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Projecting Global Oil Demand for the Buildings Sector

Fateh Belaïd and Mohammad Aldubyan

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Abstract

As one of the largest consumers of energy resources, the building sector plays a key role in the evolution of the global energy landscape. Buildings account for approximately one-third of the world's final energy consumption. This methodology paper aims to provide a projection of oil demand in the building sector. The adopted modeling framework disaggregates the oil demand outlook by four fuel types and eight regions, which, in aggregate, add up to establish the global long-term oil demand outlook for the building sector up to 2050. Specifically, we employ multivariate forecast models that include several control variables. We retain transfer functions with an autoregressive integrated moving average errors model, commonly known as the autoregressive integrated moving average with exogenous factors model. The results provide valuable insights into the dynamics and trends of oil consumption in the building sector both regionally and globally. This study highlights the need for data-driven approaches that allow for the long-term management of the energy demand in the building sector and emphasizes the importance of building energy demand forecasting and its role in shaping future energy policy.

Keywords: Energy Demand; Buildings; Forecast; Energy Models.

1. Introduction

Currently, approximately 100 million barrels of oil are consumed per day worldwide. From 1972 to 2019, the world population grew from 3.8 billion to 7.7 billion, and the annual energy demand per capita increased from 57 gigajoules to 75.7 gigajoules (BP 2020). Due mainly to improved access to energy in developing countries, increased ownership and use of energy-consuming devices and rapid growth in building size worldwide, this demand for energy continues to increase. Additional factors include increasing energy demand levels for heating and cooling, increased air conditioner ownership and recent extreme climatic events (IEA 2021b). The recent BP Energy Outlook states that the growth in energy use in buildings is entirely emanating from the developing world, as improvements in wealth and living standards enable people to live and work in greater comfort (BP 2020).

Furthermore, the U.S. Energy Information Administration's International Energy Outlook 2019 Reference case expects global energy consumption to increase by nearly 50% from 2018 to 2050 (IEO 2019). Most of this increase is expected to originate from non-Organisation for Economic Co-operation and Development countries and is being driven by regions with strong economic growth stimulating demand, particularly in Asia. During this period, the overall energy consumed in the building sector, encompassing residential and commercial buildings, will increase by 65%, from 91 quadrillion Btu to approximately 139 quadrillion Btu. This growth will be propelled by a combination of rising income and urbanization levels and increased access to electricity.

Thus, the building sector plays a key role in the evolution of the global energy landscape as one of the largest consumers of energy resources. Buildings are responsible for 30% of total worldwide energy consumption and contribute 26% of global energy-related emissions (IEA 2022).

As the world faces the urgency of climate change and the imperativeness of reducing energy demand, the accurate forecasting of long-term oil demand in buildings is essential for informing decision-making and policy formulation. Thus, accurate long-term projections of oil demand in buildings are critical in shaping strategies for reasonable energy demand, enhancing energy efficiency and supporting the transition toward clean and renewable energy alternatives. These projections serve as valuable tools for policymakers, industry stakeholders and researchers in developing targeted measures and initiatives through which to achieve sustainable energy goals.

In pursuit of these objectives, this paper aims to provide a comprehensive and forward-looking projection of oil demand in the building sector for the long term, specifically for the period 2020 to 2050. By leveraging data-driven approaches and econometric forecasting methodologies, we seek to capture the complex interplay among the variables influencing oil demand in buildings. By employing multivariate forecast models with control variables, we aim to obtain reliable insights into future energy consumption patterns in the building sector, thereby empowering decision-makers with the knowledge required to implement well-informed and cost-effective policies. The long-term projection of oil demand in the building sector holds paramount importance for several critical reasons, including energy security, environmental sustainability and strategic decision making.

The subsequent sections of this paper are organized as follows. Section 2 offers an outline of the energy demand level in the building sector and reviews various forecasting approaches. Section 3 presents the data and methodology employed in this study, Section 4 presents the results and Section 5 concludes the paper.

2. Overview of Building Energy Demand and Forecasting Approaches

The energy consumption of buildings is a complex matter driven by a multitude of interrelated factors, including energy system characteristics, building attributes, climate conditions and user behaviors. In combination, these factors create complex energy consumption patterns that are challenging to precisely predict (Belaid 2016, 2017; Fumo 2014; Levy and Belaid 2018).

Buildings require energy for utilities, such as heating water and spaces, cooking and lighting, as well as other electrical devices. While some such consumption is related to the performance of the building itself (e.g., building size, insulation levels, technical service efficiency, type of fuel used and year built), the consumption behaviors of building occupants (e.g., indoor temperature preferences, lighting levels, choice and usage of appliances and environmental awareness levels) and the influence of the local environment (Belaid and Garcia, 2016; Belaïd et al., 2020, 2021) are also crucial.

In recognition of the complexity of predicting buildings' energy consumption levels, concerted efforts from policymakers, the scientific community and the industry have fueled numerous research initiatives (Fumo 2014; Swan and Ugursal 2009). These collaborative endeavors have resulted in the design of various approaches, methods and tools for assessing and forecasting energy demand in buildings (Ahmad et al. 2014).

Several studies have estimated energy demand and developed energy forecasting models (Fumo 2014; Ghalehkhondabi et al. 2017; Suganthi et al. 2012; Swan and Ugursal 2009). For example, Suganthi and Anand (2012) provide a concise review of the commonly used methods for predicting energy demand and find that standard techniques are widely employed for demand-side management. Such techniques include econometrics, regression and time series methods, as well as heuristic computing methods, such as neural networks, fuzzy logic and genetic algorithms. In addition, emerging techniques adopted for energy demand forecasting include ant colony optimization, support vector machine regression and particle swarm optimization.

Currently, the prediction of building energy consumption is based on two main approaches: physical modeling and data-driven approaches (Amasyali and El-Gohary 2018). **Physical modeling approaches** are also known as forward (i.e., classical) methods. These methods are mainly based on thermodynamic rules for comprehensive building energy modeling and analysis. In contrast, **data-driven approaches** require less detailed data on the simulated building and instead rely on historical data available for prediction. Despite its limitations, data-driven energy forecasting has been the subject of considerable research in recent years (Esen et al. 2018).

There are three fundamental types of data-driven methods: empirical black box approaches, simulation approaches and gray box approaches. **Empirical black box approaches** employ simple or multivariate regression models to examine the relationships among input factors, including users' behavior, climate data, economic factors and energy consumption outputs. **Simulation approaches** rely on calibrated computer simulation programs, which allow for a satisfactory prediction of energy demand when combined with measured data. **Gray box approaches** involve a two-step process. First, a mathematical model is designed to represent the physical configuration of the building,

incorporating the factors that have the greatest impact on energy consumption. Second, statistical analysis is conducted to identify the key factors that contribute to accurate energy performance estimation.

In this study, we adopt an empirical approach, specifically employing multivariate regression models, to predict buildings' energy consumption. This approach allows us to examine the relationships among various input factors and energy consumption outputs, providing valuable insights into the complex dynamics of energy demand in buildings.

3. Data and Methodology

3.1. Data

Projecting long-term oil demand in accordance with the abovementioned methodology consists of collecting historical data for the eight previously specified regions: OECD America, OECD Europe, OECD Asia Oceania, Latin America, the Middle East and North Africa, China, non-OECD Asia (excluding China) and Eurasia. Each region has its own fuel models constructed based on regional historical fuel consumption data. In addition to historical fuel consumption, the long-term models incorporate data on nominal gross domestic product GDP per capita, total population, urban population and rural population as potential explanatory variables. The urban and rural population variables denote the percentages of the urban and rural population, respectively, within the total population for each region. Nominal GDP, per capita GDP and rural population data are acquired from the World Bank National Accounts database (World Bank 2022). Total population and urban population data are from the United Nations Population Division (United Nations Environment Programme. 2022). The historical data extend for 48 years, from 1971 to 2019.

After examining the consumption of different fuels in the abovementioned eight regions, we find that the building sector consumes four main fuels: liquefied petroleum gas, kerosene, gas and diesel oil and fuel oil (IEA 2022). Notably, kerosene consumption in this context does not include that kerosene used in aircraft transport. In addition, gas and diesel oil consumption excludes biofuels (IEA 2022). Although the demand for these fuels in the building sector is at a relatively low level, understanding the role of oil in shaping the energy mix in the building sector is important. The dependent variables, explanatory variables and geographical regions are listed below.

