

Drivers of change: LMDI decomposition results for productive sectors

Over the last two decades (2000–2019), Bangladesh has witnessed an average annual GDP growth rate of 6.5% (Katekar et al. 2020). During 2001–2018, economic activity growth remained the most influential factor in driving the growth in energy use (Fig. 3), accounting for 62.43% of energy consumption growth. The population growth effect was only for 15% rise and structure change effect (move away from agriculture towards industrial sector, Fig. 4) was 10.15%, energy intensity effect has been positive during 2001–2009 signifying increase in energy intensive technology penetration but eventually efficiency started improving after 2009 with policy interventions and pulling down the energy consumption growth by 9.32% from 2009 to 2018, abundance of fossil fuel use in energy mix (Fig. 5) drove the energy use up by 4.35%.

The transport service is the most energy-intensive, while the service sector is the least energy-intensive. The Government of Bangladesh initiated a range of energy-saving and efficiency initiatives, such as the World Bank-GIZ energy efficiency roadmap 2009, the Sustainable and Renewable Energy Development Authority (SREDA) Act 2012, Energy Efficiency and Conservation Master Plan up to 2030, SREDA Standard and Labelling (Appliances & Equipment) Regulation-2018, etc. (Hossain et al. 2017; Monjurul Hasan et al. 2019; IEA 2025c). Nevertheless, except for the latest SREDA-Japan International Cooperation Agency (JICA) EE&C Master Plan, 2016 (Hossain et al. 2017; Monjurul Hasan et al. 2019), these policies centered on the industry sector, which explains the 14.10% decline in industrial energy intensity in Bangladesh during 2009–18.

Drivers of change: LMDI decomposition results for the residential sector

The residential sector accounted for 31.28% of overall energy consumption in Bangladesh in 2018. The results show that the slow but rising household expenditure is the most important factor driving residential energy use, followed by population growth, energy mix (Fig. 6; Table 4) and rural-urban population distribution (Fig. 7).

The change in residential energy consumption in urban and rural areas varies significantly. The rise in household energy use in urban and rural areas differs considerably. In

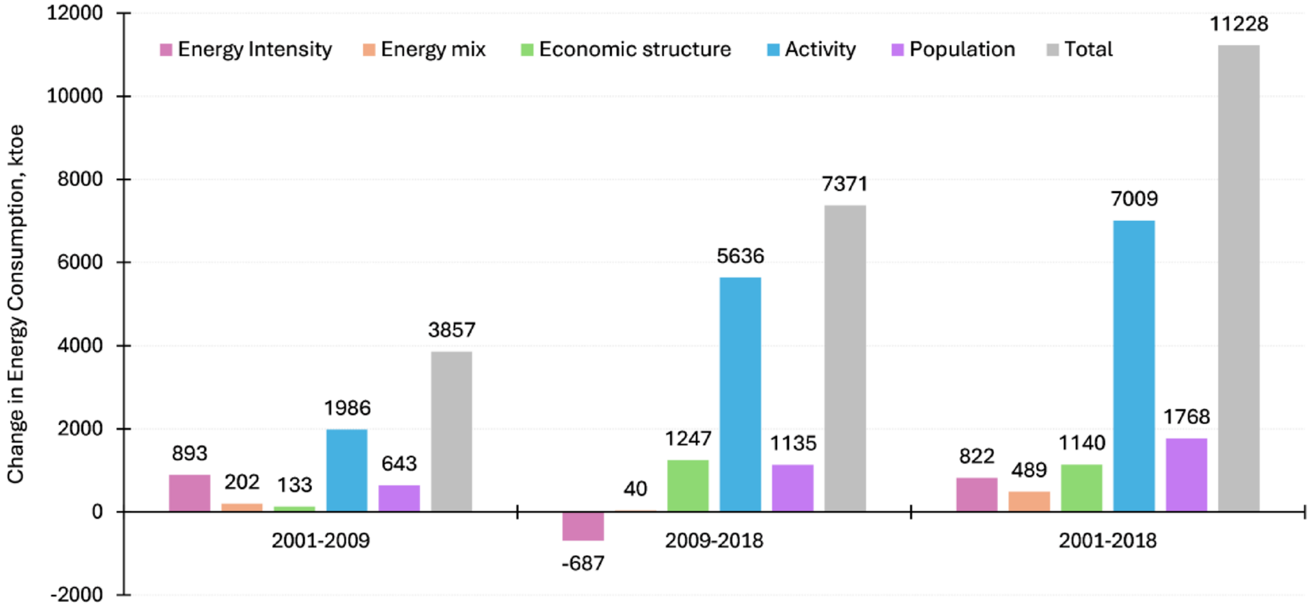

Fig. 3 LMDI decomposition of drivers of productive sector energy consumption in Bangladesh, 2001–2018

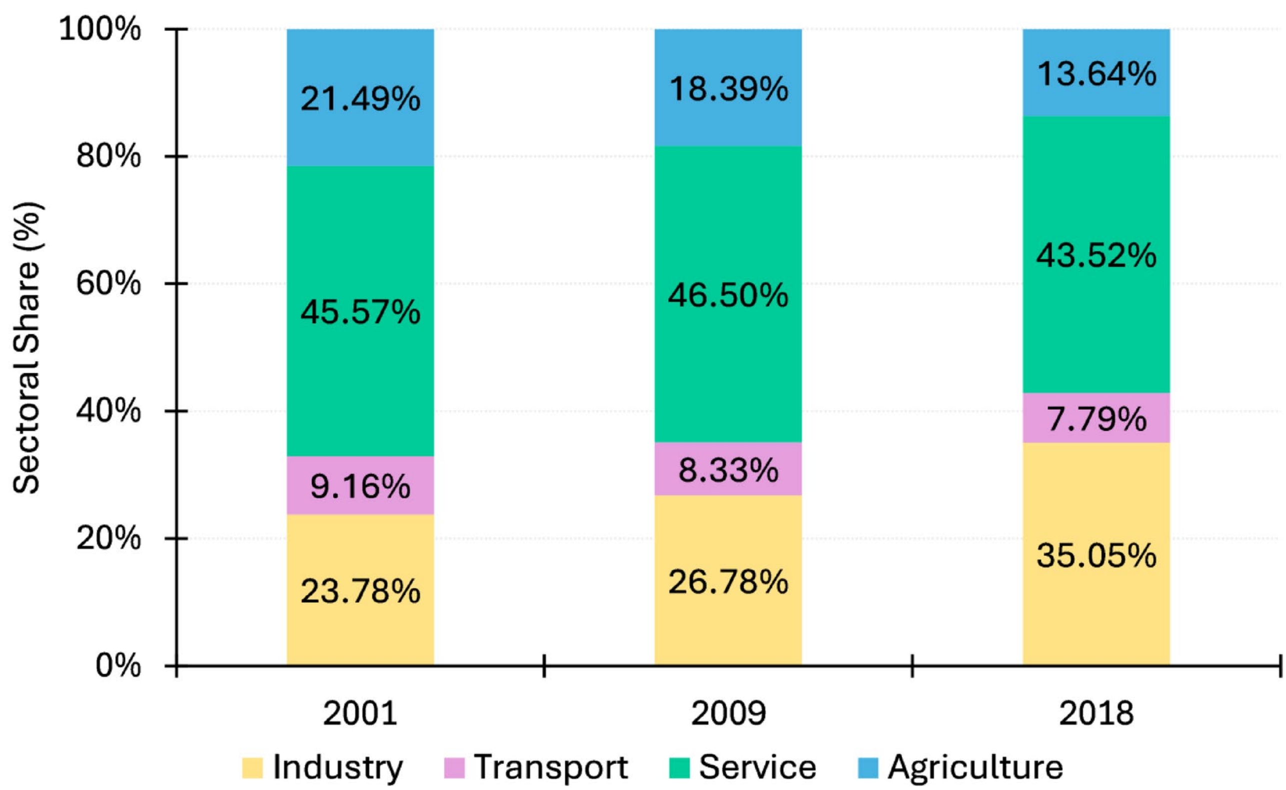

Fig. 4 Changes in Bangladesh's economic structure across major sectors, 2001–2018

the period 2001–09, gross energy usage in residential areas rose by 1045 ktoe, of which 1029.13 ktoe (98.48%) was in urban areas, and the remaining 15.87 ktoe (1.5%) was in rural areas. Moreover, in 2009–18, residential energy usage rose by 3128 ktoe, of which 2849.49 ktoe (91.09%) was in urban areas and 278.51 ktoe (8.90%) in rural areas. Therefore, the increased use of energy in urban areas is largely responsible for the overall rise in residential energy use. To fully understand the clear picture of the impacts of various factors on the shift in energy use in urban and rural areas,

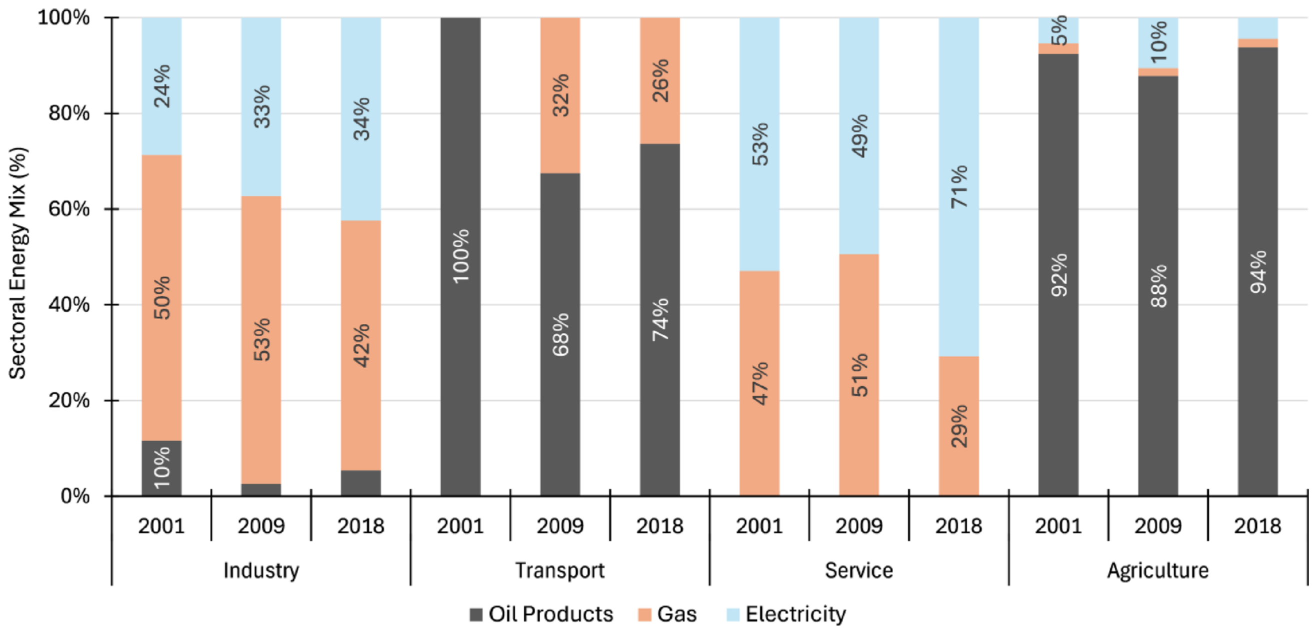

Fig. 5 Sectoral energy mix in Bangladesh, 2001–2018

Table 2 Population and GDP growth rateSource: World Bank data on GDP growth (annual%) – Bangladesh (World Bank 2025b)

Year	GDP per capita, Million USD 2010	Population, Million	Year	Total growth rate	
				GDP per capita (%)	Population (%)
2001	512.33	130.09	2001–2009	42.57	12.17
2009	730.46	145.92	2009–2018	64.73	10.57
2018	1203.25	161.36	2001–2018	134	24

Table 3 Influence of energy intensity on the change of energy consumption at the sectoral level, unit: ktoe

	Total	Sectors			
		Industry	Transport	Service	Agriculture
2001–09	893.07	540.76	300.99	27.23	24.09
2009–18	− 687.06	− 1014.19	278.90	59.17	− 10.94
2001–18	821.75	88.05	629.21	85.59	18.89

decomposition analysis is carried out at both rural and urban levels. The results of this analysis are shown in Appendix 2 with Figs. 17 and 18. This can be explained by the fact that, like other developing countries, such as China, when people migrate into urban life, they have greater access to energy, which eventually increases energy usage (Mahmud and Roy 2020, 2024).

