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Post-Pandemic Surges of Real Unit Energy Costs in Eight Industrialized Countries

Koji Nomura
Sho Inaba

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Abstract

This paper develops a high-frequency indicator to assess real price and cost differentials for energy use across eight industrialized countries: China, France, Germany, Italy, Japan, South Korea, the UK, and the U.S. The study assesses the overall energy cost burden using the real price level index (PLI) and the real unit energy cost (RUEC). The real PLI, unaffected by exchange rate fluctuations, provides a stable measure of real energy price differentials, while the RUEC indicates the challenges facing the energy transition. An analysis of RUEC trends from the first quarter of 2015 to the fourth quarter of 2023 highlights a substantial post-pandemic surge, particularly evident in Germany and Italy, where levels spiked by about 80% compared to pre-pandemic periods. This surge in Germany has coincided with a 20% decline in output within energy-intensive manufacturing by the end of 2023. Asian countries, on the other hand, managed to curb the post-pandemic RUEC surge to less than half of this level through energy subsidies and government interventions. Nonetheless, the higher RUEC levels in China and South Korea underscore the formidable challenges they encounter in propelling their energy transition initiatives forward. In Japan, about half of the limitations on the RUEC surge are attributed to reduced energy consumption resulting from the hollowing out of its industrial sector. Without a fundamental reevaluation of energy policies to ensure economic growth, the current path of the energy transition remains precarious.

Keywords: Real unit energy cost (RUEC); Real energy prices; Price level index (PLI); Real PLI; Energy productivity; Energy-intensive trade-exposed (EITE) industries

JEL classification: C81, E31, O44, Q41

† Koji Nomura is a professor at Keio Economic Observatory (KEO), Keio University, Tokyo, and Sho Inaba is a research trainee at KEO (a student at the Graduate School of Business and Commerce, Keio University.). This project was granted by the Keidanren (Japan Business Federation) Foundation for Environmental Protection Measures. The authors thank Mansaku Yoshida, Department of Business and Commerce, Keio University, for his patient research assistance. The figures reported here are preliminary estimates as of March 2024 and will be revised as more statistics become available. Please see the website (https://www.ruec.world/) for the latest estimates. Any errors that remain are our sole responsibility. Correspondent author: Koji Nomura (nomura@sanken.keio.ac.jp).

Contents

1 Introduction

The global drive to achieve carbon neutrality by mid-century is expected to unlock growth opportunities for companies with advantages in green technologies. While this demand-side effect of the energy transition seems to offer promising prospects to some sectors, it is critical to consider the risks on the supply side—higher energy costs for energy-intensive sectors from low-carbon policies may hurt price competitiveness relative to suppliers in countries with low or no carbon prices. The global economy experienced fossil fuel price surges, starting in late 2020 because of the post-COVID-19 pandemic demand recovery and further exacerbated by the war in Ukraine starting in February 2022. While the spikes began to reverse in mid-2022, they remain significantly elevated relative to pre-pandemic levels. The outlook for fossil fuel prices remains uncertain. Energy transition policies in developed countries aiming for carbon neutrality may lead to an anticipated long-term decline in fossil fuel prices.[1] On the other hand, concerns persist that sustained fossil fuel price surges could occur due to investment constraints imposed on fossil fuel suppliers or increased demand in developing countries.[2]

This study aims to develop a high-frequency indicator that effectively measures real energy cost differentials across eight industrialized countries: China, France, Germany, Italy, Japan, South Korea, the UK, and the U.S. The challenge in constructing data for this purpose is to develop monthly figures on energy costs that are as consistent as possible with economic statistics, such as national accounts and Supply and Use Tables/Input-Output Tables (SUT/IOT).[3] The overall energy cost burden relative to output (value added) is evaluated in this paper based on the real Price Level Index (PLI) for quality-adjusted final energy use and the Real Unit Energy Cost (RUEC). This allows us to closely monitor the potential of supply-side impacts on the long-term trajectory of the energy transition.

The nominal PLI for energy is the ratio of the Purchasing Power Parity (PPP) for energy to the market exchange rate. Using the U.S. as a reference country, the PLI represents the energy price differential index relative to the U.S. The fact that the nominal PLI is affected by exchange rate fluctuations leads to a phenomenon that may seem somewhat odd as a measure of international price differentials. Suppose the currency of a country facing higher energy prices becomes weaker against the U.S. dollar, assuming that electricity prices in the domestic currency are stable. In that case, the

[1] The Net Zero Emissions by 2050 Scenario (NZE) in IEA (2023b) projects a 74% drop in oil prices from $98/bbl in 2022 to $25/bbl in 2050. Under this scenario, natural gas prices in the U.S. are projected to fall 62% and common coal prices 57% between 2022 and 2050. Even in the Stated Policies Scenario (STEPS), which assumes manufacturing capacity for currently planned or implemented policies and clean energy technologies, between 2022 and 2050, the prices of crude oil and natural gas are projected to fall by 16% and coal by 23%.