Dependent Variables

- Liquefied petroleum gas (LPG)
- Other kerosene (KERO)
- Gas and diesel oil excluding biofuels (Gas)
- Fuel oil (Fuel)

Explanatory Variables

- Nominal GDP at current prices, denoted as **GDPcu**
- GDP per capita (constant 2015 US$), denoted as **GDppc**
- Real GDP (constant 2015 US$), denoted as **GDPre**
- Total population, denoted as **popul**
- Urban population (% of the total population), denoted as **urban**
- Rural population (% of the total population), denoted as **rural**
- Brent oil price, denoted as **Brent**

Regions

- OECD America
- OECD Europe
- OECD Asia Oceania
- Latin America and the Caribbean
- Middle East and Africa

- China
- Other Asia (excluding China)
- Eurasia

3.2. Methodology

The methodological approach used in this study is based on the autoregressive integrated moving average with exogenous factors model, which has the ability to identify underlying patterns in time series data and quantify the influence of external factors. This capability allows for the effects of high-impact variations in external and internal factors to be identified (Andrews et al., 2013).

The ARIMAX model is an extended version of the autoregressive integrated moving average model. Known also as the Box-Jenkins method (Box and Jenkins, 1990), the ARIMA model requires historical time series information of the underlying variable. The ARIMAX model is quite similar to the ARIMA model except that it also includes relevant explanatory factors. Although the incorporation of exogenous factors increases the complexity of the model-building process, the model can accommodate the impact of external drivers (e.g., the economic situation).

The ARIMAX design works similar to a multivariate regression model. However, this approach leverages the autocorrelation that may be present in the residuals of the regression to improve forecasting accuracy. Specifically, the ARIMAX model is a multiple linear regression model that includes autoregressive and/or moving average terms. The AR terms denote that the factor of interest is regressed on its own value, while the MA terms specify that regression error is a linear combination of past error values. Finally, the integrated part represents the differentiation order needed to transform the time series into a stationary series (if needed).

The general specifications of the ARIMAX models are expressed below.

ARX: AR model with exogenous factors:

$$Y_t = \emptyset(L)Y_t + \beta X_t + \varepsilon_t; \quad (1)$$

MAX: MA model with exogenous factors:

$$Y_t = \varphi(L)\varepsilon_t + \beta X_t; and \quad (2)$$

ARMAX: AR MA with exogenous factors:

$$\emptyset(L)Y_t = \varphi(L)\varepsilon_t + \beta X_t, \quad (3)$$

where X_t depicts the explanatory factors, β depicts the model coefficients, $\emptyset(L)Y_t$ depicts the AR model and $\varphi(L)\varepsilon_t$ depicts the MA model.

The ARIMAX model is described by the following parameters:

- p: number of AR terms,
- d: number of nonseasonal differences required for stationarity,
- q: number of lagged forecast errors in the prediction equation and
- n: number of explanatory factors.

Mathematically, the model can be specified as follows:

$$ARIMAX(p,d,q,n): Y_t = \omega + \sum_{i=1}^{p} \varphi_i Y_{t-1} - \sum_{j=1}^{q} \theta_j \varepsilon_{t-j} + \sum_{l=1}^{n} \delta_l X_l, \quad (4)$$

where ω represents the model constant and $\varphi_i, i = 1, \dots, p;\ \theta_j, j = 1, \dots, q;$ and $\delta_l, l = 1, \dots, n$ represent the model parameters. Y_t *and* Y_{t-1} *for* $i = 1, \dots, p$ are the predicted values of the outcome variable; $\varepsilon_{t-j}\ for\ j = 1, \dots, q$ represents the regression error; and $X_l\ for\ l = 1, \dots, n$ represents the explanatory factors.

To assess the validity of the ARIMAX model, it is necessary to verify six conditions. Among these six conditions, two (hypotheses 1 and 2) are related to the residuals generated by the model, and the remaining four (hypotheses 3-6) pertain to the exogenous factors that make up the model (Andrews et al. 2013):

H1: The stationarity of the series indicates that the residuals' mean and variance are stable over time.

H2: There is an absence of serial correlation.

H3: The coefficient estimates of the explanatory variables must be significantly different from zero.

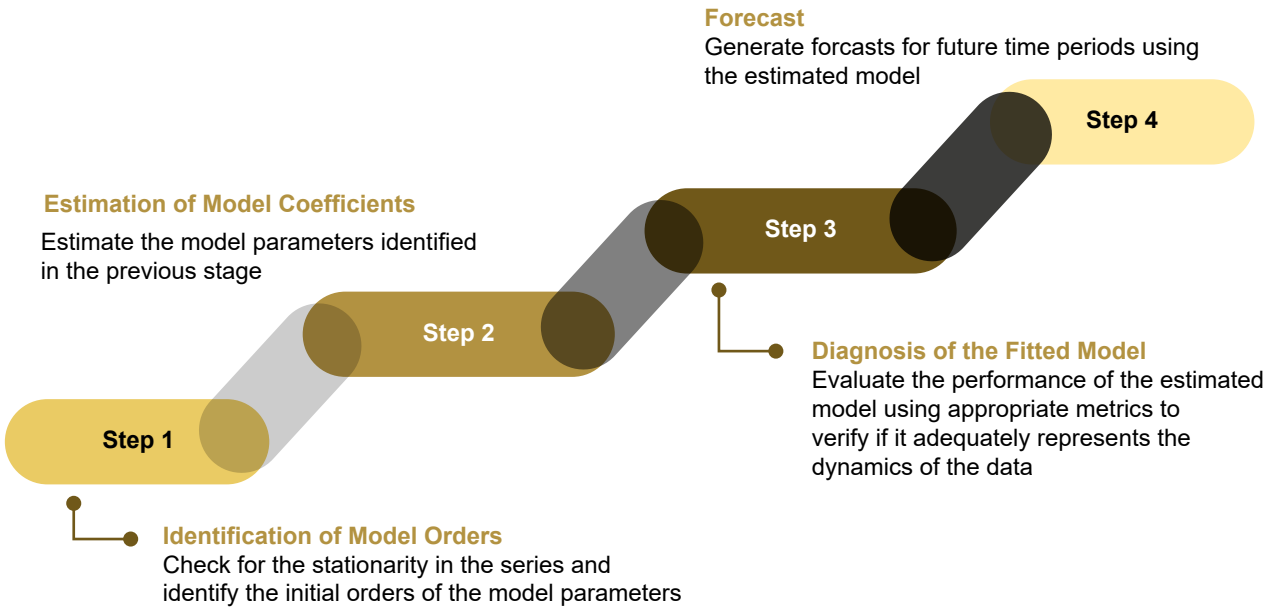
H4: There is an absence of reverse causality.

H5: The coefficient sign of each significant external factor must be appropriate.

H6: There is an absence of multicollinearity.

Figure 1 displays the key steps used to construct and assess the validity of the prediction models.

Figure 1. ARIMAX model forecasting steps.



Source: Authors' elaboration.

4. Results

4.1. Regression results

It is important to ensure the validity of the constructed models prior to generating projections for fuel consumption demand in the building sector according to each of the eight regions and according to fuel type. To achieve this goal, as discussed earlier, we apply various tests, including normality, autocorrelation, heteroskedasticity and specification tests, to assess the robustness of the models. For each of the fuel types, we then select the specification in which the results of the robustness tests are conclusive. For clarity purposes, we present the validation results pertaining solely to the OECD America region. The results for the other seven regions are given in the appendix (Tables A1-A7).

Table 1 shows the regression results for the demand for LPG, kerosene, gas and fuel in the building sector in **the OECD America region**. For simplicity, we report only the key regressors (i.e., we do not include dummy factors). We observe that the key determinants of energy demand in buildings for the different categories of energy are GDP, population and oil prices. The findings show that GDP has a significant positive effect on energy demand for both kerosene and fuel. The oil price (excluding gas) is shown to significantly and negatively affect the different types of oil demand in buildings. Furthermore, the population factor significantly affects the different types of oil demand, except for kerosene, in buildings in the OECD America region.

Table 1. Key determinants of LPG, kerosene, gas and fuel in the building sector in the OECD America region.