The effect of the ratio of household energy expenditure to total household expenditure (Fig. 6), showing a lowering of energy consumption, is an interesting point to note. The declining trend of the energy expenditure ratio in 2001–2009 in Bangladesh is attributable to forced power cuts in the form of load shedding. The residential energy mix has shifted differently across urban and rural areas. In urban areas, the rising share of natural gas reflects increased access through pipeline networks, while in rural areas, limited access to gas infrastructure has instead driven a gradual rise in electricity use, partly linked to growing appliance ownership among households (Fig. 8).

Future scenarios: SPINE model results and analysis

The SPINE model results for alternative future scenarios provide us with the possible future trajectories of energy use growth for Bangladesh. SPINE model provides insights into how Bangladesh's energy consumption might evolve under different policy and socio-economic conditions from 2019 to 2030. These scenarios reflect varying assumptions (presented in the Appendix in Table A1) about economic growth, energy efficiency improvements, and policy interventions aligned with national goals and global climate targets.

Drivers of future energy demand growth for the productive sectors in alternative scenarios

Drivers of change continue to be the economic activity, energy intensity, economic structure, and energy mix in Bangladesh's productive sectors. Projected energy demand changes from 2019 to 2030 are due to alternative scenario

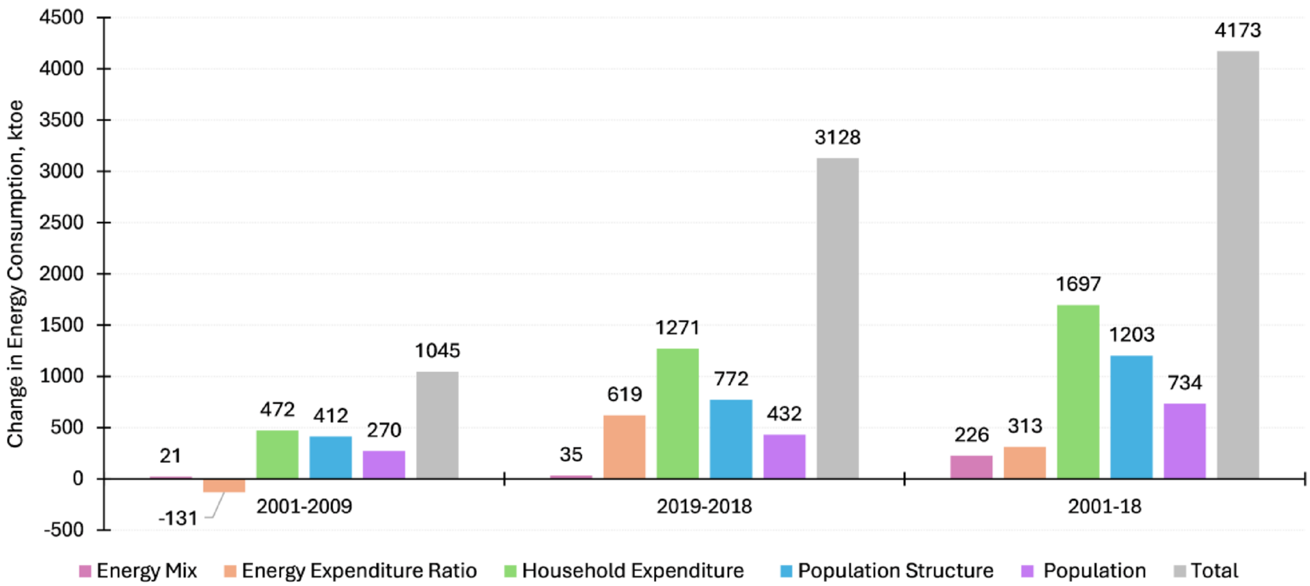

Fig. 6 LMDI decomposition of drivers of residential sector energy consumption in Bangladesh, 2001–2018

Table 4 Contribution of different factors in residential energy consumption

Year	Change in energy consumption, ktoe	Contribution of different factors in residential (aggregate) energy consumption				
		Energy mix effect (%)	Energy Expenditure/total household expenditure ratio effect (%)	Per capita expenditure growth effect (%)	Rural-urban population distribution effect (%)	Population growth effect (%)
2001–09	1045.00	2.05	− 12.51	45.19	39.41	25.87
2009–18	3128.00	1.11	19.77	40.65	24.67	13.80
2001–18	4173.00	5.42	7.50	40.68	28.82	17.58

assumptions adopted (Table S2), and each one has various policy implications.

The no policy scenario represents the 2019 policy freeze and change in GDP growth consistent with the historical growth rate in Defdem_noPol scenario and aspirational growth rates for achieving higher GDP growth for high human wellbeing in Hwl_noPol scenario. So, in this scenario, we see all the drivers of change are pushing in a positive direction, the energy demand (Fig. 9), while providing a historical wellbeing level on average to the people of Bangladesh. However, compared to the Defdem_noPol scenario, the Hwl_noPol scenario growth path, which includes access to efficient technology and GDP growth consistent with national aspiration for high wellbeing, results in a sharper rise in total energy demand for Bangladesh in the near future (Fig. 9). This scenario provides the highest economic energy growth scenario.

In the Defdem_noPol scenario, productive energy demand increases by 123.70%, accompanied by a total energy demand rise of 115.24%, primarily driven by GDP growth of 83.53% in 11 years (2019–2030). The Hwl_noPol scenario projects the highest total energy demand increase (176.27%) due to stronger GDP growth (107.24%) and improved access to efficient technologies. However, the effect is still a rise in total energy consumption, but with better efficient use.

Under 1.5 °C-aligned pathways, energy demand is significantly moderated through higher targets of energy efficiency improvements. In the Defdem_1.5 scenario, productive energy demand increases by 72.42%, with total energy demand rising by 71.05% despite maintaining the same GDP growth as Defdem_noPol. This reflects aggressive efficiency gains. The Hwl_1.5 scenario also demonstrates moderation, with a 94.68% rise in productive demand and a 127.38% rise in total demand.

Role of drivers in future energy demand growth trajectories

Productive sector

The model analysis (Fig. 10) reveals that economic activity to meet wellbeing-enhancing service demand remains the dominant driver of productive energy demand growth across all scenarios. In contrast, the effects of energy intensity, economic structure, and fuel mix vary depending on

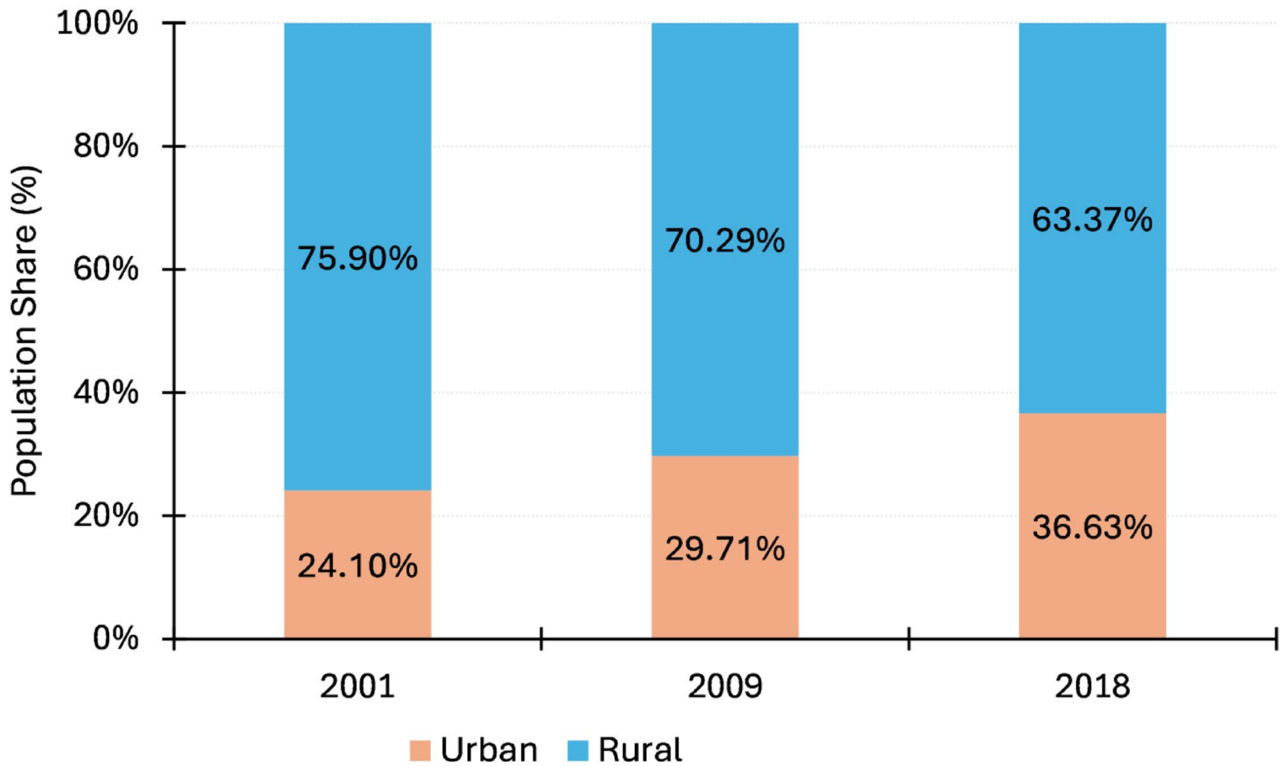

Fig. 7 Population distribution and demographic structure in Bangladesh, 2001–2018

the policy and growth pathway. In the Defdem_noPol scenario, productive sector demand increases by 123.70%, primarily due to economic activity (75.23%) and rising energy intensity (13.65%), with modest contributions from structural changes (11.03%) and a negligible energy mix effect (0.09%). The Hwl_noPol scenario, which assumes higher GDP growth (107.24% increase in 2030 compared to 2019) without climate policies, sees the highest demand increase (152.59%), driven by an even more substantial activity effect (78.45%) and moderate efficiency gains.

In contrast, 1.5 scenarios consider the impact of national targets for efficiency improvements. The Defdem_1.5 scenario achieves only 72.42% growth in demand, despite similar GDP growth as Defdem_noPol, due to a substantial reduction from the energy intensity effect (− 70.82%) and a positive economic structure effect (22.61%) that reflects a relative declining share of energy-intensive sectors such as industry, agriculture, transport, and the service sector. The Hwl_1.5 scenario, which combines high GDP growth and 1.5 °C-aligned policies, results in 94.68% demand growth, with the intensity effect (− 50.06%) and structural shift (16.02%) moderating the impact of strong economic activity (133.96%).