[2] The High Zero-Carbon Technology Cost (HighZTC) scenario in the U.S. EIA (2023) assumes no learning cost reductions in the capital costs of zero-emission power generation facilities, while the Low Zero-Carbon Technology Cost (LowZTC) scenario assumes a 40% lower cost level in 2050 (compared to the reference case). Crude oil prices are projected to be about the same in 2050 regardless of these two scenarios, rising to about 1.9 times the 2022 level. Natural gas price is also expected to increase after falling to pre-war levels in Ukraine until 2027 and is projected to increase by about 1.2 times in the HighZTC and remain about the same in the LowZTC compared to 2022.

[3] Energy statistics are characterized by their promptness in reporting, focusing mainly on energy volume balances. However, the monthly data on energy consumption costs, comparable with nominal GDP, have yet to be established universally, with notable exceptions in countries such as the U.S., the UK, and France. Even in the UK and France, they are regarded as insufficiently consistent with the economic statistics. In contrast, economic statistics incorporating energy consumption data exhibit a less timely reporting pattern, often published with a lag of one to several years. Through the establishment of comprehensive monthly data on energy costs, appropriate aggregate energy prices are constructed, and the factors contributing to their fluctuations are also decomposed by energy type or sector in Section 4.1.

energy price differential in dollar terms is understood to be rather smaller. The real PLI, which is the focus of this paper, is defined as the ratio of the nominal PLI for energy divided by the nominal PLI for output (real GDP). This measure is unaffected by exchange rate fluctuations and can provide a more stable real energy price differential.

The RUEC is an indicator that includes adaptation due to changes in real energy prices and can be seen as an indicator of economic vulnerability to energy price increases.[4] The change in RUEC is defined as the growth of real energy price (REP) minus the growth of average energy productivity (AEP). An increase in the RUEC means that the economy has become more vulnerable to higher energy prices, as the increase in REP outweighs the moderating effect of improved AEP. If the increase in energy use prices could be fully passed through to output prices, the rise in REP would be reduced, and the real burden would be lessened. And if the increase in REP could improve AEP, the real burden would be reduced. Such AEP changes may be limited in the short term. Even in the long run, improvements in AEP may be limited in countries that have long faced energy prices more than twice as high as those in the U.S.[5]

In the energy transition context, the RUEC can indicate the challenges a country faces in implementing ambitious green policies. Countries with higher nominal energy prices, lower value-added prices for their outputs, more energy-intensive industries, and lower energy productivity tend to have higher RUECs. These countries may struggle to manage the high-cost burden associated with the energy transition. The post-pandemic surge in energy prices provided an unexpected lesson in these dynamics.

This paper evaluates the monthly energy costs using various energy and economic statistics in each country and the quarterly estimates of real PLI and RUEC, corresponding to the official quarterly GDP in current and constant prices published by the national statistical offices in each country. While this measurement covers January 2015 to December 2023, the recent monthly energy cost estimates are preliminary due to the available energy price and volume data limitations. Therefore, they are updated with the latest annual statistics on volumes from energy statistics and nominal values from economic statistics as soon as they are available, which serve as annual benchmarks for 2019–2022.[6]

The data developed in this paper are called multilateral energy cost monitoring (ECM).[7] In addition to assessing price and cost aspects like the real energy cost, the ECM tries to monitor output changes in energy-intensive trade-exposed (EITE) industries. This paper primarily concentrates on

[4] A similar indicator, real unit labor cost, is well known and has many examples of measurement, but there are few examples of RUEC measurement. The European Commission (2014) indicated a gradual increase in RUEC in the manufacturing sector of major developed countries between 1995 and 2009. Nomura (2023, Chapter 3) analyzes the long-term RUEC changes and their industrial origins from 1955 to 2019 in the Japanese economy.

[5] Japan's PLI for energy use has always been quite high, ranging from 1.5 to 3.0 times that of the U.S. from 1955 to 2019. As energy prices rose in the 2000s, Japan's advantage in AEP over the U.S. shrank since the U.S., with its relatively lower energy prices, improved its AEP at a faster pace (Nomura 2023, p. 93).

[6] In ECM_202403, the yearly totals of energy use volumes are benchmarked with the IEA's *World Energy Balances* in 2021. The annual totals of nominal energy costs are benchmarked with the available SUT/IOT or national accounts in 2019 for South Korea, 2020 for China, Germany, and Italy, and 2022 for the rest. The limitations of the paper's approach, such as estimating nominal values from price and volume estimates, should be recognized. In particular, the large price fluctuations in 2022–2023 could lead to significant revisions in future annual benchmarks.

[7] The ECM for Japan began development in January 2022 to construct a monthly RUEC for the Japanese economy (Nomura and Inaba 2023). In parallel with this project, monthly estimates of production-side GDP (output price and volume), named JMGDP, are being developed for each of the 36 industries in the Japanese economy. For developing the multilateral ECM in this paper, the Japanese ECM was revised for better comparability based on the common sectors in Table 2 in Section 2.1. (Before the revision, the Japanese ECM separated only two non-transforming sectors.)

international comparisons of the former while utilizing Germany as a case study to illustrate the latter. The latest ECM (i.e., ECM_202403) also provides a short-term outlook, calculated using the U.S. Energy Information Administration's (EIA) outlook for energy prices and the OECD's forecast for economic growth up to December 2024.