Dep variables	Ln(LPG)	Ln(KERO)	Ln(Gas)	Ln(Fuel)
Regressors				
$Ln(GDPRE_i)$				0.57***
$Ln(GDPR)_{t-1}$			-1.22***	
$Ln(pop_i)$	-43.99***		-58.08***	138.70***
$Ln(pop)_{t-1}$	40.28***		115.17***	
$Ln(Brent_i)$				-142.94***
$Ln(Brent)_{t-1}$	-0.057***	-0.16***		
$Ln(LPG)_{t-1}$				
$Ln(KERO)_{t-1}$		0.83***		
$Ln(Gas)_{t-1}$			0.53****	
$Ln(Fuel)_{t-1}$				0.57***
C	73.88***	1.74***	43.41**	86.48***
Adj. R^2	0.87	0.95	0.98	0.96
Number of observations	47	47	47	47
Normality test: $Chi^2(2)$	1.5920 [0.4511]	5.1528 [0.0760]	6.0131 [0.0595]	0.77098 [0.6801]
Hetero test	F(11,36) = 0.51520 [0.8803]	F(7,39) = 1.9675 [0.0848]	F(11,34) = 0.52419 [0.8732]	F(10,35) = 0.63172 [0.7766]
RESET23 test	F(2,39) = 3.0703 [0.0578]	F(2,40) = 2.0181 [0.1257]	F(2,37) = 1.5682 [0.2220]	F(2,37) = 1.9520 [0.0878]

Notes:
* Significant at 10%, ** Significant at 5%, *** Significant at 1%.

Source: Authors' calculations.

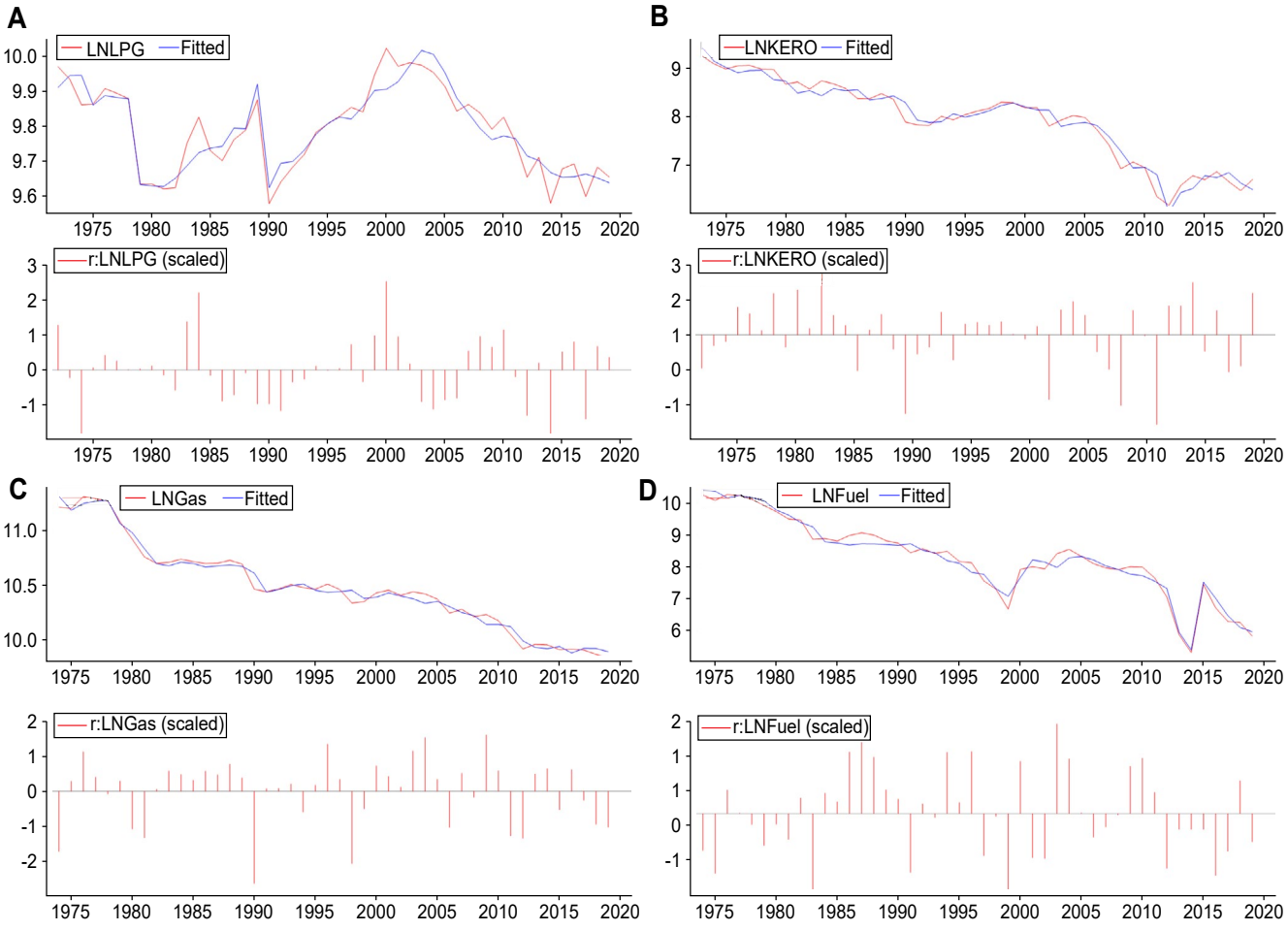
4.2 Prediction Results

The resulting estimates from the ARIMAX model are used to project the demand for LPG, kerosene, gas and fuel in the building sector for the period 2021 to 2050. Figure 2 shows the comparison between the observed and predicted values of energy demand at the OECD level for the different types of energy considered in this study. We observe that the predicted and observed values are adequately similar, which supports the validity of the approach used and strengthens our confidence in the use of the resulting equation to predict energy demand.

The projections of building energy demand levels across the different regions for the period ending in 2050 are reported and presented in Tables 2-5 and Figures 3-6.

Demand for LPG: Based on the projected global LPG demand levels in the building sector, it is apparent that the demand for LPG will continue to grow steadily in the coming decades. By 2050, we anticipate that the demand for LPG will reach an estimated 746,374 kilotons of oil equivalent which is a significant increase from the current level. This increase in demand will be

Figure 2. Comparison of observed and predicted energy demand values in the OECD America region.



Source: Authors' elaboration.

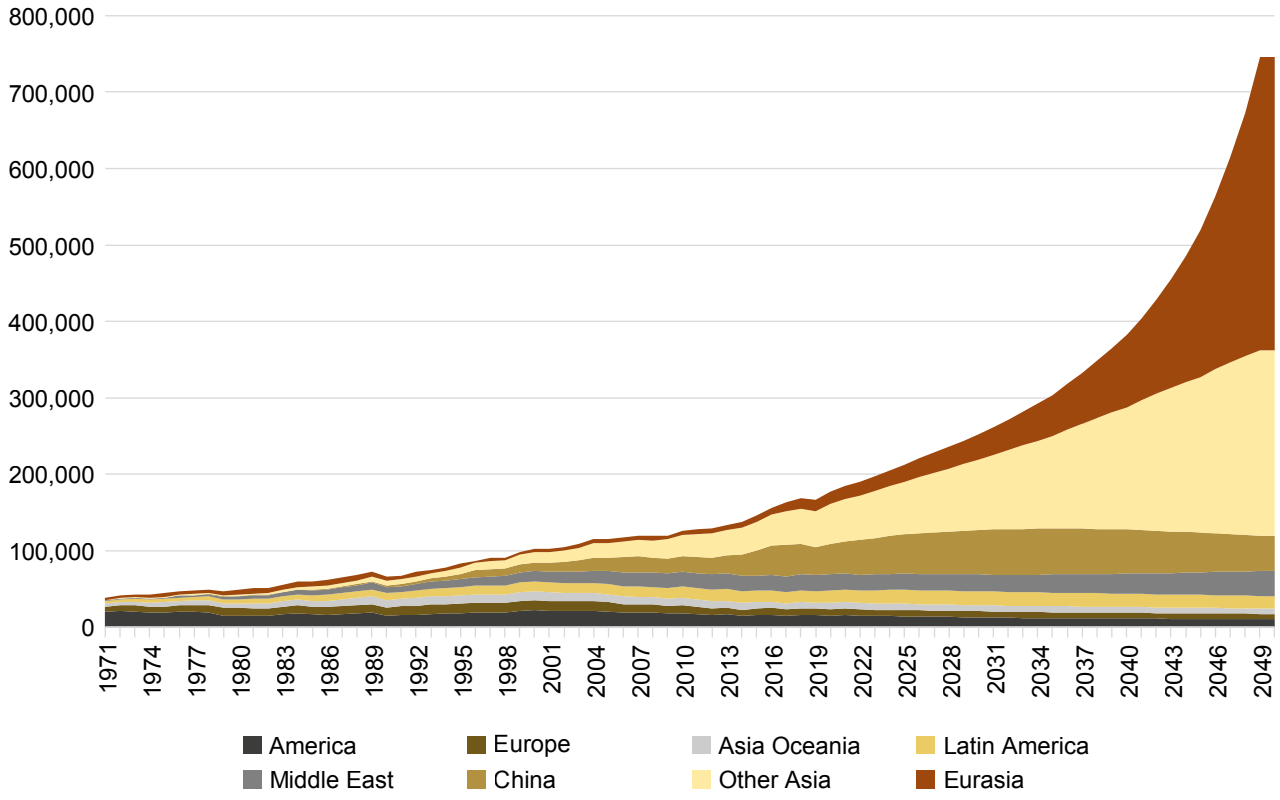
driven primarily by the China and Eurasia regions, where industrialization, urbanization and economic growth are increasing the need for energy. In these regions, LPG is increasingly considered an attractive alternative to other traditional fuels, such as coal and wood, due to its affordability, cleanliness and versatility. Additionally, growth in the residential and commercial sectors combined with favorable government policies will further boost the demand for LPG.