In summary, policy packages that help push the structural shift towards a service sector-based economy and unleash the energy potential within the economy through technology choice and infrastructure design will enable achieving Hwl_1.5 scenarios.

Residential sector

The SPINE model decomposes (Fig. 11) residential energy demand growth following the identity (2) into four primary drivers: household expenditure, rural-urban population distribution, energy expenditure intensity (EER), and the energy structure effect. In the Defdem_noPol scenario, residential energy demand rises by 89.56% from 2019 to 2030. This growth is driven mainly by increases in household expenditure (46.42%) and population growth effect (41.89%), reflecting the effects of urbanization and economic development on energy consumption. The EER effect contributes 11.58%, indicating a gradual rise in per-unit energy consumption. The energy structure effect is minimal at 0.11%, showing a negligible change in the residential energy mix.

In the Hwl_noPol scenario, which assumes higher income growth and faster urbanization, residential energy demand surges by 250.85%, the highest among all scenarios. Here, the EER effect of 4.44% indicates an increase in energy use intensity associated with rising wellbeing. The household expenditure growth reaches 58.02%, while population growth also remains a major driver (37.50%). In contrast, the Defdem_15 scenario reflects strong efficiency policies

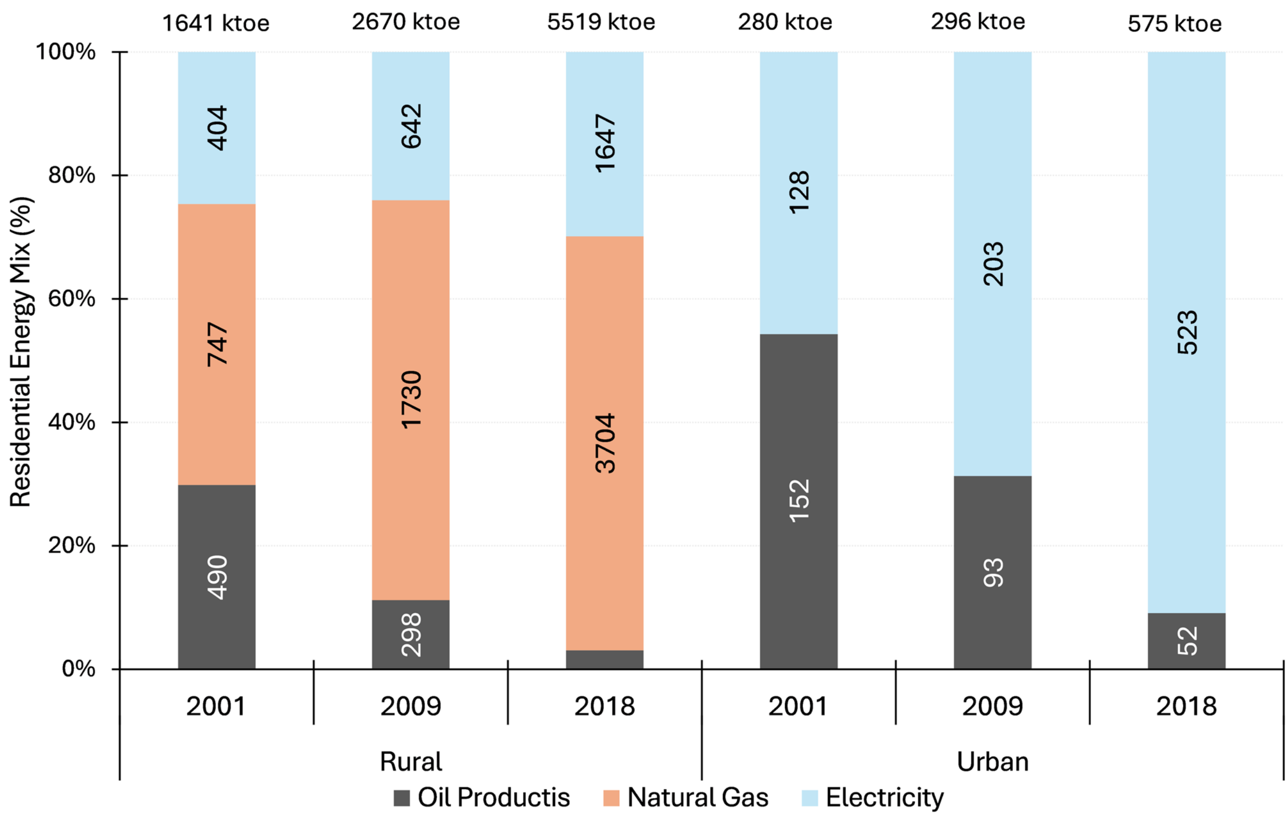

Fig. 8 Shifts in the residential energy consumption mix in Bangladesh, 2001–2018. The bars represent the percentage share of different fuels (oil products, natural gas, and electricity) in the total residential energy mix for rural and urban households. The numerical values shown inside each bar indicate the absolute consumption levels in ktoe

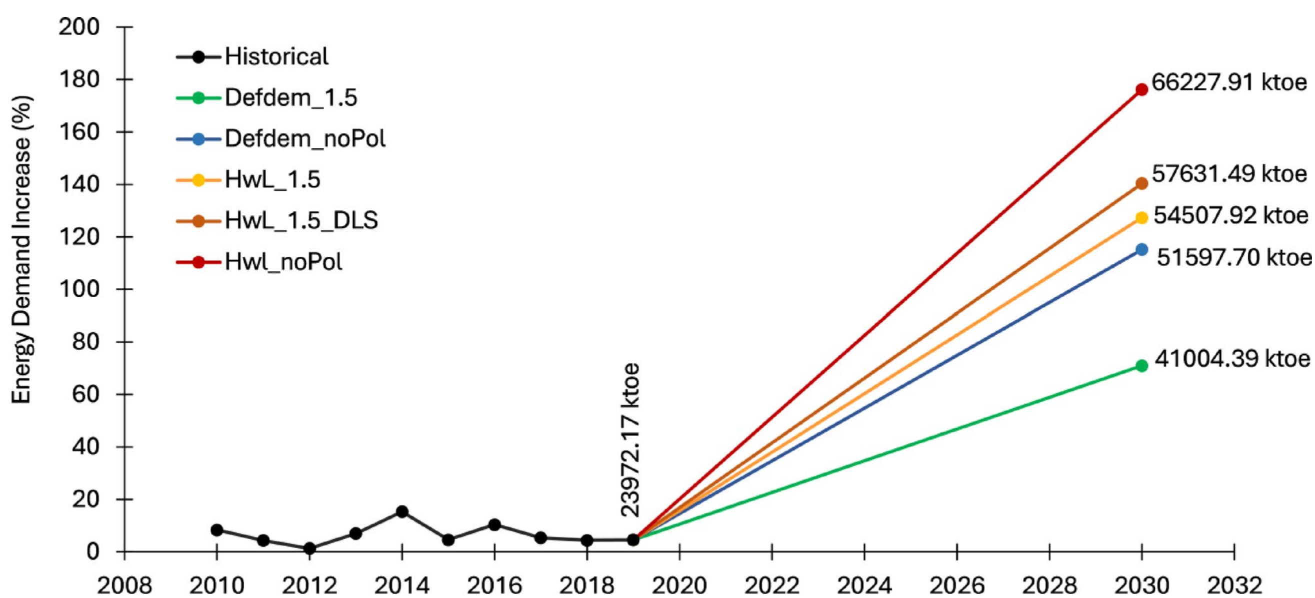

Fig. 9 Historical (per year from 2010 to 2019) and projected cumulative energy demand growth across future scenarios for the period 2019–2030 (compared to the 2019 baseline)

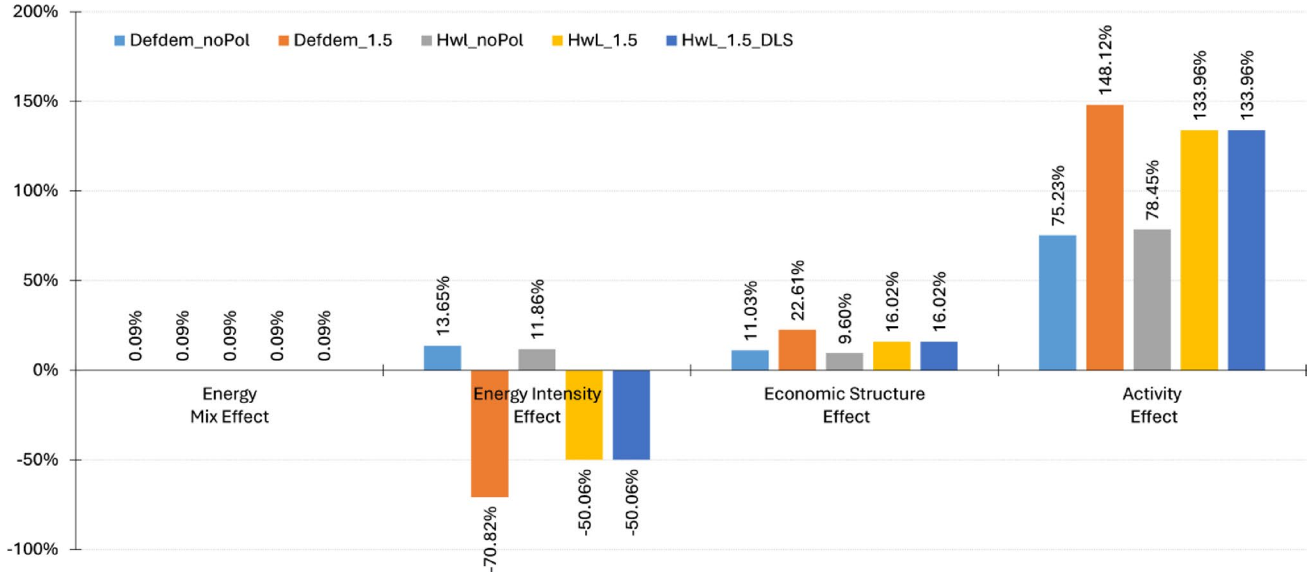

Fig. 10 Decomposition of the productive sector energy demand drivers across alternative future scenarios, 2019–2030