This paper is structured as follows. Section 2 presents the framework for measuring energy costs and energy price differentials. Section 3 describes the measurement processes. Section 4 analyzes the sources of monthly energy price changes in each country and provides the quarterly estimates of real PLI and the RUEC from the first quarter of 2015 to the fourth quarter of 2023, with forecasts up to the fourth quarter of 2024. Germany had the largest post-pandemic surge in RUEC among the eight countries covered. Section 4.3.2 assesses the impact of industrial hollowing out in Germany. Section 5 concludes. Appendix A discusses the nominal PLIs measured monthly in ECM with nominal exchange rate fluctuations. Our methodology for measuring monthly energy costs can be applied to historical data to help verify its accuracy. Some verification works are provided in Appendix C. Finally, the supplementary figures are presented in Appendix D.

2 Framework

The ECM elementary level of final energy consumption (FEC) is defined as the i-product and j-energy-using sector. We define the following variables in ECM:

- E_{ij} FEC at the elementary level, assessed in terms of calorific value,
- P_{ij}^{E} Energy unit price at purchaser's price[8] in the elementary level, measured at LCU,
- V_{ij}^{E} Energy costs at the elementary level $(= P_{ij}^{E}E_{ij})$,
- V^{E} Energy costs at the aggregate level, defined as $\sum_{ij} V_{ij}^{E}$,
- E Energy use at the aggregate level, defined in Eq. (4),
- P^{E} Energy use price at the aggregate level, implicitly defined as V^{E}/E,
- $\bar{E}$ FEC at the aggregate level, expressed as a simple aggregation $(\sum_{ij} E_{ij})$,
- $\bar{P}^{E}$ Average energy price at the aggregate level, defined as $V^{E}/\bar{E}$,
- X Aggregate output (real GDP),
- V^{X} Aggregate output value (GDP at current prices), and
- P^{X} Aggregate output price (GDP deflator) measured at LCU, implicitly defined as V^{X}/X.

Note that all variables are defined by country (c) and period (t), i.e., monthly for energy uses and quarterly for outputs, but they are omitted here for simplicity. Unit prices and costs are assessed at each country's local currency units. Table 1 presents the ECM product classification and its concordance with the IEA World Energy Balances product (IEA 2020). The ECM defines six major product categories (1. Coal products, 2. Natural gas, 3. Oil products, 4. Electricity, 5. Heat, and 6. Others) and 29 sub-categories.

[8] The ECM defines the energy prices at the purchaser's price (including trade margins and transportation costs) for international comparison. This corresponds to the end-use price in the IEA's *Energy Prices and Taxes*.

Table 1: Product Classification

ECM products	IEA World Energy Balances products	ECM products	IEA World Energy Balances products
1. Coal products		307. Fuel oil	Fuel oil
101. Coal	Hard coal (if no detail)	308. Naphtha	Naphtha
	Brown coal (if no detail)	309. Lubricants	Lubricants
	Anthracite	310. Other oil product	Refinery gas
	Coking coal		Petroleum coke
	Other bituminous coal		Ethane
	Sub-bituminous coal		White spirit & SBP
	Lignite		Bitumen
	Patent fuel		Paraffin waxes
	BKB		Other oil products
102. Coal coke	Coke oven coke	4. Electricity	
	Gas coke	401. Electricity	Electricity
	Coal tar	402. Autoproducer electricity	Elec/heat output from non-specified manufactured gases
103. Coal gas	Gas works gas	5. Heat	Heat
	Coke oven gas		Heat output from non-specified combustible fuels
	Blast furnace gas	6. Others	
	Other recovered gases	601. Waste	Industrial waste
104. Peat and peat products	Peat		Municipal waste (renewable)
	Peat products		Municipal waste (non-renewable)
105. Oil shale and oil sands	Oil shale and oil sands	602. Biofuels	Primary solid biofuels
2. Natural gas	Natural gas		Biogases
3. Oil products			Biogasoline
301. Crude,NGL and feedstocks	Crude/NGL/feedstocks (if no detail)		Biodiesels
	Crude oil		Bio jet kerosene
	Refinery feedstocks		Other liquid biofuels
	Additives/blending components		Non-specified primary biofuels and waste
	Other hydrocarbons		Charcoal
	Natural gas liquids	603. Nuclear	Nuclear
302. Liquefied petroleum gases	Liquefied petroleum gases (LPG)	604. Hydro	Hydro
303. Motor gasoline excl. biofuels	Motor gasoline excl. biofuels	605. Geothermal	Geothermal
304. Jet fuel	Aviation gasoline	606. Solar photovoltaics	Solar photovoltaics
	Gasoline type jet fuel	607. Solar thermal	Solar thermal
	Kerosene type jet fuel excl. biofuels	608. Tide, wave and ocean	Tide, wave and ocean
305. Kerosene	Other kerosene	609. Wind	Wind
306. Gas/diesel oil	Gas/diesel oil excl. biofuels	610. Other sources	Other sources

Sources: ECM_202403 and IEA (2020). Note: Each product is defined separately for domestically produced and imported products, as shown in Table 3.