Table 2. Projections of LPG demand levels for buildings by region for the period 2020-2050.

Year	America	Europe	Asia Oceania	Latin America	Middle East	China	Other Asia	Eurasia	Global
2020	15,271	8,330	8,465	15,601	21,814	39,594	52,001	16,018	177,095
2021	15,633	8,538	8,393	15,920	21,564	42,484	54,856	16,988	184,377
2022	14,765	8,298	8,319	16,519	20,863	45,126	57,679	18,272	189,841
2023	14,512	8,223	8,279	17,234	20,914	47,527	61,125	19,528	197,344
2024	14,331	8,239	8,254	17,718	21,115	49,700	64,872	20,969	205,198
2025	14,101	8,243	8,227	18,042	21,303	51,660	68,620	22,526	212,723
2026	13,797	8,222	8,194	18,086	21,189	53,412	73,649	24,264	220,814
2027	13,537	8,187	8,156	18,131	21,204	54,968	78,102	26,180	228,466
2028	13,252	8,145	8,114	18,104	21,349	56,322	82,431	28,330	236,046
2029	12,953	8,098	8,066	18,167	21,618	57,468	86,784	30,734	243,889
2030	12,671	8,046	8,015	18,201	21,986	58,404	91,306	33,447	252,076
2031	12,434	7,989	7,961	17,994	22,143	59,142	97,728	36,506	261,897
2032	12,218	7,931	7,906	17,899	22,411	59,693	103,531	39,973	271,562
2033	12,060	7,873	7,852	17,878	22,785	60,063	109,189	43,909	281,610
2034	11,922	7,818	7,798	17,852	23,257	60,251	115,002	48,399	292,298
2035	11,792	7,763	7,744	17,908	23,800	60,261	121,102	53,546	303,916
2036	11,696	7,708	7,691	17,702	24,126	60,096	129,628	59,474	318,120
2037	11,572	7,654	7,638	17,551	24,530	59,767	137,508	66,335	332,557
2038	11,454	7,601	7,585	17,580	25,025	59,277	144,948	74,326	347,797
2039	11,351	7,547	7,533	17,542	25,573	58,629	152,275	83,663	364,114
2040	11,238	7,494	7,482	17,546	26,208	57,831	159,550	94,670	382,019
2041	11,154	7,442	7,431	17,339	26,716	56,896	169,691	107,690	404,358
2042	11,052	7,389	7,380	17,148	27,286	55,838	179,003	123,205	428,301
2043	10,938	7,337	7,330	17,085	27,931	54,669	187,630	141,824	454,744
2044	10,861	7,286	7,280	17,086	28,653	53,394	195,816	164,307	484,682
2045	10,749	7,235	7,230	17,000	29,433	52,022	203,428	191,686	518,783
2046	10,688	7,184	7,181	16,758	30,194	50,566	214,784	225,268	562,622
2047	10,586	7,133	7,133	16,558	31,035	49,036	225,017	266,800	613,298
2048	10,488	7,083	7,084	16,408	31,934	47,439	233,994	318,740	673,170
2049	10,362	7,033	7,036	16,450	32,890	45,783	242,626	384,192	746,374
2050	10,362	7,033	7,036	16,450	32,890	45,783	242,626	384,192	746,374

Source: Authors' calculations.

Figure 3. Estimated demand levels for regional LPG usage in buildings for the period ending in 2050.



Source: Authors' elaboration.

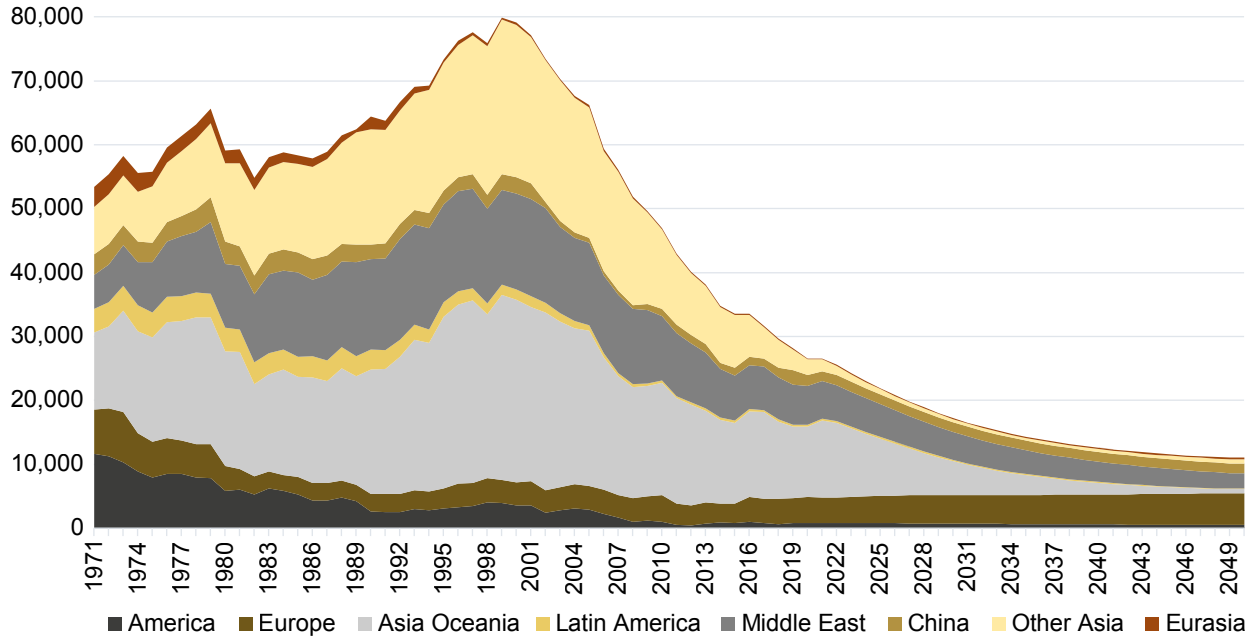
Demand for kerosene: The current estimates show a consistent downward trajectory in the global demand for kerosene in buildings. The projections indicate that this trend is set to continue into the foreseeable future. Moreover, it is projected that the demand for kerosene in buildings will significantly decline from 28,164 Ktoe in 2020 to approximately 11,025 Ktoe by 2050. This reduction in demand represents a considerable decrease of more than one-half. Such a reduction will undoubtedly have a wide range of implications and consequences for various stakeholders in the industry, which may lead to decreased levels of production and distribution of kerosene for residential and commercial buildings, as well as a potential shift toward the use of alternative energy sources and technologies.

Table 3. Projections of kerosene demand levels for buildings by region for the period 2020-2050.