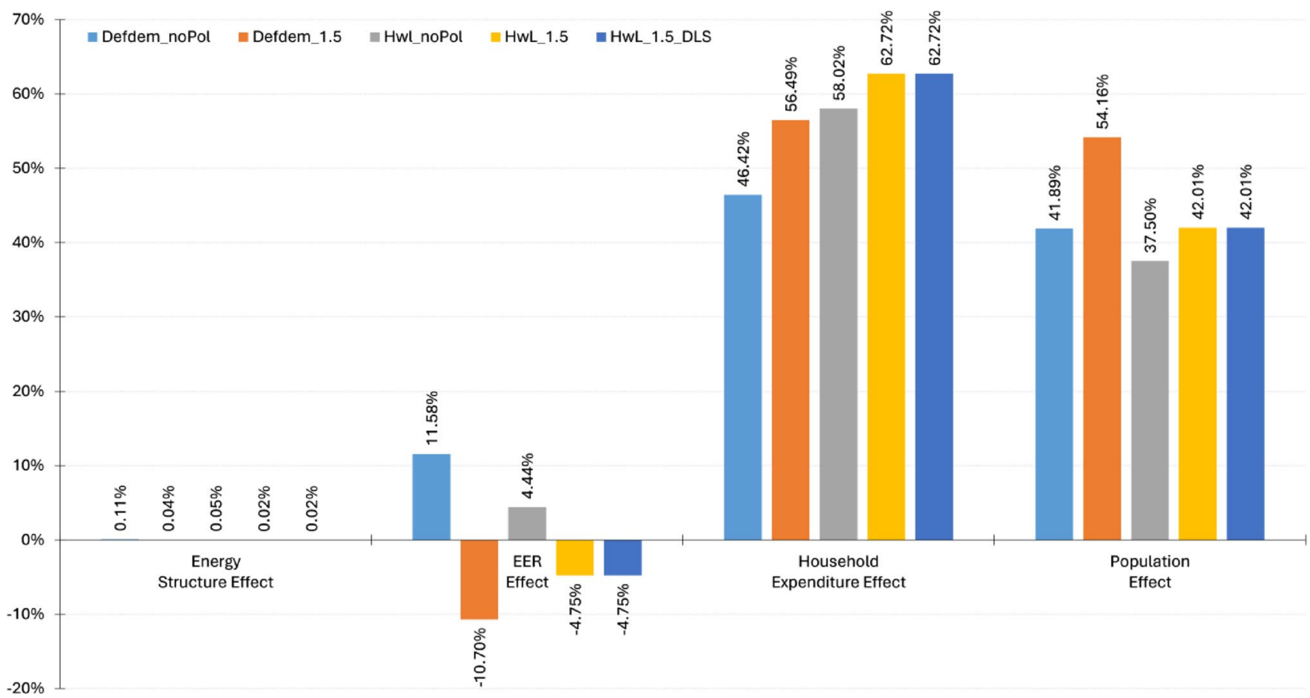

Fig. 11 Decomposition of the residential sector energy demand drivers across alternative future scenarios, 2019–2030

aligned with climate goals, moderating demand growth to 67.39%, despite high contributions from household expenditure (56.49%) and population (54.16%), as a substantial negative EER effect (–10.70%) offsets much of the increase. The Hwl_1.5 scenario, combining high growth with climate alignment, results in a 218.42% increase in residential demand. This is driven by household expenditure (62.72%) and population (42.01%), partially mitigated by improved efficiency (–4.75%) and a marginal energy structure shift (0.02%). These results highlight that while household welfare and demographic expansion are key drivers, energy efficiency gains remain critical in constraining residential energy demand growth under climate-compatible futures.

Energy demand with decent living standard (DLS) scenario

The Hwl_1.5_DLS scenario extends the 1.5 °C-aligned HwL_1.5 framework by incorporating a Decent Living

Standard (DLS) benchmark, wherein the minimum per capita energy demand is set at 12.35 GJ/year by 2030 (Rao and Min 2018). This ensures decent access to essential energy services. All other structural, economic, and technological assumptions remain identical to those in the Hwl_1.5 scenario, including GDP growth of 107.24% (Fig. 12) and associated wellbeing improvements.

Model results show that residential energy demand (Fig. 12) increases by 236.68%, higher than the 218.42% observed under Hwl_1.5. This reflects the additional energy required to close service access gaps while maintaining efficiency-oriented trajectories. Productive energy demand (Fig. 12) grows by 105.84%, also marginally above Hwl_1.5 (94.68%), to meet the energy needs associated with enhanced living standards for all. However, the overall energy system remains consistent with climate-aligned objectives due to the continued emphasis on energy efficiency and sectoral shifts. This increase in energy use in the DLS scenario confirms the fact that 100% of the population in Bangladesh has access to the energy needed to meet DLS. In all other scenarios, per capita energy access is otherwise less than the DLS level. The DLS energy gap can be met with an additional energy demand rise of 2931.89 ktoe (Fig. 9). The policy implication is very important. Climate action that provides climate justice for Bangladesh needs to make necessary provisions for bridging the DLS energy access gap. However, it is also noteworthy that integrating DLS targets within climate policy frameworks can deliver equitable development outcomes with only moderate increases in total energy demand.

Policy implications and limitations of the study

Policy implications

The SPINE results show that Bangladesh can combine rapid economic growth, improved wellbeing, and 1.5 °C-compatible energy demand if near-term policy focuses on three broad levers: energy efficiency, structural change, and managed growth in decent-living energy use.

From a policy perspective, the main implications are:

- The sharp reduction in industrial energy intensity after 2009 indicates that targeted policies work. Similar

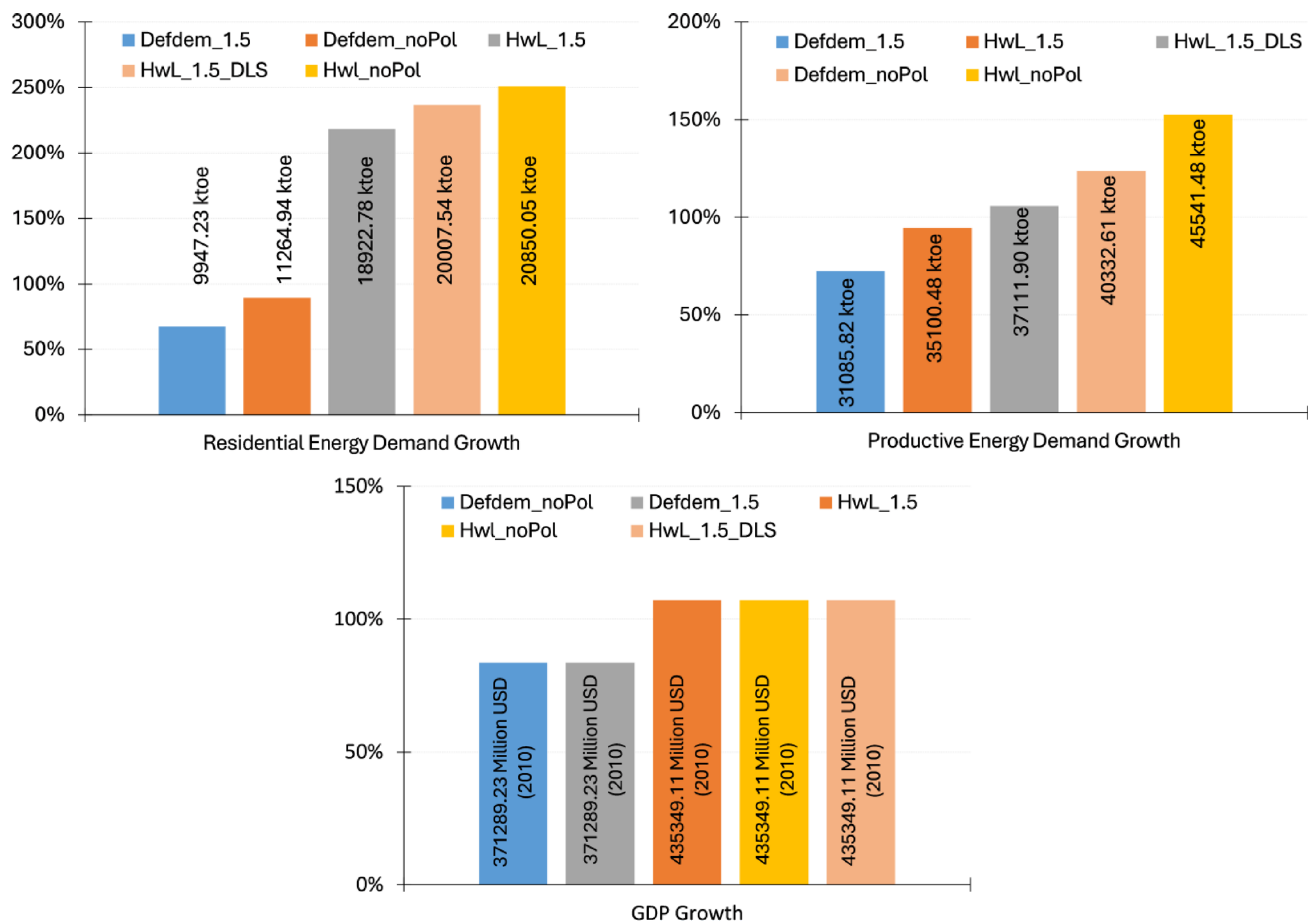

Fig. 12 Comparative trends of total (residential and productive sector) energy demand growth and GDP growth across scenarios, 2019–2030

policy packages are needed in all sectors—combining regulatory reforms across generation, transmission, and distribution, clear efficiency targets, and incentives for efficient consumption (tariff design, rebates, standards).
- LED and DLS-consistent pathways require that growing electricity demand be met increasingly from low-carbon sources. This calls for long-term grid infrastructure planning, land acquisition strategies for renewable projects, and coordinated action among national energy institutions to integrate renewables while maintaining reliability.
- Achieving the assumed efficiency gains and technology shifts depends on upskilling and reskilling of the workforce, and on stronger institutional capacity. Policies should support human capacity building in utilities, industry, and local governments, including planning, operation, and maintenance of efficient and digitalized systems.
- The study highlights the role of cloud computing, efficient energy storage, big data analytics, Internet of Things (IoT), and blockchain as tools to improve system monitoring, demand management, and transaction costs, and to strengthen MRV (Monitoring, Reporting, and Verification) systems. Incorporating these digital technologies into power-sector and end-use programs can both unlock the efficiency improvements embedded in the SPINE scenarios and enhance the accuracy and transparency of MRV frameworks needed for effective implementation of NDC commitments.
- Targeted incentive schemes for energy-efficient equipment, buildings, and transport—supported by international cooperation for innovation and technology transfer—are critical to realizing low-energy-demand outcomes. These should be coordinated with existing plans such as the EECMP and sectoral master plans.

These insights derived from our model based on NDC 2.0 targets are not in contradiction with Bangladesh's updated NDC 3.0. NDC 3.0 strengthens mitigation ambition, introduces explicit 2030 milestones to avoid a "2035 cliff edge", and aligns national efforts with 1.5 °C pathways and the first Global Stocktake. While this study was calibrated using NDC 2.0 and related national planning documents, the LED- and DLS-consistent scenarios provide quantitative 2030 energy-demand waypoints that can inform the design and assessment of NDC 3.0 implementation strategies. Table 5 maps key elements of NDC 2.0 and NDC 3.0 to assess how the results from our modelling study are applicable.

Limitations and future research

This study can be advanced in multiple ways. The discussion below highlights four limitations that can form an immediate future research agenda.

First, the temporal scope is restricted to a 2001–2018 baseline and projections to 2030. This choice allows a clean pre-COVID, pre-NDC-implementation reference, but does not reflect post-2018 structural and policy changes or explicit inclusion of additional features of NDC 3.0 and the 2035 horizon. As shown in Table 5, various scenarios that are considered in this paper are already consistent with NDC 3.0 in qualitative terms.

Second, the analysis focuses on energy demand only, as our goal was to see how low energy demand can maintain high wellbeing in the case of Bangladesh. No emissions decomposition is conducted, and electricity is treated as an aggregate carrier without distinguishing between renewable and non-renewable sources. As a result, the scenarios indicate demand-side pathways consistent with LED/1.5 °C benchmarks, but not full emission mitigation pathways.

Third, residential demand is split into rural and urban components using fixed ratios from a single survey, due to the lack of any accessible time-series data. This approximation ignores the dynamics of rural-urban population distribution over time.