2.1 Unit Energy Costs

Based on these variables defined above, the nominal unit energy cost (NUEC) at LCU at the aggregate level is defined as the nominal FEC cost per unit of real GDP as follows:

(1) $$NUEC = V^E/X.$$

The real unit energy cost (RUEC) is a measure of the NUEC deflated by aggregate output price (P^X).

(2) $$RUEC = NUEC/P^X = V^E/V^X = REP/AEP,$$

where REP is the real energy price and AEP is the (gross) average energy productivity, defined as:

(3) $$REP = P^E/P^X \text{ and } AEP = X/E.$$

As shown in Eq. (2), the RUEC is recognized as the ratio of nominal energy costs to nominal GDP (V^E/V^X) and as an index of REP divided by AEP. The RUEC rises when the improvement in AEP cannot cover the increase in REP, indicating that the country is vulnerable to higher energy prices.

The energy use (E) in AEP is defined as the quality-adjusted measure using the Translog index:

(4) $$\Delta \ln E = \sum_{ij} \bar{v}_{ij} \Delta \ln E_{ij},$$

where Δ is the difference between two consecutive periods and $\Delta \ln E_{ij}$ is the growth rate of each FEC by product (i) and sector (j). The above equation aggregates the growth rates weighted by the two-period average cost share of each product and sector ($\bar{v}_{ij}$) in total energy use ($\sum_{ij} \bar{v}_{ij}$=1). The price per unit of calorific value varies depending on the quality of the product. The price of quality-adjusted energy use (P^E) is implicitly defined by V^E/E.

An index calculated from the quantity of energy use (E) and FEC ($\bar{E}$) is defined as q:

(5) $q = E/\bar{E} = \bar{P}^E/P^E$.

We call q the energy quality index.[9] Electricity has a higher price per unit of calorific value than utility gas. Thus, when there is an energy shift from utility gas to electricity in FEC, q increases, even if $\bar{E}$ remains constant. This quality index is recognized from a price side as a relative price of $\bar{P}^E/P^E$ in Eq. (5).

Table 2 presents the ECM sector classification. There, it is broadly divided into the 1. Transformation sector and 2. Non-transformation sector. The transformation sector comprises five two-digit categories (11. Electricity, 12. Heat, 13. Coke and refinery petroleum products, 14. Mining and quarrying, and 15. Biofuel) and the non-transformation sector has five industries (21. Industries, 22. Transport, 23. Residential, 24. Commercial and public services, and 25. Agriculture, forestry, and fishing). Among 21. Industries, 211. EITE industries and 211. Non-EITE industries are separated. For correspondence with economic statistics, the transport sector is divided into consumption by households (2201) and non-households (2202). In ECM, "household" is defined as the sum of 2201. Transport activities by households and 23. Residential and "industry" as the sum of 21. Industries, 2202. Transport activities by non-households, 24. Commercial and public services, and 25. Agriculture, forestry, and fishing. This sector classification allows annual benchmarking (Section 3.3) with economic statistics such as the SUT/IOT.

Table 2: Sector Classification

ECM sectors		ECM sectors	
1	Transformation sector	12	Heat
11	Electricity	13	Coke and refinary petroleum products
1101	Electricity–Coal	1301	Oil
1102	Electricity–Oil	1302	Coal coke
1103	Electricity–Natural gas	1303	Coal gas
1104	Electricity–Combustible renewables	14	Mining and quarrying
1105	Electricity–Other combustible non-renewables	1401	Coal
1106	Electricity–Nuclear	1402	Crude, NGL, and feedstocks
1107	Electricity–Hydro	1403	Natural gas
1108	Electricity–Wind	15	Biofuel
1109	Electricity–Solar	2	Non–transformation sector
1110	Electricity–Geothermal	21	Industries
1111	Electricity–Other renewables	2101	EITE industries
1112	Electricity–Others	21011	Iron and steel
1113	Autoproducer electricity–Coal	21012	Chemical and petrochemical
1114	Autoproducer electricity–Oil	21013	Non-ferrous metals
1115	Autoproducer electricity–Natural gas	21014	Non-metallic minerals
1116	Autoproducer electricity–Combustible renewables	21015	Paper, pulp, and print
1117	Autoproducer electricity–Other combustible non-renewables	2102	Non–EITE industries
1118	Autoproducer electricity–Nuclear	22	Transport
1119	Autoproducer electricity–Hydro	2201	Transport activities by households
1120	Autoproducer electricity–Wind	2202	Transport activities by non–households
1121	Autoproducer electricity–Solar	23	Residential
1122	Autoproducer electricity–Geothermal	24	Commercial and public services
1123	Autoproducer electricity–Other renewables	25	Agriculture, forestry, and fishing
1124	Autoproducer electricity–Others		

Sources: ECM_202403. Note: Household is defined as the sum of 2201 and 23, and industry is as the sum of 21, 2202, 24, and 25.