Year	America	Europe	Asia Oceania	Latin America	Middle East	China	Other Asia	Eurasia	Global
2020	857.18	4,008.70	11066.01	302.57	6026.93	1714.77	2440.53	158.96	26575.64
2021	822.51	3,975.16	12052.10	303.52	5828.95	1579.62	1860.32	156.98	26579.15
2022	791.01	3,997.62	11649.63	289.78	5638.20	1649.19	1423.74	158.60	25597.76
2023	782.10	4,090.37	10736.27	288.58	5454.38	1594.56	1128.34	161.31	24235.91
2024	781.67	4,190.69	9811.53	292.43	5277.23	1555.40	933.47	163.85	23006.27
2025	779.52	4,270.20	8957.48	290.24	5106.48	1553.08	798.41	166.08	21921.49
2026	773.40	4,328.76	8126.19	284.15	4941.88	1543.81	697.01	168.10	20863.3
2027	764.00	4,372.29	7326.65	271.26	4783.19	1534.44	622.88	169.99	19844.69
2028	751.98	4,405.09	6583.58	259.47	4630.17	1530.88	567.93	171.79	18900.89
2029	737.94	4,430.24	5905.90	246.90	4482.61	1528.17	527.06	173.53	18032.34
2030	722.33	4,449.67	5290.95	237.43	4340.29	1525.74	496.66	175.22	17238.28
2031	706.29	4,467.30	4738.23	228.07	4203.00	1524.33	471.97	176.89	16516.09
2032	690.70	4,485.74	4247.81	214.46	4070.57	1523.41	454.82	178.56	15866.08
2033	676.01	4,506.38	3815.85	204.20	3942.79	1522.70	443.73	180.24	15291.91
2034	662.29	4,529.04	3431.40	196.19	3819.48	1522.23	437.52	181.94	14780.1
2035	649.38	4,552.88	3088.34	188.75	3700.49	1521.92	435.34	183.65	14320.76
2036	637.15	4,577.39	2778.47	183.36	3585.64	1521.70	434.52	185.36	13903.59
2037	625.52	4,602.82	2499.13	173.89	3474.77	1521.55	437.25	187.09	13522.02
2038	614.39	4,629.18	2245.52	166.05	3367.74	1521.45	443.30	188.87	13176.5
2039	603.69	4,656.35	2016.02	161.65	3264.39	1521.38	452.40	190.70	12866.59
2040	593.39	4,684.52	1807.61	156.59	3164.60	1521.33	464.47	192.58	12585.08
2041	583.43	4,713.57	1617.59	152.51	3068.22	1521.29	477.14	194.50	12328.25
2042	573.76	4,743.26	1444.71	145.64	2975.13	1521.27	492.86	196.46	12093.09
2043	564.36	4,773.36	1287.81	139.46	2885.21	1521.26	511.74	198.45	11881.65
2044	555.20	4,803.69	1145.15	135.47	2798.33	1521.24	533.86	200.46	11693.41
2045	546.27	4,834.14	1016.06	132.63	2714.39	1521.24	559.54	202.50	11526.76
2046	537.54	4,864.59	899.69	128.87	2633.27	1521.23	585.63	204.55	11375.37
2047	529.01	4,895.03	795.12	123.35	2554.87	1521.23	615.13	206.61	11240.35
2048	520.64	4,925.61	700.94	118.69	2479.10	1521.23	648.61	208.71	11123.51
2049	512.44	4,956.63	616.84	114.95	2405.85	1521.22	685.83	210.85	11024.61
2050	512.44	4,956.63	616.84	114.95	2405.85	1521.22	685.83	210.85	11024.61

Source: Authors' calculations.

Figure 4. Estimated demand levels for regional kerosene usage in buildings for the period ending in 2050.



Source: Authors' elaboration.

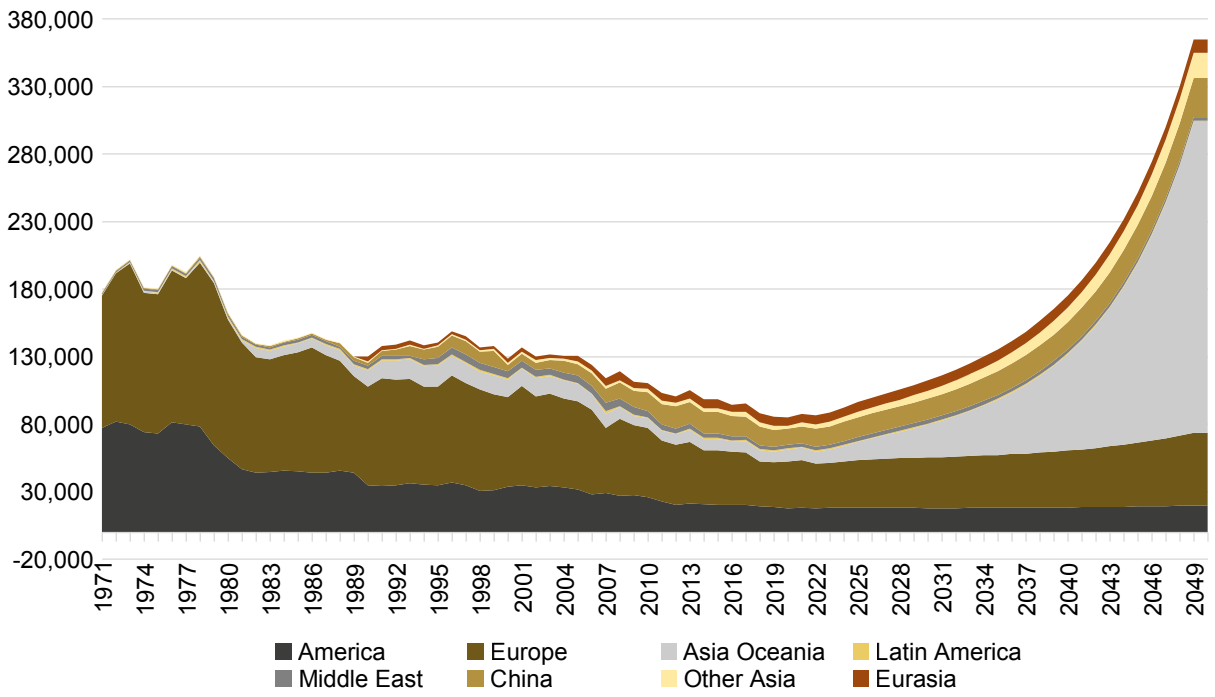
Demand for gas and diesel oil: As with LPG, there is growing global demand for gas and diesel oil (excluding biofuels) in buildings worldwide according to projections, with such increases in demand levels being driven mainly by China and other Asian regions. This trend is expected to continue steadily and increase significantly over time. The demand for gas and diesel oil, excluding biofuels, is estimated to be 87,840 Ktoe in 2021. However, by 2050, the demand is projected to reach approximately 365,103 Ktoe — a staggering increase that highlights the growing dependency on these nonrenewable resources. The upward trend in demand is particularly significant in the Asia Oceania, China, and other Asia regions, suggesting that these regions will play an essential role in driving the need for gas and diesel oil in the future.

Table 4. Projections of gas and diesel oil (excluding biofuels) demand levels for buildings by region for the period 2020-2050.