Fourth, scenario drivers such as GDP growth, sectoral structure, energy intensity, fuel mix, urbanization, and household expenditure are specified exogenously from historical trends and planning documents (IEPMP, EECMP, NDC 2.0). Feedback from technology costs, behavior, international finance, carbon markets, and institutional or social dimensions of NDC 3.0 (adaptation interventions, loss-and-damage finance, GEDSI, just-transition governance) are not modelled, which can generate multiple future research agendas.

Conclusion

National aspiration to achieve developed country status in the next two decades, and NDCs towards climate action can go hand in hand to build resilience, energy security, and sustainability. The Integrated Decent Living Standard, High Wellbeing with Low Demand and 1.5 °C Pathway scenario is the best-case scenario for Bangladesh to embark on in the near term, both from a fast economic growth, high human wellbeing, and climate justice point of view, consistent with carbon constraint at the global level. Energy intensity targets provide moderating forces in rising energy demand through the penetration of modern technology access for all productive sectors, as well as in the residential sector. Past

Table 5 Assessment of our results using NDC 2.0 and NDC 3.0, taking some selected aspects

Aspect	NDC 2.0 (2021)	NDC 3.0 (2025)	Assessment based on the strengths of this paper
Gender, disability, social inclusion (GEDSI)	Limited emphasis	Dedicated chapter with GEDSI principles; human rights-based approach	DLS framing implicitly covers the equity issue: The paper's emphasis on "decent living standards for all" addresses equitable energy access across populations. The Hwl_1.5_DLS scenario (12.35 GJ/capita minimum) ensures no population is left behind. Gender dimensions emerge in the discussion of household energy expenditure and rural-urban residential sector disparities
Just transition	Not explicitly framed	Dedicated chapter with guiding principles, sectoral pathways, and enabling measures	Climate justice framing: The paper explicitly references "climate justice" and "injustices in transition" in the introduction section. The policy sequencing and sectoral shift toward services (away from energy-intensive industry) inherently represent a just transition pathway. Scenarios emphasize "avoiding unintended commitment to long-term cost burden and injustices in transition."
Youth participation	General mention	Explicit commitment to green skills, curriculum integration, and climate education	Addressed but not quantified: The paper focuses on sectoral energy demand and workforce/skills development. Future research on the implementation of technological innovation and capacity building (mentioned in the Conclusion) does imply the working population, which takes care of our youth engagement in reskilling programs. It has been quantified in another article (Nahid and Roy 2025)
Technology transfer	Identified as necessary	Extensive section on technology needs (energy storage, green hydrogen, grid modernization, sustainable aviation fuel, etc.)	Core methodological focus: Energy intensity improvements in the SPINE model (21% industry, 28.8% residential, 20% agriculture, 15% transport) directly represent technology adoption. The paper identifies "integration of advanced technologies: cloud computing, efficient energy storage, big data analytics, IoT, blockchain" as critical barriers-overcoming mechanisms. Technology transfer is explicitly discussed as a policy lever for unlocking sustained progress
2030 milestones	Not specified	New: 2030 waypoints for energy measures to avoid "2035 cliff edge" (RE share, capacity additions, storage, efficiency savings)	Core contribution: The entire paper centers in 2030 as the critical timeline for decisions towards a sustainable future. Scenarios quantify 2030 energy demand (growth shown in Fig. 9) under various scenarios with fuel mix and efficiency targets (EI improvements). The paper directly addresses what action is needed by 2030 to avoid long-term lock-in
Global stocktake response	Basic alignment mentioned	Explicit alignment with GST1 outcomes; contribution to 1.5 °C pathways stated	Explicitly framed: Paper states scenarios are "consistent with the IPCC's low energy demand (LED) scenario" and "1.5°C-compatible efficiency targets." The Hwl_1.5 and Hwl_1.5_DLS pathways demonstrate Bangladesh's contribution to the Paris goals. Paper notes alignment with "well below 2°C stabilization goal" and LED's role in avoiding negative emission technology deployment
Implementation governance	NDC Advisory Committee structure outlined	Enhanced governance with expanded Advisory Committee roles, a coordination mechanism, and MRV requirements	Partially addressed: The paper focuses on energy-demand modelling, and various scenarios show what kind of policy sequencing and regulatory reforms can be planned ahead without delay to stay on a sustainable path, and what needs to be monitored
Capacity building	General areas identified	Specific focus on green skills integration into TVET education by 2030	Implicit: The paper identifies "investment in human capital through upskilling and reskilling programs" as critical for policy success and "policies centered on the industry sector" (e.g., SREDA standards, EE&C Master Plan implementation)

studies have identified various barriers to energy efficiency improvement and progress in energy access (Mahmud and Roy 2020, 2021; Nahid et al. 2024). These can be overcome by policy sequencing and policy packaging, such as regulatory reforms across generation, transmission, distribution, and incentives to drive efficient consumption; promotion of renewable energy deployment through institution and human capacity building; and integration of advanced technologies such as cloud computing, efficient energy storage, big data analytics, Internet of Things (IoT), and blockchain. Bangladesh's Nationally Determined Contributions on energy efficiency, together with the national aspiration to increase the role of services in GDP, are broadly consistent with low-energy-demand (LED) development pathways.

Additionally, targeted incentive schemes for accelerating energy efficiency, international cooperation for innovation and technology transfer, long-term grid infrastructure planning, land acquisition strategies for renewable projects, coordinated action among national energy institutions, and investment in human capital through upskilling and reskilling programs are critical to unlocking sustained progress. These results are only preliminary, beginning with analysis in the Bangladesh context with Low Energy Demand (LED) scenario-based pathway development. The findings show that future energy demand outcomes vary sharply depending on scenario assumptions. For instance, under the default demand without any new policy scenario, productive sector demand rises by 123.7% and residential demand by 89.6% by 2030, reflecting historical growth extended without policy action. By contrast, aligning with 1.5 °C-compatible efficiency targets reduces the productive sector's energy demand growth to 72.4% (Default Demand with

1.5 °C). The High Wellbeing with Low Demand without any new policy pathway yields the highest demand increase (176.3%), driven by stronger GDP growth (107.2%) and higher household expenditure, but relatively less energy efficiency improvement. In the Integrated Decent Living Standard, High Wellbeing with Low Demand and 1.5 °C scenario, residential energy demand increases by 236.7% and productive demand by 105.8%, as additional energy is required to close the decent living standard gap of 12.35 GJ/capita for the entire population of Bangladesh by 2030. These variations demonstrate that GDP growth remains the dominant driver, while efficiency targets and structural shifts strongly moderate demand trajectories.

Taken together, the results provide a first LED- and DLS-consistent energy demand pathways development for Bangladesh, grounded in nationally observed trends and policy targets. Studies have shown that Bangladesh can integrate renewable energy into its power generation mix (Nahid and Roy 2025) through strategic planning. Growing urbanization and rising electrification in the residential sector and expansion of rural electrification in Bangladesh can provide various entry points for low-carbon, low-demand scenarios.

Appendix 1

Appendix 1 provides the detailed mathematical formulation of the SPINE model's decomposition framework and comprehensive quantified scenario assumptions for all five alternative futures scenarios.

Scenario assumptions

Table 6 details the year-specific input parameters, including GDP growth rates, sectoral economic structure transitions, energy intensity improvement targets by sector, fuel mix projections, urbanization rates, and household expenditure trajectories—all essential for executing the SPINE model and generating the energy demand pathways.

Mathematical details of the LMDI approach in this study

The energy consumption at the national level can be expressed as

$$E = \sum_i EP_i + \sum_k ER_{Rk} = \sum_{i,\,j} \frac{E_{ij}}{E_i} \times \frac{E_i}{G_i} \times \frac{G_i}{G} \times \frac{G}{P} \times \mathrm{P} + \sum_{k,\,j} \frac{E_{kj}}{E_k} \times \frac{E_k}{HE_k} \times \frac{HE_k}{P_k} \times \frac{P_k}{P} \times \mathrm{P} \quad (3)$$

Where *EP* is the productive sector energy consumption, and ER is residential energy consumption, i = 1,2,3, 4 denotes the type of productive sector, i.e., industry, transport, service, and agriculture. *k* represents the type of resident, i.e., rural and urban. *J* represents the type of energy source, i.e., coal, oil products, natural gas, or electricity

E_{ij} is the *j* type energy consumption by productive sector *i*, E_i is total energy consumption by productive sector *i*, G_i is value added of production sector *i*, *G* is total GDP, *P* is total population, E_{kj} is *j* type energy consumption by residential area *k*, E_k is total energy consumption by residential area *k*, HE_k is total household expenditure in residential area *k*, P_k is population in residential area *k*

The above equation can be rewritten as

$$E = \sum_{ij} EM_{ij} \times EI_i \times ES_i \times EA \times \mathrm{P} + \sum_{kj} REM_{kj} \times EER_k \times REC_k \times PS \times \mathrm{P}_R \quad (4)$$

Where EM_{ij} is end use energy mix effect, *EIi* energy intensity effect, ES_i is economic structure effect, *EA* is economic activity/affluence effect, *P* is population effect in energy consumption by productive sector and REM_{kj} is end use energy mix effect for residential sector, EER_k energy expenditure ratio effect, REC_k per capita residential expenditure effect, *PS* population structure effect, P_R population effect in residential energy consumption

In accordance with the LMDI method developed by Ang (2004) and the above Eq. (2), the change in energy consumption ΔE_{tot} between the base year (2019) and the target year *t* can be decomposed into a variety of determinant factors as shown in the following formula:

$$\Delta E_{tot} = \Delta EP + \Delta ER = (EP^t - EP^0) + (ER^t - ER^0) = (\Delta E_{EM} + \Delta E_{EI} + \Delta E_{ES} + \Delta E_{EA} + \Delta E_P) + (\Delta E_{REM} + \Delta E_{EER} + \Delta E_{REC} + \Delta E_{PS} + \Delta E_{P_R}) \quad (5)$$

Where ΔE_{EM} is energy mix effect; ΔE_{EI} is energy intensity effect; ΔE_{ES} is economic structure effect; ΔE_{EA} is affluence effect; ΔE_p is population effect that influences productive sector energy consumption, and ΔE_{REM} is residential energy mix effect; ΔE_{EER} is energy expenditure ratio effect; ΔE_{REC} is per capita residential expenditure effect; ΔE_{PS} is population structure effect; ΔE_{PR} is population effect that influences