The ECM constructs the monthly estimates of an energy use matrix by product and sector. Table 3 provides the structure of the ECM's energy use table. Each product consumption is estimated separately for energy transformation (E'_{ij} defined in the upper block) and final consumption (E_{ij}

[9] A more complete picture of the relationship between primary energy consumption (PEC), FEC, and (quality-adjusted) energy use is provided in Nomura (2023, Chapter 2).

defined in the lower block), which are further divided into domestic products (D) and imported products (M), respectively. The energy use tables are measured at a monetary term ($V_{ij}^{E'}$ and V_{ij}^{E}) and a calorific value (E'_{ij} and E_{ij}). This paper's price/cost differentials are measured based on the final energy use table, shown in the lower block of Table 3.

Table 3: Energy Use Table

<table>
<tr><td colspan="3" rowspan="3">(Unit : LCU)</td><td colspan="9">ECM sector (j)</td><td rowspan="3">Domestic consumption</td></tr>
<tr><td colspan="4">1. Transofrmation sector</td><td colspan="5">2. Non–transformation sector</td></tr>
<tr><td>11.Electricty</td><td>12. Heat</td><td>13. Coke and refinary petroleum products</td><td>. . .</td><td>21. Industries</td><td>22. Transport</td><td>23. Residential</td><td>24. Commercial and public</td><td>25. Agriculture, forestry, and fishing</td></tr>
<tr><td rowspan="4">ECM products (i)</td><td rowspan="2">Transformation processes (Intermediate consumption)</td><td>Domestic products (D)
101. Coal
102. Coal coke
.
.
.
610. Other sources</td><td colspan="4">$P^{E}_{ij,D}\ E'_{ij,D}$</td><td colspan="5" rowspan="2">0</td><td>$P^{E}_{i,D}\ E'_{i,D}$</td></tr>
<tr><td>Imported products (M)
101. Coal
102. Coal coke
.
.
.
610. Other sources</td><td colspan="4">$P^{E}_{ij,M}\ E'_{ij,M}$</td><td>$p^{E}_{i,M}\ E'_{i,M}$</td></tr>
<tr><td rowspan="2">Final energy consumption</td><td>Domestic products (D)
101. Coal
102. Coal coke
.
.
.
610. Other sources</td><td colspan="4" rowspan="2">0</td><td colspan="5">$P^{E}_{ij,D}\ E_{ij,D}$</td><td>$P^{E}_{i,D}\ E_{i,D}$</td></tr>
<tr><td>Imported products (M)
101. Coal
102. Coal coke
.
.
.
610. Other sources</td><td colspan="5">$P^{E}_{ij,M}\ E_{ij,M}$</td><td>$P^{E}_{i,M}\ E_{i,M}$</td></tr>
</table>

Sources: ECM_202403. Notes: See Table 1 for product classification and Table 2 for sector classification in ECM. The ECM energy use tables are measured monthly at a monetary term and a calorific value.

2.2 Price Differentials

Nominal PLI measures the energy price differential between countries for FEC, a PPP ratio to the market exchange rate (e_t). The PPP for energy use between the country-c_1 and the country-c_2 is defined as the Fisher index.

$$(6) \qquad \mathrm{PPP}_{c_1 c_2}^{\mathrm{E(F)}} = \sqrt{\mathrm{PPP}_{c_1 c_2}^{\mathrm{E(L)}} \mathrm{PPP}_{c_1 c_2}^{\mathrm{E(P)}}},$$

where $\mathrm{PPP}_{c_1 c_2}^{\mathrm{E(L)}}$ and $\mathrm{PPP}_{c_1 c_2}^{\mathrm{E(P)}}$ are the PPPs based on the Laspeyres and Paasche PPP indices between the country-c_1 and the country-c_2, which are defined as, respectively:

$$(7) \qquad \mathrm{PPP}_{c_1 c_2}^{\mathrm{E(L)}} = \sum_{ij} \frac{P_{ij,c_2}^{E} E_{ij,c_1}}{P_{ij,c_1}^{E} E_{ij,c_1}} \text{ and } \mathrm{PPP}_{c_1 c_2}^{\mathrm{E(P)}} = \sum_{ij} \frac{P_{ij,c_2}^{E} E_{ij,c_2}}{P_{ij,c_1}^{E} E_{ij,c_2}}.$$

Since the Fisher index in Eq. (6) does not satisfy the transitivity test in multilateral comparison, we measure the PPP for energy uses based on the EKS (Éltető-Köves-Szulc) method as:

$$(8) \qquad \mathrm{PPP}_{c_1 c_2}^{\mathrm{E}} = \prod_{c_3} \left(\mathrm{PPP}_{c_1 c_3}^{\mathrm{E(F)}} \mathrm{PPP}_{c_3 c_2}^{\mathrm{E(F)}} \right)^{1/\mathrm{N}},$$

where N is the number of countries this paper covers (i.e., eight). The EKS-PPP for energy use is measured in this paper for the base year (T=2015), in which this paper attempts to capture the most accurate unit price information by product and sector as discussed in Section 3.1. The times-series

PPP estimates are extrapolated using the energy price indices measured in each county ($P_{c,t}^{E}$), which are normalized as 1.0 at T.