Year	America	Europe	Asia Oceania	Latin America	Middle East	China	Other Asia	Eurasia	Global
2020	17,688.57	34915.29	8566.38	941.65	2709.89	11830.59	2497.02	6223.63	85373.00
2021	18,062.42	35634.79	8934.80	892.16	2703.65	12257.86	2789.70	6564.54	87839.93
2022	17,990.44	32716.67	9184.18	877.79	2771.67	13320.82	3044.00	6819.37	86724.94
2023	18,334.15	32883.63	10097.22	890.08	2815.92	13638.42	3306.37	7017.61	88983.4
2024	18,358.69	34013.70	11589.85	902.12	2842.08	14151.10	3580.07	7144.33	92581.94
2025	18,379.03	35149.57	13318.81	906.60	2856.46	14576.74	3883.71	7249.70	96320.61
2026	18,320.69	35941.84	15204.12	906.47	2863.04	14837.82	4211.80	7349.11	99634.89
2027	18,338.84	36463.08	17230.70	904.87	2864.89	15003.09	4569.94	7444.64	102820.1
2028	18,229.63	36850.18	19398.95	902.72	2863.06	15168.97	4940.23	7537.58	105891.3
2029	18,080.46	37210.82	21720.61	900.39	2858.52	15385.79	5322.37	7628.86	109107.8
2030	17,979.48	37537.28	24235.84	897.91	2850.98	15649.96	5717.36	7719.00	112587.8
2031	17,978.04	37825.66	26950.82	895.88	2840.48	15959.44	6127.81	7809.89	116388
2032	17,983.46	38156.23	29904.33	894.60	2827.32	16302.13	6570.97	7901.04	120540.1
2033	18,071.67	38488.60	33138.10	893.96	2813.41	16662.53	7022.75	7993.73	125084.8
2034	18,132.53	38839.52	36767.53	893.63	2798.61	17047.67	7483.50	8087.86	130050.9
2035	18,169.50	39253.33	40835.82	893.36	2782.87	17473.01	7959.76	8182.91	135550.6
2036	18,259.11	39705.78	45468.16	892.91	2766.24	17943.89	8451.02	8276.95	141764.1
2037	18,257.81	40191.45	50698.66	892.35	2748.86	18449.53	8994.88	8374.75	148608.3
2038	18,295.29	40770.26	56679.83	891.77	2731.85	18987.08	9573.30	8475.76	156405.1
2039	18,379.97	41418.70	63474.53	891.09	2715.12	19570.70	10186.36	8579.49	165216
2040	18,444.51	42114.89	71258.91	890.36	2698.57	20222.30	10839.19	8687.56	175156.3
2041	18,600.98	42917.36	80251.38	889.46	2682.26	20963.89	11522.48	8797.01	186624.8
2042	18,703.98	43838.02	90636.79	888.42	2666.09	21800.57	12275.39	8908.60	199717.9
2043	18,807.66	44859.77	102640.27	887.33	2650.59	22714.49	13073.59	9022.08	214655.8
2044	19,029.92	45992.69	116634.65	886.22	2635.72	23681.23	13918.42	9137.01	231915.8
2045	19,154.84	47263.38	132912.15	885.02	2621.42	24679.87	14809.93	9253.22	251579.8
2046	19,442.84	48646.80	151859.59	883.65	2607.65	25709.18	15723.39	9369.95	274243
2047	19,598.79	50166.00	173931.85	882.20	2594.36	26792.21	16724.39	9488.29	300178.1
2048	19,809.11	51861.43	199895.87	880.65	2581.60	27942.37	17783.09	9609.12	330363.2
2049	19,978.10	53727.53	230170.33	879.15	2569.31	29147.96	18896.92	9733.18	365102.5
2050	19,978.10	53727.53	230170.33	879.15	2569.31	29147.96	18896.92	9733.18	365102.5

Source: Authors' calculations.

Figure 5. Estimated demand levels for gas and diesel oil usage in buildings for the period ending in 2050.



Source: Authors' elaboration.

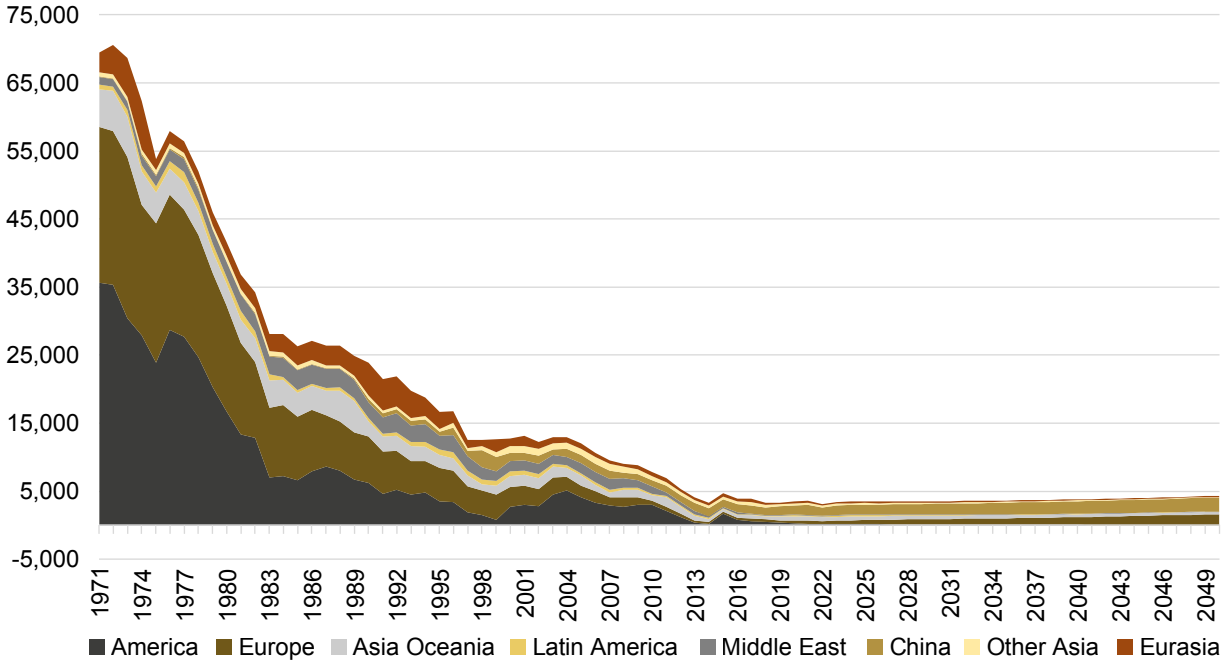
Demand for fuel oil: The global demand for fuel oil in buildings has consistently decreased over recent decades. However, our projections suggest that this trend has stabilized and will continue to remain relatively stable in the future. In fact, the model predicts a slight increase in demand, with an estimated increase from 3,625 in 2021 to 4,263 by 2050. This increase in demand can be attributed to various factors. First, in some regions or countries, the transition to cleaner energy sources may be slower, potentially due to economic constraints or infrastructure limitations. Second, the global population is projected to continue growing, which will result in an increased need for residential, commercial and industrial buildings. In areas with limited access to alternative energy sources, fuel oil may still be used as either a primary or backup fuel source for heating and energy.

Table 5. Projections of fuel oil demand levels for buildings by region for the period 2020-2050.

Year	America	Europe	Asia Oceania	Latin America	Middle East	China	Other Asia	Eurasia	Global
2020	285.34	431.53	555.72	169.28	107.42	1,324.66	310.27	306.02	3490.247
2021	234.34	490.10	571.71	95.01	93.48	1,549.63	294.79	296.34	3625.398
2022	207.70	382.83	577.77	130.73	91.76	1,238.56	279.32	229.17	3137.852
2023	185.31	457.99	575.06	198.38	91.78	1,421.69	264.41	209.31	3403.931
2024	168.69	541.25	567.01	218.84	88.91	1,413.00	250.32	221.78	3469.793
2025	154.97	606.47	556.96	214.87	86.33	1,409.62	237.13	232.80	3499.151
2026	143.86	647.39	545.83	166.43	78.04	1,440.48	224.84	232.87	3479.75
2027	132.65	684.00	534.26	145.27	75.56	1,483.28	213.58	227.31	3495.913
2028	122.82	715.97	522.78	121.85	73.53	1,524.35	203.16	219.77	3504.231
2029	114.59	751.78	511.71	117.60	71.97	1,556.10	193.52	211.91	3529.175
2030	107.09	787.43	501.15	108.46	70.47	1,586.03	184.57	203.79	3549.005
2031	99.19	817.66	491.20	77.04	64.88	1,615.62	176.28	195.65	3537.524
2032	91.22	852.56	481.95	66.87	63.12	1,643.77	168.70	188.20	3556.388
2033	82.58	888.48	473.46	62.74	61.61	1,673.04	161.70	181.65	3585.255
2034	73.98	920.36	465.61	57.38	60.20	1,701.07	155.22	176.14	3609.962
2035	65.96	957.72	458.28	57.42	58.70	1,726.54	149.20	171.40	3645.226
2036	58.29	994.77	451.45	41.72	54.20	1,749.33	143.62	167.19	3660.571
2037	51.83	1029.32	445.04	34.81	52.45	1,772.18	138.53	163.21	3687.371
2038	46.30	1069.44	439.03	36.11	50.99	1,796.16	133.85	159.28	3731.149
2039	41.40	1110.91	433.36	33.05	49.36	1,819.11	129.51	155.89	3772.61
2040	37.27	1146.75	428.01	31.96	48.14	1,839.87	125.49	152.59	3810.086
2041	33.48	1188.53	422.90	24.04	45.33	1,857.77	121.74	149.61	3843.388
2042	30.27	1236.26	417.98	19.64	43.88	1,873.20	118.33	147.00	3886.558
2043	27.63	1280.61	413.21	19.06	42.65	1,889.00	115.19	144.55	3931.916
2044	25.14	1325.29	408.55	19.35	41.56	1,906.85	112.29	142.44	3981.462
2045	23.12	1373.67	404.01	17.23	40.45	1,926.83	109.58	140.57	4035.463
2046	21.11	1420.48	399.55	13.00	38.95	1,948.92	107.06	138.91	4087.978
2047	19.49	1465.60	395.18	10.93	38.05	1,970.68	104.77	137.88	4142.567
2048	18.10	1515.22	390.87	9.86	37.11	1,990.60	102.68	137.04	4201.481
2049	17.05	1563.40	386.62	11.15	36.22	2,010.77	100.73	136.67	4262.621
2050	17.05	1563.40	386.62	11.15	36.22	2,010.77	100.73	136.67	4262.621

Source: Authors' calculations.