Table 6 Scenario assumptions across the scenarios

Year 2030	DefDem_noPol	Hwl_noPol	DefDem_1.5	Hwl_1.5	Hwl_1.5_DLS
GDP	The GDP projection is based on the summation of sectoral gross domestic product (GDP), with an assumed average annual growth rate of 5.55% up to 2030	GDP is assumed to grow consistently with the "steady development" trajectory as described in the National Power and Energy Master Plan (IEPMP 2023). The year-wise GDP growth rates are projected as follows: 2019: 8.2%, 2020: 3.4%, and 2021–2030: 7.2% per annum on average	GDP is assumed to follow the same growth trajectory as in the DefDem_noPol policy scenario, that is, an average annual growth rate of 5.55% up to 2030	GDP growth is assumed to follow the same growth trajectory as in the Hwl_noPol scenario, which reflects the steady development case outlined in the IEPMP (2023) with year-wise growth rates of 2019: 8.2%, 2020: 3.4%, and 2021–2030: 7.2% on average	GDP growth is assumed to follow the same growth trajectory as in the Hwl_noPol scenario, which reflects the steady development Scenario: Hwl_1.5_DLS GDP growth is assumed to be identical to the Hwl_1.5 scenario, following the IEPMP (2023) projections with average growth rates of 2019: 8.2%, 2020: 3.4%, and 2021–2030: 7.2% per annum
Economic Structure	The sectoral composition of GDP is projected based on polynomial trends of historical values. The assumed annual average growth rates by sector are as follows: Agriculture GDP: 2.96% Industry GDP: 7.10% Transport GDP: 5.38% Services GDP: 4.91%	The economic structure is assumed to follow the same sectoral growth path as in the DefDem_noPol scenario. That is: Agriculture GDP: 2.96% Industry GDP: 7.10% Transport GDP: 5.38% Services GDP: 4.91%	GDP composition by sector is assumed to follow the same polynomial trend as in DefDem_noPol. The projected annual average growth rates are: Agriculture GDP: 2.96% Industry GDP: 7.10% Transport GDP: 5.38% Services GDP: 4.91%	The GDP structure is assumed to follow the same historical polynomial growth trend as in the Hwl_noPol scenario, with the following annual average sectoral growth rates: Agriculture GDP: 2.96% Industry GDP: 7.10% Transport GDP: 5.38% Services GDP: 4.91%	GDP sectoral composition is assumed to be identical to the Hwl_1.5 scenario. The projected annual average growth rates are: Agriculture GDP: 2.96% Industry GDP: 7.10% Transport GDP: 5.38% Services GDP: 4.91%

Table 6 (continued)

Year 2030	DefDem_noPol	Hwl_noPol	DefDem_1.5	Hwl_1.5	Hwl_1.5_DLS
Energy Intensity	Energy intensity is assumed to follow a linear trend based on historical values, with sector-wise increases as follows: Agricultural energy intensity: increases from 45.278 to 46.52 toe per million USD Industrial energy intensity: increases from 138.28 to 176.28 toe per million USD Service energy intensity: increases from 7.89 to 9.36 toe per million USD Transport energy intensity: increases from 275.78 to 356.82 toe per million USD	The assumptions for sectoral energy intensity are the same as in DefDem_noPol, reflecting a continuation of historical linear growth trends: Agricultural energy intensity: increases from 45.278 to 46.52 toe per million USD Industrial energy intensity: increases from 138.28 to 176.28 toe per million USD Service energy intensity: increases from 7.89 to 9.36 toe per million USD Transport energy intensity: increases from 275.78 to 356.82 toe per million USD	Energy intensity is assumed to improve significantly as per the stretch scenario of the Energy Efficiency and Conservation Master Plan (EECMP 2016) and Bangladesh INDC commitments. Reductions in energy intensity by sector are projected as follows: Industry: 21% improvement by 2030 Residential: 28.8% improvement by 2030 Commercial: 10% improvement by 2030 Agriculture: 20% improvement by 2030 Transport: 15% improvement in fuel efficiency by 2030 (consistent with INDC targets)	The energy intensity trajectory mirrors DefDem_1.5, applying the targets from Bangladesh's INDC and the EECMP (2016). The expected improvements by 2030 are: Industry: 21% Residential: 28.8% Commercial: 10% Agriculture: 20% Transport: 15% in fuel efficiency	The energy system in this scenario is assumed to deliver at least 12.35 GJ of energy per capita by 2030. This assumption goes beyond sectoral intensity improvements, ensuring a minimum per-capita supply of energy consistent with equitable development considerations.
Agricultural energy consumption mix	The agricultural energy consumption mix is assumed to follow a linear trend based on historical data. Aggregate agricultural energy consumption is calculated using energy intensity values and sectoral GDP projections. The projected shares of different energy carriers in total agricultural energy use by 2030 are: Oil products: 91.98% Gas: 1.34% Electricity: 6.67% For comparison, the base-year (2019) distribution was: oil 91.75%, gas 1.70%, electricity 6.55%	The agricultural energy mix in this scenario is assumed to follow the same linear trend and calculation method as in the DefDem_noPol scenario. Therefore, the projected shares for 2030 are: Oil products: 91.98% Gas: 1.34% Electricity: 6.67%	The agricultural energy mix is assumed to remain consistent with the projections in the DefDem_noPol scenario, following a linear trend and sectoral GDP–energy intensity calculation. Accordingly, the 2030 share of energy carriers in agriculture is: Oil products: 91.98% Gas: 1.34% Electricity: 6.67%	The agricultural energy mix in this low-emission policy scenario is likewise aligned with DefDem_1.5, maintaining the linear extrapolation of historical values. Thus, by 2030, the projected shares are: Oil products: 91.98% Gas: 1.34% Electricity: 6.67%	This scenario applies the same assumptions for agricultural energy consumption as in Hwl_1.5. The energy mix by 2030 is therefore projected as: Oil products: 91.98% Gas: 1.34% Electricity: 6.67%

Table 6 (continued)

Year 2030	DefDem_noPol	Hwl_noPol	DefDem_1.5	Hwl_1.5	Hwl_1.5_DLS
Industrial energy consumption mix	The industrial energy consumption mix is assumed to follow a linear trend based on historical data. Aggregate industrial energy consumption is calculated using sectoral GDP projections and energy intensity values. The projected composition of industrial energy use by 2030 is as follows: Coal: 16.69% Oil products: 4.17% Gas: 41.00% Electricity: 38.14% For comparison, the base-year (2019) distribution was: Coal: 15.30% Oil products: 3.79% Gas: 45.51% Electricity: 35.40%	This scenario assumes the same growth trajectory as DefDem_noPol, with industrial energy consumption calculated based on energy intensity and sectoral GDP projections. The projected 2030 shares are: Coal: 16.69% Oil products: 4.17% Gas: 41.00% Electricity: 38.14%	The industrial energy consumption mix in this scenario mirrors the DefDem_noPol assumptions, with a linear trend projection of sectoral demand. The 2030 energy shares are: Coal: 16.69% Oil products: 4.17% Gas: 41.00% Electricity: 38.14%	This scenario assumes the same industrial energy mix structure as DefDem_1.5, reflecting linear trends from historical data. The projected 2030 shares of energy use are: Coal: 16.69% Oil products: 4.17% Gas: 41.00% Electricity: 38.14%	The industrial energy mix in this scenario is assumed to be identical to Hwl_1.5, maintaining the same 2030 distribution: Coal: 16.69% Oil products: 4.17% Gas: 41.00% Electricity: 38.14%
Transport energy consumption mix	The transport energy consumption mix is projected to follow a linear trend based on historical patterns. Aggregate energy demand in the transport sector is calculated using sectoral GDP projections and energy intensity values. By 2030, the shares of oil products and gas in total transport energy use are expected to be: Oil products: 78.01% Gas: 21.99% For comparison, the base-year (2019) shares were: Oil products: 72.07% Gas: 27.93%	In this scenario, the transport energy mix follows the same trajectory as DefDem_noPol, with consumption calculated from energy intensity and GDP projections. The projected 2030 shares are: Oil products: 78.01% Gas: 21.99%	The transport energy mix under this scenario is assumed consistent with DefDem_noPol, maintaining the same linear trend projection. By 2030, the composition is expected to be: Oil products: 78.01% Gas: 21.99%	This scenario adopts the same assumptions as DefDem_1.5. Transport energy in 2030 remains dominated by oil products and gas, distributed as follows: Oil products: 78.01% Gas: 21.99%	The transport energy composition follows the same values as the Hwl_1.5 scenario. In 2030, the transport sector energy mix is projected as: Oil products: 78.01% Gas: 21.99%

Table 6 (continued)

Year 2030	DefDem_noPol	Hwl_noPol	DefDem_1.5	Hwl_1.5	Hwl_1.5_DLS
Residential energy consumption mix	Residential energy demand is divided into urban and rural consumption, with trends projected based on historical data. Urban households: Energy consumption shares were estimated by applying linear trends to gas and electricity shares, assuming a constant share for oil products (normalized distribution). By 2030, the urban residential energy mix is: Gas: 67.72%, Electricity: 29.50%, Oil products: 2.78% For comparison, the base-year (2019) urban shares were: gas 68.34%, electricity 28.63%, and oil products 3.03%. Rural households: Residential energy shares follow a logarithmic trend for electricity, with oil products considered as the balancing component. By 2030, the rural residential energy mix is: Electricity: 91.70%, Oil products: 8.30% For comparison, the base-year (2019) rural shares were: electricity 83.64%, oil products 16.36%.	The residential energy consumption mix (urban and rural) in this scenario is assumed to be identical to DefDem_noPol. Thus, by 2030: Urban households: Gas 67.72%, Electricity 29.50%, Oil products 2.78% Rural households: Electricity 91.70%, Oil products 8.30%	This scenario follows the same assumptions as DefDem_noPol, projecting linear and logarithmic historical growth trends for urban and rural energy use. By 2030: Urban households: Gas 67.72%, Electricity 29.50%, Oil products 2.78% Rural households: Electricity 91.70%, Oil products 8.30%	The residential energy mix under this scenario follows the same assumptions as DefDem_1.5 (continuity of historical linear/logarithmic trends). Thus, the projected 2030 shares are: Urban households: Gas 67.72%, Electricity 29.50%, Oil products 2.78% Rural households: Electricity 91.70%, Oil products 8.30%	The residential energy consumption mix here mirrors the Hwl_1.5 projection. By 2030: Urban households: Gas 67.72%, Electricity 29.50%, Oil products 2.78% Rural households: Electricity 91.70%, Oil products 8.30%
Other services energy consumption mix	Aggregate energy consumption in the services sector is calculated using sectoral GDP projections and energy intensity assumptions. The shares of different energy carriers are projected to follow historical trends. By 2030, the service sector energy consumption mix is expected to be: Gas: 29.00% Electricity: 71.00% For comparison, the base-year (2019) distribution was: Gas: 36.98% Electricity: 63.02%	The services sector energy mix is assumed to follow the same trajectory as in DefDem_noPol, with energy demand projected from GDP and intensity trends. By 2030, the shares remain: Gas: 29.00% Electricity: 71.00%	This scenario applies the same assumptions as DefDem_noPol, with services sector demand reflecting sectoral GDP projections and energy intensity. By 2030, the shares are: Gas: 29.00% Electricity: 71.00%	The services consumption mix follows the same approach as DefDem_1.5. By 2030, the distribution of energy use is projected to be: Gas: 29.00% Electricity: 71.00%	This scenario adopts the same assumptions for the service energy demand as Hwl_1.5. Therefore, the projected 2030 shares of services sector energy use are: Gas: 29.00% Electricity: 71.00%
per capita HH expenditure	Household expenditure per capita is projected to increase following polynomial trends derived from historical data. The assumed annual average growth rates are: Urban households: 2.18% Rural households: 4.03%	Household expenditure per capita is assumed to grow in line with the GDP growth projections of the "steady development" trajectory outlined in the Integrated Energy and Power Master Plan (IEPMP 2023). The year-wise GDP growth rates underpinning the expenditure projections are: 2020: 3.4% 2021–2030: 7.2% annually	Per capita household expenditure is assumed to grow according to the same underlying assumptions as in the DefDem_noPol scenario. The annual average growth rates by residence type are: Urban households: 2.18% Rural households: 4.03%	This scenario assumes the same expenditure growth pattern as Hwl_noPol, where per capita household expenditure growth is aligned with GDP growth rates assumed in the IEPMP (2023). The projections are based on: 2020: 3.4% 2021–2030: 7.2% annually	Per capita household expenditure in this scenario is assumed to follow the same trajectory as in Hwl_1.5, with growth aligned to GDP projections from the IEPMP 2023. Growth rates are: 2020: 3.4% 2021–2030: 7.2% annually