(9) $$\text{PPP}_{c_1c_2,t}^{\text{E}} = \text{PPP}_{c_1c_2,T}^{\text{E}} \frac{P_{c_1,t}^{E}}{P_{c_2,t}^{E}}.$$

These time series PPPs for energy use are measured using the monthly energy use tables described in Table 3. Based on this EKS-PPP for energy use ($\text{PPP}_{c_1c_2,t}^{\text{E}}$) and the average exchange rate ($\text{e}_{c_1c_2,t}$), the nominal PLI for energy use is defined as

(10) $$\text{PLI}_{c_1c_2,t}^{\text{E}} = \text{PPP}_{c_1c_2,t}^{\text{E}} / \text{e}_{c_1c_2,t}.$$

The real PLI is measured every quarter. On the PPP for output ($\text{PPP}_{c_1c_2,T}^{\text{X}}$) at the base year ($T$=2017), we follow the estimate in the 2017 International Comparisons Program (ICP) round (World Bank 2020). And the time series estimates of the PPP for output ($\text{PPP}_{c_1c_2,t}^{\text{X}}$) are measured using the GDP prices measured in the quarterly national accounts in each country, in a similar way of Eq. (9). The real PLI is defined as:

(11) $$\text{Real PLI}_{c_1c_2,t}^{\text{E}} = \text{PLI}_{c_1c_2,t}^{\text{E}} / \text{PLI}_{c_1c_2,t}^{\text{X}} = \text{PPP}_{c_1c_2,t}^{\text{E}} / \text{PPP}_{c_1c_2,t}^{\text{X}}.$$

This real price differential measure is not affected by exchange rate fluctuations.

3 Measurement

The measurement of multilateral ECM consists of the following four processes:

1) Establish volume and value balances of annual energy use tables in Table 3 for the base year (i.e., 2015 in ECM_202403) and split it into monthly energy use tables (i.e., from January to December 2015), using monthly energy volume/value data (explained in the 2nd process),
2) Update the monthly energy use table up to the most recent month (i.e., December 2023), using monthly data on energy prices and volumes, based on the monthly table for December 2015 (or for December after the most recent annual benchmark carried out in the next 3rd process),
3) Benchmark monthly estimates (updated in the 2nd process) against available recent annual data on energy use volume and value estimates (i.e., the 2016 value, …, 2021 value), and
4) Forecast 6–12 months ahead of the most recent observation period (i.e., from January 2024 to December 2024).

Section 3.1 describes the development of the annual energy use table for the base year, described in the first process. Section 3.2 presents the methodology for developing monthly estimates in the second process (and the information required for the division into monthly tables in the first process). Sections 3.3 and 3.4 describe the third and fourth processes, respectively.

3.1 Base Year Estimates

The year 2015 is the base year of ECM_202403, providing the initial annual energy use table. The unit prices of a given product can differ considerably by sector in the energy use value table defined in Table 3, depending on the differences in energy kind, quality, consumption size, contract, and so on. In the base year, unit price differentials among sectors are considered in each product as much as possible, while the monthly estimates discussed in Section 3.2 basically capture only product-specific price changes. Table 4 provides the data for annual estimates for nominal values (P^E) and volume measure (E). The first block from the top of Table 4 organizes data commonly used for several countries, including the data by the IEA, Eurostat, and OECD, identified using the data code (D01–D06) in the second column.