Figure 6. Estimated demand levels for fuel oil usage in buildings for the period ending in 2050.



Source: Authors' elaboration.

5. Conclusions

This study provides a comprehensive long-term outlook on global oil consumption in the building sector. By disaggregating the oil demand outlook based on fuel type and geographical location into eight regions and constructing models for total global consumption, the study elucidates the dynamics and trends of oil consumption in this critical sector. Moreover, multivariate forecast models, particularly the ARIMAX model, which incorporates several control variables, can be used to provide valuable insights into future trends in oil consumption patterns in buildings.

The findings of this analysis contribute to a deeper understanding of energy consumption in the building sector and can serve as crucial resources for policymakers, energy planners and stakeholders in formulating sustainable strategies and policies to address the sector's energy demand levels and challenges. Moreover, the methodology presented in this paper can serve as a basis for future research and refinement, further enhancing our ability to manage global energy demand both efficiently and sustainably in the building sector. This study lays the groundwork for informed decision-making in the pursuit of a more energy-efficient and environmentally responsible future.

This study highlights the inherent complexity of the energy demand levels of buildings and the complexity involved in providing accurate demand forecasts. In fact, demand is a function of a multitude of interlinked factors, such as users' behaviors, economic factors, environmental conditions and buildings' technical features. Accordingly, a reliable energy demand forecast depends heavily on assumptions regarding future climate conditions, behavioral uncertainties induced by changes in contextual and socioeconomic factors, energy prices and issues related to the complex nature of supply and loads and data and approaches allowing for causal estimation and accurate correlation between energy demand and its driving factors.

The modeling approach employed in this study is both robust and comprehensive. However, caution is crucial when interpreting these results, considering the inherent limitations and potential uncertainties associated with long-term predictions. One crucial factor that warrants careful consideration is data quality. The accuracy and reliability of the results depend strongly on the accuracy and reliability of the data inputs.

Additionally, long-term projections inherently have limitations and potential shortcomings. These projections do not account for future policies and technological disruptions that may significantly impact the outcomes. As such, while the initial estimation provides valuable insights, it should not be viewed as an infallible prediction of future events. Instead, the initial estimation should be regarded as a helpful tool with which to understand potential trends and to inform decision making.

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Appendix

Table A1. Key determinants of LPG, kerosene, gas, and fuel in the building sector in China.

Dep variables	Ln(LPG)	Ln(KERO)	Ln(Gas)	Ln(Fuel)
Regressors				
$Ln(GDPRE_i)$			2.26***	
$Ln(GDPR)_{t-1}$				–4.48***
$Ln(GDPR)_{t-2}$			–1.88***	4.69***
$Ln(pop)_{t-1}$	3.84***			
$Ln(Brent)_{t-2}$				0.11***
$Ln(LPG)_{t-1}$	0.64***			
$Ln(KERO)_{t-1}$		0.34***		
$Ln(KERO)_{t-3}$		0.16***		
$Ln(Gas)_{t-1}$			0.65***	
C		3.63***	50.29***	
Adj. R^2	0.99	0.99	0.99	0.99
Number of observations	47	47	47	47
Normality test: $Chi^2(2)$	0.30666 [0.8578]	0.20430 [0.9029]	0.68225 [0.7110]	2.3153 [0.3142]
Hetero test	F(4,41) = 0.97488 [0.4317]	F(16,25) = 0.78569 [0.6871]	F(11,35) = 1.1604 [0.3483]	F(30,12) = 1.5060 [0.2292]
RESET23 test	F(2,41) = 0.58137 [0.5637]	F(2,30) = 0.38950 [0.6808]	F(2,38) = 3.1879 [0.0525]	F(2,23) = 0.52813 [0.5967]

Notes:
* Significant at 10%.
** Significant at 5%.
*** Significant at 1%.

Source: Authors' calculations.

Appendix

Table A2. Key determinants of LPG, kerosene, gas and fuel in the building sector in Latin America.

Dep variables	Ln(LPG)	Ln(KERO)	Ln(Gas)	Ln(Fuel)
Regressors				
$Ln(GDPR)_{t-1}$				2.35***
$Ln(pop_i)$	34.45***		0.34***	
$Ln(pop)_{t-1}$	-33.01***	59.72***		692.79***
$Ln(pop)_{t-2}$		-59.55***		-681.60***
$Ln(Brent_i)$			-0.11***	
$Ln(LPG)_{t-1}$	0.59***			
$Ln(KERO)_{t-1}$		0.62***		
$Ln(Gas)_{t-1}$			0.29***	
$Ln(Fuel)_{t-1}$				0.33***
C	-25.26***	-1.6***	-1.49***	-259.04***
Adj. R^2	0.99	0.98	0.95	0.99
Number of observations	47	47	47	47
Normality test: $Chi^2(2)$	1.1482 [0.5632]	1.1026 [0.5762]	3.7122 [0.1563]	1.4701 [0.4795]
Hetero test	F(6,39) = 1.0763 [0.3933]	F(7,39) = 1.3410 [0.2577]	F(6,39) = 1.9855 [0.0913]	F(13,33) = 1.7982 [0.0859]
RESET23 test	F(2,40) = 2.9834 [0.0620]	F(2,40) = 0.71827 [0.4938]	F(2,40) = 0.31181 [0.7339]	F(2,37) = 0.74472 [0.4819]

Notes:
* Significant at 10%.
** Significant at 5%.
*** Significant at 1%.

Source: Authors' calculations.

Table A3. Key determinants of LPG, kerosene, gas and fuel in the building sector in the MENA.

Dep variables	Ln(LPG)	Ln(KERO)	Ln(Gas)	Ln(Fuel)
Regressors				
$Ln(GDPR)_{t-1}$				-0.55**
$Ln(GDPR)_{t-2}$			-0.44***	
$Ln(pop_i)$	-17.59***			-81.67***
$Ln(pop)_{t-1}$	17.41***			136.63***
$Ln(pop)_{t-2}$			0.53***	-55.02***
$Ln(Brent_i)$				
$Ln(Brent)_{t-2}$	0.04***			0.19***
$Ln(LPG)_{t-1}$	0.94***			
$Ln(KERO)_{t-1}$		0.99***		
$Ln(Gas)_{t-1}$			0.88***	
$Ln(Fuel)_{t-1}$				0.86***
C	4.49***		2.60**	17.82***
Adj. R^2	0.99	0.94	0.95	0.99
Number of observations	47	47	47	47
Normality test: $Chi^2(2)$	5.0856 [0.0786]	1.4850 [0.4759]	1.1471 [0.5635]	1.2580 [0.5331]
Hetero test	F(8,38) = 1.4019 [0.2272]	F(8,37) = 0.59030 [0.7794]	F(8,37) = 1.5443 [0.1757]	F(15,27) = 0.53729 [0.8955]
RESET23 test	F(2,40) = 0.89086 [0.4183]	F(2,40) = 1.4645 [0.2433]	F(2,39) = 2.0096 [0.1477]	F(2,31) = 0.13810 [0.8715]

Notes:
* Significant at 10%.
** Significant at 5%.
*** Significant at 1%.

Source: Authors' calculations.

Appendix

Table A4. Key determinants of LPG, kerosene, gas and fuel in the building sector in OECD Asia.