Table 6 (continued)

Year 2030	DefDem_noPol	Hwl_noPol	DefDem_1.5	Hwl_1.5	Hwl_1.5_DLS
Household energy expenditure ratio, toe/USD	The household energy expenditure ratio is projected according to historical trends, with separate urban and rural trajectories: Urban households: The ratio remains nearly stable, increasing marginally from 86.24 toe/USD in 2019 to 86.37 toe/USD in 2030. Rural households: The ratio is projected to increase at an annual average growth rate of 5.38%, following a polynomial trend. (If a linear trend were applied instead, the rural ratio would decline.)	This scenario assumes the same trend as DefDem_noPol. Thus, the household energy expenditure ratios in 2030 are projected as: Urban households: 86.37 toe/USD (from 86.24 in 2019) Rural households: Average annual growth of 5.38%, following a polynomial trend	In this policy scenario, energy efficiency measures are assumed to improve household energy expenditure performance. The ratio is projected to improve at 0.5% per year from the reference-year level, consistent with the Advanced Technological Scenario (ATS) of the Integrated Energy and Power Master Plan (IEPMP 2023).	The household energy expenditure ratio in this scenario follows the same assumption as DefDem_1.5. An annual improvement of 0.5% is applied from the base-year level, in line with IEPMP 2023 ATS projections.	The assumptions for this scenario mirror those of Hwl_1.5. The household energy expenditure ratio improves by 0.5% per year starting from the base year (2019), consistent with IEPMP 2023 ATS.
Population & Urbanization	Population growth is assumed to follow a linear trend, with an annual average growth rate of 1.06%. Within this trajectory, the urban population is assumed to increase at an average yearly growth rate of 1.79%.	Population growth follows projections from the Integrated Energy and Power Master Plan (IEPMP 2023). Total population is assumed to increase linearly, reaching 168 million by 2020 and 191 million by 2030. The share of people living in urban areas will grow at an annual average rate of 3.61%, consistent with the national vision of achieving 80% urbanization by 2041.	The population and urbanization assumptions mirror DefDem_noPol, with a total population growth rate of 1.06% per year and an urban growth rate of 1.79% per year leading up to 2030.	Population and urbanization assumptions follow those in Hwl_noPol. The total population is expected to reach 191 million by 2030, with the urban population increasing by 3.61% annually, aligning with the long-term vision of achieving 80% urbanization by 2041.	The assumptions in this scenario are identical to Hwl_1.5. By 2030, the total population is projected at 191 million, and the urban population continues to expand at 3.61% per year, ensuring consistency with the goal of 80% of people living in urban areas by 2041.

residential energy consumption. Each of these effects can be expressed as

$$\Delta E_{EM} = \sum_{i,j} \omega({EP_{ij}}^t\ ,\ {EP_{ij}}^0) \ln\left(\frac{{EM_{ij}}^t}{{EM_{ij}}^0}\right) \tag{6}$$

$$\Delta E_{EI} = \sum_{i,j} \omega({EP_{ij}}^t\ ,\ {EP_{ij}}^0) \ln\left(\frac{{EI_i}^t}{{EI_i}^0}\right) \tag{7}$$

$$\Delta E_{ES} = \sum_{i,j} \omega({EP_{ij}}^t\ ,\ {EP_{ij}}^0) \ln\left(\frac{{ES_i}^t}{{ES_i}^0}\right) \tag{8}$$

$$\Delta E_{EA} = \sum_{i,j} \omega({EP_{ij}}^t\ ,\ {EP_{ij}}^0) \ln\left(\frac{EA^t}{EA^0}\right) \tag{9}$$

$$\Delta E_{P} = \sum_{i,j} \omega({EP_{ij}}^t\ ,\ {EP_{ij}}^0) \ln\left(\frac{P^t}{P^0}\right) \tag{10}$$

$$\Delta E_{REM} = \sum_{k,j} \omega({ER_{kj}}^t\ ,\ {ER_{kj}}^0) \ln\left(\frac{{REM_{kj}}^t}{{REM_{kj}}^0}\right) \tag{11}$$

$$\Delta E_{EER} = \sum_{i,j} \omega({ER_{kj}}^t\ ,\ {ER_{kj}}^0) \ln\left(\frac{{EER_k}^t}{{REM_k}^0}\right) \tag{12}$$

$$\Delta E_{REC} = \sum_{i,j} \omega({ER_{kj}}^t\ ,\ {ER_{kj}}^0) \ln\left(\frac{{REC_k}^t}{{REC_k}^0}\right) \tag{13}$$

$$\Delta E_{EP} = \sum_{i,j} \omega({ER_{kj}}^t\ ,\ {ER_{kj}}^0) \ln\left(\frac{{EP_k}^t}{{EP_k}^0}\right) \tag{14}$$

$$\Delta E_{P_R} = \sum_{i,j} \omega({ER_{kj}}^t\ ,\ {ER_{kj}}^0) \ln\left(\frac{{P_{Rk}}^t}{{P_{Rk}}^0}\right) \tag{15}$$

where $\omega({EP_{ij}}^t,\ {EP_{ij}}^t) = \frac{({EP_{ij}}^t - {EP_{ij}}^0)}{(\ln {EP_{ij}}^t - \ln {EP_{ij}}^o)}$ and $\omega({ER_{kj}}^t,\ {ER_{kj}}^t)\ \frac{({ER_{kj}}^t - {ER_{kj}}^0)}{(\ln {ER_{kj}}^t - \ln {ER_{kj}}^o)}$

Appendix 2

Appendix 2 presents detailed historical decomposition results for Bangladesh's energy consumption during 2001–2018. Figures 13, 14, 15, 16, 17 and 18 visualize energy demand evolution by sector, fuel mix, economic structure, and the quantitative contribution of each decomposition driver (energy mix, energy intensity, economic structure, economic activity, and population effects) at aggregate and sectoral levels. These figures illustrate how past energy consumption dynamics were driven by structural economic changes, technological innovation, demographic growth, and fuel diversification.

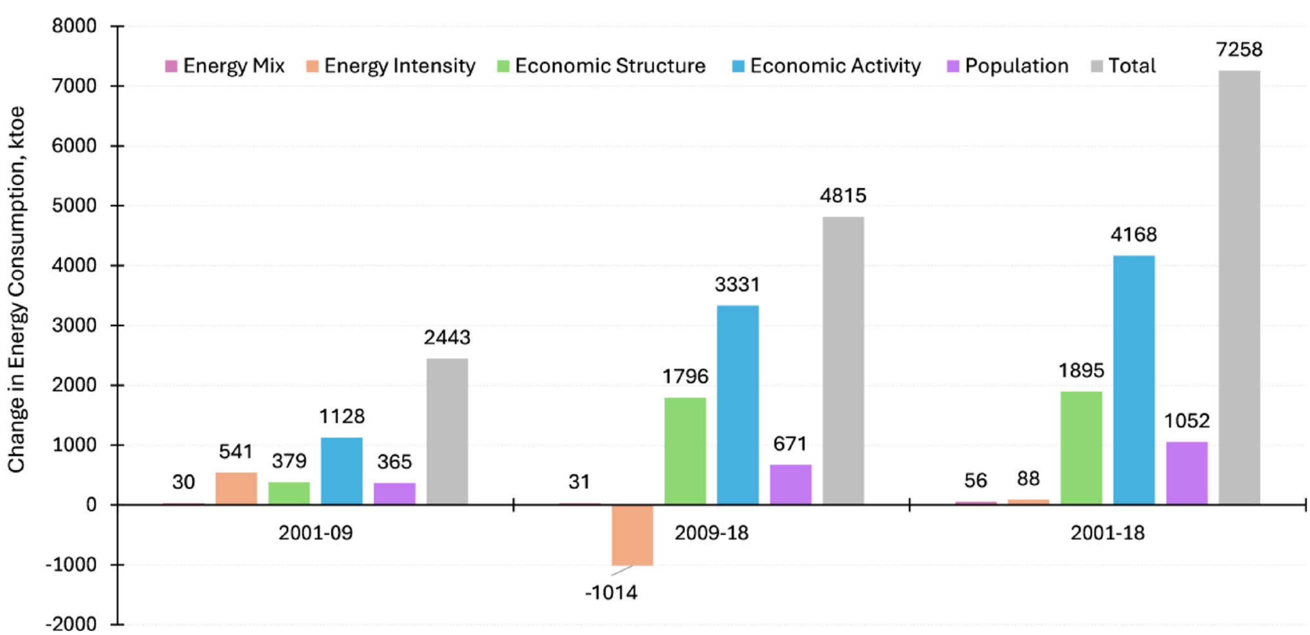

Fig. 13 LMDI decomposition of drivers of energy consumption in the industry sector, 2001–2018

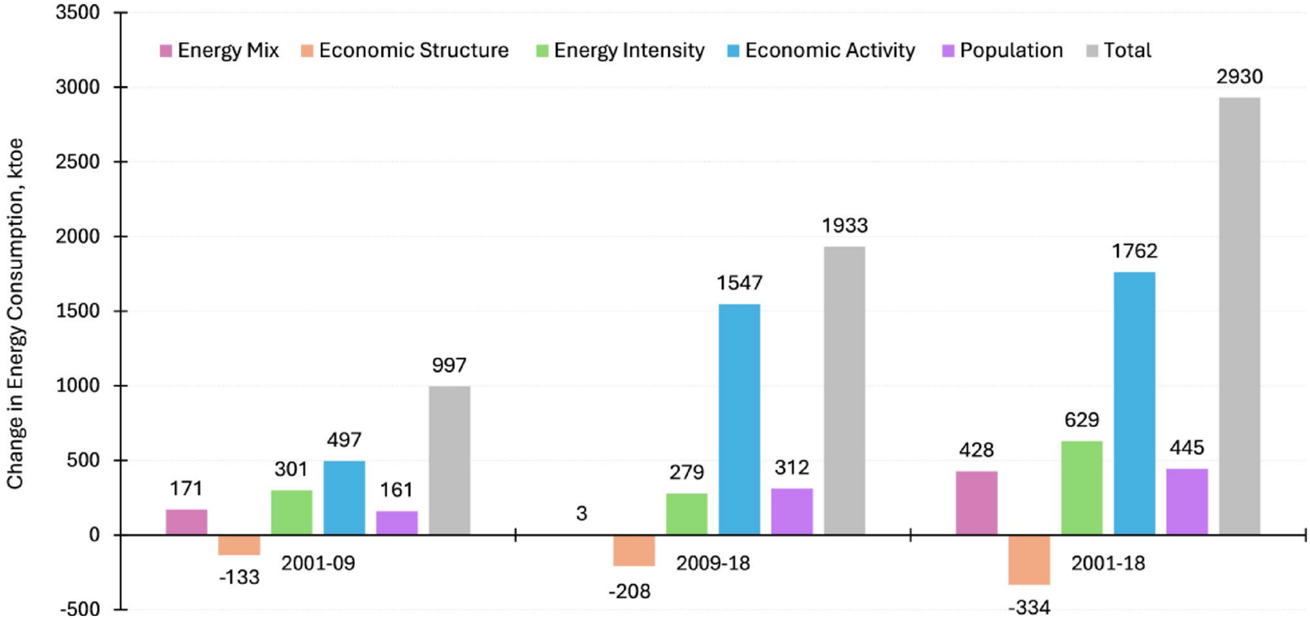

Fig. 14 LMDI decomposition of drivers of energy consumption in the transport sector, 2001–2018