Table 4: Data Used for Annual Estimates

Country	Data code	Variables	Data	Organization
International				
	D01	E	World Energy Balances	IEA
	D02	E	Physical Energy Flow Accounts	Eurostat
	D03	E	Energy Statistics	Eurostat
	D04*	P^E	Energy Prices and Taxes	IEA
	D05*	E	Quarterly National Accounts	OECD
	D06*	E	Economic Outlook	OECD
China	D01, D05, D06, and			
	CHN-D01	V^E	全国投入产出表 (Input-Output Table)	National Bereau of Statistics (NBS)
	CHN-D02	P^E	全国居民消费价格指数 (Consumer Price Indices by Category)	China Statistical Press
	CHN-D03	P^E	全国电力价格情况监管通报 (National Electricity Price Supervision Report)	Nationl Energy Administration (NEA)
	CHN-D04	P^E	中国石油天然气股份有限公司2015 年度报告 (Petro China Company Limited 2015 Annual Report)	PetroChina Company Limited (CNPC)
Japan	D01, D05, D06, and			
	JPN-D01	V^E, E	産業連関表 (Input-Output Table)	Ministry of Internal Affairs and Communications (MIC)
	JPN-D02	V^E, P^E	国民経済計算年報 (JSNA)	Economic and Social Research Institute (ESRI)
	JPN-D03	V^E, E	KEO Database	Keio Economic Observatory (KEO)
	JPN-D04	E	総合エネルギー統計 (General Energy Statistics)	Ministry of Economy, Trade and Industry (METI)
Korea	D01, D04, D05, D06, and			
	KOR-D01	V^E	산업연관표 (Input-Output Tables)	Bank of Korea (BOK)
	KOR-D02	E	확장 밸런스 (Extended Energy Balance)	Korea Energy Statistical Information System (KESIS)
	KOR-D03	E	상용자가발전업체조사 (Survey of Commercial Self-Generators)	Korea Energy Statistical Information System (KESIS)
U.S.	D01, D04, D05, D06, and			
	USA-D01	V^E	Input-Output Accounts Data	U.S Bureau of Economic Analysis (BEA)
	USA-D02	V^E, E	State Energy Data System	Energy Information Administration (EIA)
	USA-D03	V^E, E	Electricity Power Annual	Energy Information Administration (EIA)
	USA-D04*	V^E, E	Quarterly Coal Report	Energy Information Administration (EIA)
France	D01, D02, D03, D04, D05, D06, and			
	FRA-D01	V^E	Tableau des Entrées-Sorties (Input-Output Table)	The French National Institute of Statistics and Economic Studies (INSEE)
	FRA-D02	V^E	Bilan Énergétique de la France (France's Energy Balance)	The French National Institute of Statistics and Economic Studies (INSEE)
Germany	D01, D02, D03, D04, D05, D06, and			
	DEU-D01	V^E	Verwendungstabelle (Use Table)	Federal Statistical Office Germany (Destatis)
	DEU-D02	V^E, P^E	Volkswirtschaftlichen Gesamtrechnungen (VGR)	Federal Statistical Office Germany (Destatis)
	DEU-D03	V^E	Kostenstrukturerhebung im Verarb. Gewerbe, Bergbau (Cost Structure Survey in Manufacturing, Mining and Quarrying)	Federal Statistical Office Germany (Destatis)
	DEU-D04	E	Energieverwendung der Betriebe im Verarb. Gewerbe (Energy Use of Companies in the Manufacturing Sector)	Federal Statistical Office Germany (Destatis)
Italy	D01, D02, D03, D04, D05, D06, and			
	ITA-D01	V^E	Le Tavole Delle Risorse E Degli Impieghi (the Supply and Use Table)	The National Institute for Statistics (Istat)
	ITA-D02	V^E	Conti Economici NazionalI (National Accounts)	The National Institute for Statistics (Istat)
UK	D01, D02, D03, D04, D05, D06, and			
	GBR-D01	V^E	Supply and Use Tables	Office of National Statistics (ONS)
	GBR-D02	V^E, E	Digest of UK Energy Statistics (DUKES)	Department for Energy Security and Net Zero
	GBR-D03*	P^E	Prices of Fuels Purchased by Manufacturing Industry	Department for Energy Security and Net Zero

Source: ECM_202403. Note: * are quarterly data.

The ECM mainly follows the IEA's *Energy Prices and Taxes* (data code: D04) for unit prices by product and broad sector (i.e., electricity, industry, and residential). For China, which D04 does not cover, and for products for which data is unavailable in D04, some country-specific annual data presented from the second block in Table 4 or monthly data provided in Table 5 (Section 3.2) are used. For example, for Japan, the 2015 Benchmark-year IOT (JPN-D01) and the energy account in the KEO Database (JPN-D03) provide detailed unit price data of energy uses. For the U.S., the EIA's *Monthly Energy Review* (data code is USA-D05 in Table 5) provides high-quality data on energy use volumes and unit prices by product and broad sector. In other countries, unit price data are supplemented by China

(CHN-D01, D03–D04, D12, and D13 in Table 5), South Korea (KOR-D01 and D04), France (FRA-D02 and D03), Italy (ITA-D01, D02, and D04), and the UK (GBR-D03, D06, and D07).

When some unit cost data are not available at the detailed level of energy use tables, we assumed the differential unit price ratio among products, measured as the Jevons index, aggregating the price differential indices observed in other countries. For example, in Germany, if the unit price data for 103. Coal gas is unavailable, we set 101. Coal as a reference product. The unit price for 103 is estimated by multiplying the unit price for 101 observed in Germany by the Jevons index of 103 to 101.[10]

Finally, the unit prices in base year 2015 are adjusted so that base year annual consumption values, defined as yearly aggregates of the product of monthly energy use volume and its unit price, correspond to nominal values recorded in the SUT/IOT and the system of national accounts.[11] These adjustments in terms of nominal values are conducted based on the classifications available in the SUT/IOT to maintain consistency at a more aggregated level of product (e.g., the first-digit ECM product as 1. Coal product or 3. Oil product) than the energy use tables (based on the three-digit ECM product). On the other hand, the above energy statistics do not give unit cost differentials of a product for industrial use. Still, more detailed differentials across industries are available from the SUT/IOT. Such industry-specific unit costs can be reflected in the finalized base year estimates, for example, in the EITE industries breakdown in the ECM (sector 21011–21015).