Dep variables	Ln(LPG)	Ln(KERO)	Ln(Gas)	Ln(Fuel)
Regressors				
$Ln(GDPR)_{t-1}$		-1.53***	2.24***	-0.41***
$Ln(pop)_{t-1}$		6.53***	-10.64+	
$Ln(pop)_{t-2}$				
$Ln(Brent)_{t-1}$	-0.025***	-0.09***	-0.15***	
$Ln(LPG)_{t-1}$	0.93**			
$Ln(KERO)_{t-1}$		0.74***		
$Ln(Gas)_{t-1}$			0.55***	
$Ln(Gas)_{t-2}$			0.11	
$Ln(Fuel)_{t-1}$				0.76**
C	0.65**	-76.83***	140.98***	13.84**
Adj. R^2	0.96	0.94	0.98	0.91
Number of observations	47	47	47	47
Normality test: $Chi^2(2)$	2.3801 [0.3042]	0.35688 [0.8366]	0.92805 [0.6287]	1.0523 [0.5909]
Hetero test	F(4,42) = 0.52390 [0.7187]	F(9,36) = 1.1056 [0.3836]	F(11,33) = 2.4721 [0.0220]	F(4,42) = 1.9216 [0.1246]
RESET23 test	F(2,42) = 1.5353 [0.2272]	F(2,38) = 0.87908 [0.4234]	F(2,36) = 10.279 [0.0003]	F(2,42) = 1.3193 [0.2782]

Notes:
* Significant at 10%.
** Significant at 5%.
*** Significant at 1%.

Source: Authors' calculations.

Table A5. Key determinants of LPG, kerosene, gas and fuel in the building sector in OECD Europe.

Dep variables	Ln(LPG)	Ln(KERO)	Ln(Gas)	Ln(Fuel)
Regressors				
$Ln(GDPRE_i)$		0.34***		
$Ln(GDPR)_{t-1}$				
$Ln(GDPR)_{t-2}$			1.15***	3.06***
$Ln(pop_i)$			-10.72***	-28.44***
$Ln(pop)_{t-1}$				
$Ln(pop)_{t-2}$				38.69***
$Ln(Brent)_{t-1}$	-0.06***	-0.075***		-0.12***
$Ln(Brent)_{t-2}$	0.03***			
$Ln(LPG)_{t-1}$	0.92**			
$Ln(KERO)_{t-1}$		0.63***		
$Ln(KERO)_{t-3}$				
$Ln(Gas)_{t-1}$			0.45***	
$Ln(Gas)_{t-2}$				
$Ln(Fuel)_{t-1}$				
C	0.76**	-7.04***	186***	–293.25***
Adj. R^2	0.95	0.92	0.96	0.99
Number of observations	47	47	47	47
Normality test: $Chi^2(2)$	0.64318 [0.7250]	0.51750 [0.7720]	1.1729 [0.5563]	1.3142 [0.5183]
Hetero test	F(6,40) = 1.4237 [0.2297]	F(7,39) = 1.3838 [0.2396]	F(6,40) = 0.42026 [0.8611]	F(13,33) = 1.9912 [0.0548]
RESET23 test	F(2,41) = 0.46480 [0.6315]	F(2,40) = 0.099547 [0.9055]	F(2,41) = 0.86389 [0.4290]	F(2,37) = 0.53640 [0.5893]

Notes:
* Significant at 10%.
** Significant at 5%.
*** Significant at 1%.

Source: Authors' calculations.

Appendix

Table A6. Key determinants of LPG, kerosene, gas and fuel in the building sector in Other Asia.

Dep variables	Ln(LPG)	Ln(KERO)	Ln(Gas)	Ln(Fuel)
Regressors				
$Ln(GDPRE_i)$				
$Ln(GDPR)_{t-1}$		0.50***	3.16***	
$Ln(GDPR)_{t-2}$				
$Ln(pop_i)$	-63.38***	18.30***		
$Ln(pop)_{t-1}$	63.94***	-19.33***	-9.49***	-2.49
$Ln(pop)_{t-2}$				
$Ln(Brent)_{t-1}$	-0.04***	-0.05***	0.08***	
$Ln(Brent)_{t-2}$				
$Ln(LPG)_{t-1}$	0.61***			
$Ln(KERO)_{t-1}$		0.92***		
$Ln(KERO)_{t-3}$				
$Ln(Gas)_{t-1}$				
$Ln(Gas)_{t-2}$				
$Ln(Fuel)_{t-1}$				0.53
C	-7.04	7.72	119.48***	56.78
Adj. R^2	0.95	0.99	0.96	0.85
Number of observations	47	47	47	47
Normality test: $Chi^2(2)$	0.050806 [0.9749]	0.050806 [0.9749]	2.3475 [0.3092]	2.0315 [0.3621]
Hetero test	F(12,34) = 0.59054 [0.8344]	F(12,34) = 0.59054 [0.8344]	F(15,31) = 0.23982 [0.9975]	F(8,39) = 2.4228 [0.0314]
RESET23 test	F(2,38) = 0.86747 [0.4282]	F(2,38) = 0.86747 [0.4282]	F(2,35) = 0.57579 [0.5675]	F(2,41) = 0.27255 [0.7628]

Notes:
* Significant at 10%.
** Significant at 5%.
*** Significant at 1%.

Source: Authors' calculations.

Table A7. Key determinants of LPG, kerosene, gas and fuel in the building sector in Eurasia.

Dep variables	Ln(LPG)	Ln(KERO)	Ln(Gas)	Ln(Fuel)
Regressors				
$Ln(GDPRE_j)$		0.43	1.01	-2.08
$Ln(GDPR)_{t-1}$				2.78
$Ln(pop)_{t-1}$				-14.21
$Ln(pop)_{t-2}$	-1.76			
$Ln(Brent)_{t-1}$				-0.5
$Ln(LPG)_{t-1}$	0.57			
$Ln(LPG)_{t-2}$	0.50			
$Ln(KERO)_{t-1}$		0.46		
$Ln(Fuel)_{t-1}$				0.36
C	34.21	-9.52	-19.96	266.59
Adj. R^2	0.86	0.98	0.95	0.94
Number of observations	47	47	47	47
Normality test: $Chi^2(2)$	1.4197 [0.4917]	2.3673 [0.3062]	1.6127 [0.4465]	0.47990 [0.7867]
Hetero test	F(9,36) = 0.23358 [0.9872]	F(8,38) = 1.6285 [0.1491]	F(5,21) = 1.1031 [0.3883]	F(10,18) = 0.62058 [0.7776]
RESET23 test	F(2,38) = 2.7892 [0.0741]	F(2,40) = 0.14722 [0.8636]	F(2,21) = 1.9909 [0.1615]	F(2,21) = 1.2317 [0.3120]

Notes:
* Significant at 10%.
** Significant at 5%.
*** Significant at 1%.

Source: Authors' calculations.

About the Authors



Fateh Belaïd

Fateh was a full professor of economics at Lille Catholic University and the director of the Smart and Sustainable Cities research unit. Fateh has also held various positions at the French Scientific and Technical Center for Building and led multiple collaborative projects for the French Ministry of Ecological Transition and the European Commission. He is an energy and environmental economist who draws from the fields of applied microeconomics, energy modeling and econometrics. He has published widely on household energy consumption, energy-saving behaviors, individual preference and investment in energy efficiency, energy poverty, renewables and energy policy. He received a habilitation for supervising doctoral research from Orléans University, a doctorate in economics, a Master of Science in Applied Economics and Decision Theory from Littoral University and an engineering degree in statistics. His work has been published in journals, including Ecological Economics, The Energy Journal, Energy Economics, Economic Surveys, Energy Policy and Environmental Management.



Mohammad Aldubyan

Mohammad is a research lead in KAPSARC's Climate and Sustainability program. His research focuses on energy efficiency and energy demand in buildings. He is currently leading the Residential Energy Model program, which simulates residential energy demand and estimates the impact of energy efficiency programs on Saudi Arabia's housing sector. He also leads the long-term KAPSARC Oil Market Outlook in buildings and agriculture sectors. Mohammad holds a Master of Science in Renewable and Clean Energy from the University of Dayton in Ohio and a Master of Science in Economics from Purdue University, West Lafayette.

About the Project

The aim of this project is to construct a model to forecast the direct oil demand driven by the building and agriculture sectors. The forecast takes into consideration the growth in the building and agriculture sectors and its contribution to the overall oil demand by accounting for some factors that primarily impact energy demand, such as national economy growth and national economy growth and energy efficiency level, etc. It also considers some technical and economic characteristics of both demand- and supply-side economics. The main goal of conducting this forecast is to feed the long-term KAPSARC Oil Market Outlook model to enhance long-term oil demand outlook. This project is expected to provide an annual long-term forecast of oil demand associated with buildings and agriculture sectors. A detailed forecast of oil demand will be explained by many factors, such as the growth of each building type relative to the others, overall energy efficiency level and geographical distribution, to name a few.



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