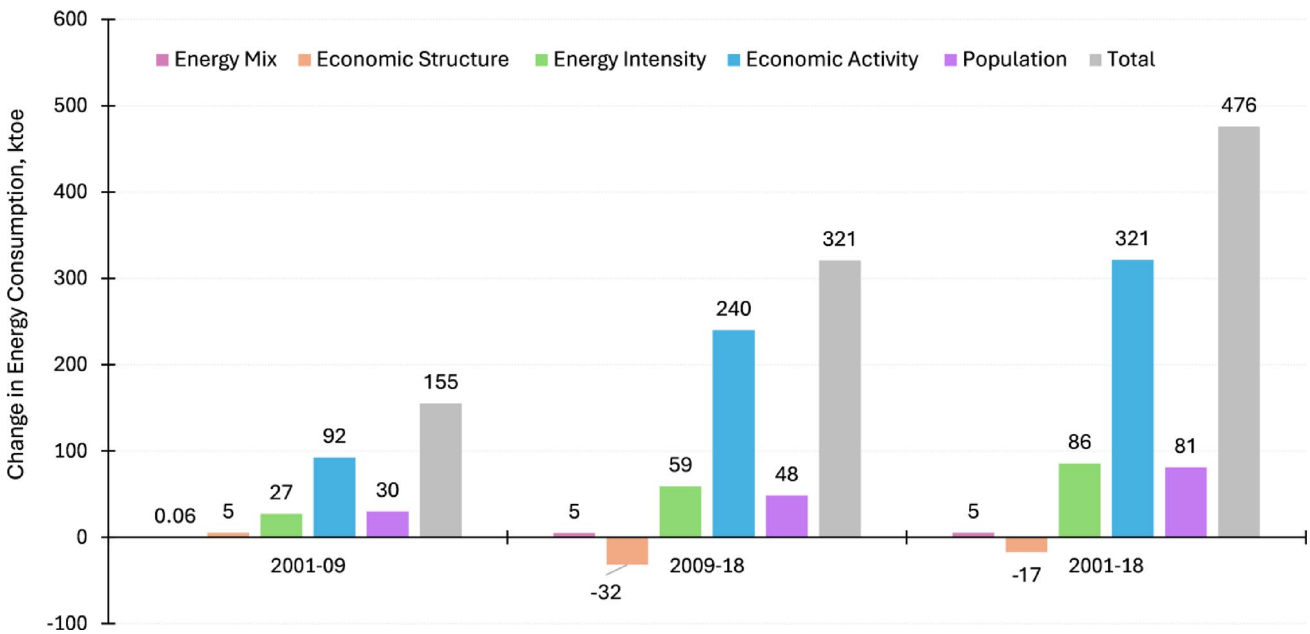

Fig. 15 LMDI decomposition of drivers of energy consumption in the service sector, 2001–2018

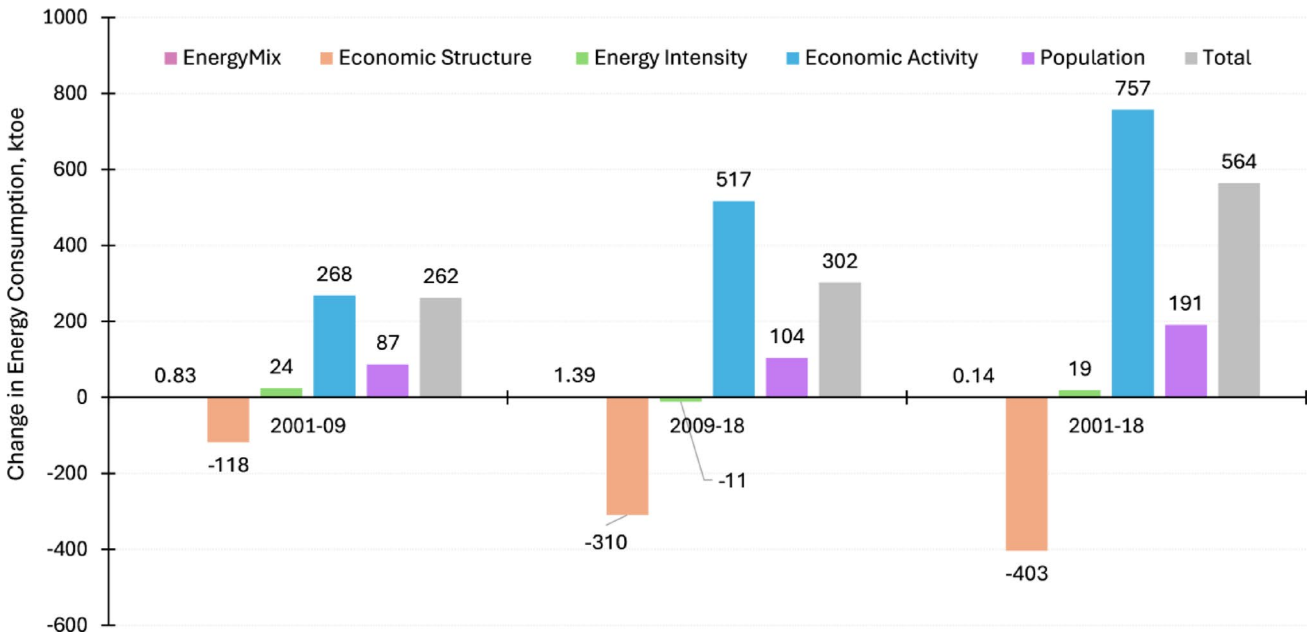

Fig. 16 LMDI decomposition of drivers of energy consumption in the agriculture sector, 2001–2018

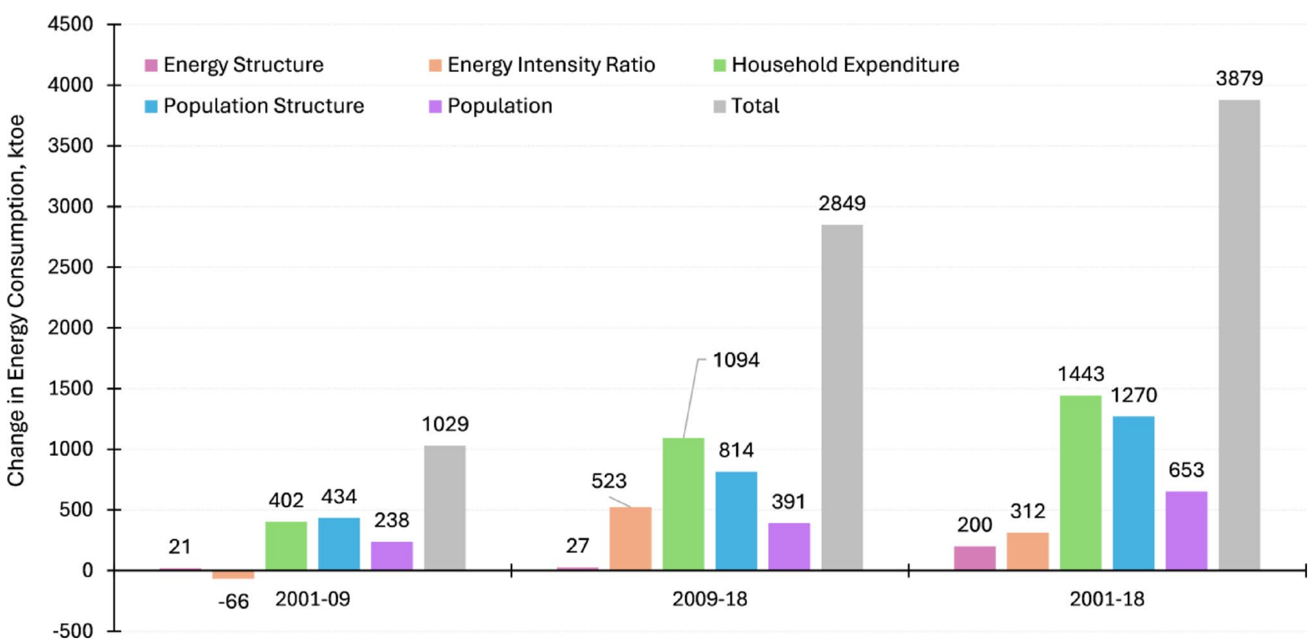

Fig. 17 LMDI decomposition of drivers of urban residential energy consumption in Bangladesh, 2001–2018

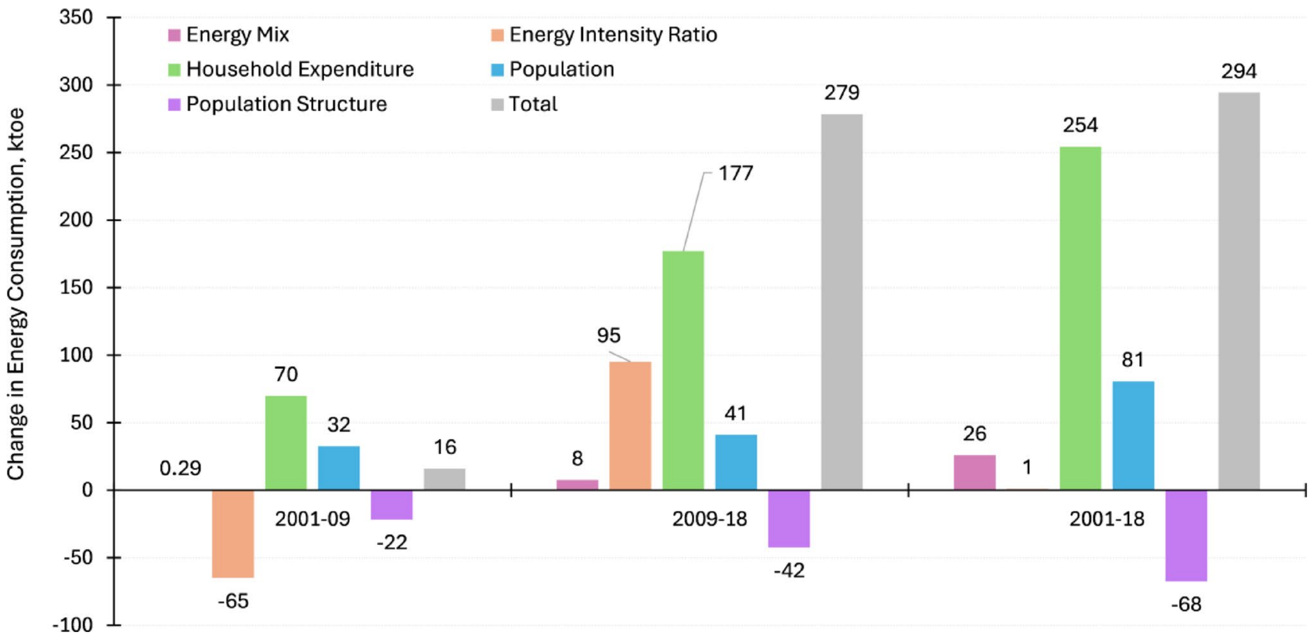

Fig. 18 LMDI decomposition of drivers of rural residential energy consumption in Bangladesh, 2001–2018

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Data availability Data will be made available upon request.

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