A similar process of aligning monthly estimates with annual nominal values, such as IOT, is also applied to the annual benchmark of nominal values for non-base years in Section 3.3. However, in the base year, the 2015 benchmark IOTs are available in Japan and South Korea and reflect more detailed information than those used for the annual benchmarks.

3.2 Monthly Estimates

Table 5 provides the data for monthly estimates of energy prices and volumes in ECM to develop the monthly energy use tables (Table 3). The first block from the top of Table 5 organizes data commonly used for several countries, including the U.S. EIA, Eurostat, and IEA data, identified using the data code (D04–D11) in the second column. The second through ninth blocks of Table 5 provide a list of country-specific data with data codes (e.g., CHN-D05, JPN-D05, and so on) for each of the eight countries. The data used to estimate energy use volumes is denoted by E and the energy price data by P^E in the third column.

The monthly energy use table establishes the volume balance by product between domestic demand, which consists of transformation use (E'_{ij}) and final use (E_{ij}), and domestic supply (E_i), which is defined as domestic shipment plus net imports. In the US, the EIA publishes complete monthly data on energy demand and supply for almost all products in the *Monthly Energy Review* (USA-D05), while in other countries, we must fill in missing volumes in the respective data on domestic demand and/or domestic supply by product.

[10] There are some cases where such an application is difficult, for example, in 601. Waste, consumption prices are highly subsidized, so the disparity rates observed in other countries may not provide a good approximation. The lowest unit price (per calorific value) among products is assumed for such products.

[11] The annual value data are China (CHN-D01), Japan (JPN-D01 and D02), South Korea (KOR-D01), the U.S. (USA-D01), France (FRA-D02), Germany (DEU-D01 and D02), Italy (ITA-D01 and D02), and the UK (GBR-D01).

Table 5: Data Used for Monthly Estimates

Country	Data code	Variables	Data Name	Organization
International				
	D07	E	Energy Statistics	Eurostat
	D08	E	Production in Industry	Eurostat
	D09	E	Production in Services	Eurostat
	D10	p^E	Harmonised Indices of Consumer Prices	Eurostat
	D11	p^E	Energy Prices and Costs in Europe	European Commission (EC)
	D12	E	Monthly Electricity Statistics	International Energy Agency (IEA)
	D13	V^E, E	International Trade in Goods	Eurostat
	D14	P^E, E	Short-term Energy Outlook	Energy Information Administration (EIA)
China	D12, D14, and			
	CHN-D05	E	能源主要产品产量 (Output of Energy Products)	National Bureau of Statistics of China (NBS)
	CHN-D06	E	工业主要产品产量 (Output of Major Industrial Products)	National Bureau of Statistics of China (NBS)
	CHN-D07	E	服务业生产指数 (Index of Service Production)	National Bureau of Statistics of China (NBS)
	CHN-D08	p^E	工业生产者出厂价格指数 (Producer Price Indices)	National Bureau of Statistics of China (NBS)
	CHN-D09	p^E	居民消费价格分类月度环比指数 (Month-to-Month Consumer Price Index by Category)	China Statistical Press
	CHN-D10	p^E	居民消费价格指数 (Consumer Price Indices by Category)	National Bureau of Statistics of China (NBS)
	CHN-D11	p^E	商品零售价格指数 (Retail Price Indicies)	National Bureau of Statistics of China (NBS)
	CHN-D12	p^E	流通领域重要生产资料市场价格变动情况 (Market Price of Important Means of Production in Circulation)	National Bureau of Statistics of China (NBS)
	CHN-D13	p^E	各省区市和中心城市汽、柴油最高零售价格表 (List of Maximum Retail Prices of Gasoline and Diesel in Various Provinces, Autonomous Regions, Municipalities and Central Cities)	National Development and Reform Commision (NDRC)
	CHN-D14	p^E	Energy Prices in the EU and Main Trading Partners	European Commission (EC)
	CHN-D15	V^E, E	海关统计 (Customs Statistics)	General Administration of Customs of the People's Republic of China
Japan	D14 and			
	JPN-D05	E	電力調査統計 (Electric Power Investigation Statistics)	Ministry of Economy, Trade and Industry (METI)
	JPN-D06	E	鉱工業指数 (Indices of Industrial Production)	Ministry of Economy, Trade and Industry (METI)
	JPN-D07	E	第3次産業活動指数 (Indices of Terciary Industry Activity)	Ministry of Economy, Trade and Industry (METI)
	JPN-D08	E	石油等消費動態統計 (Monthly Report of the Current Survey of Energy Consumption)	Ministry of Economy, Trade and Industry (METI)
	JPN-D09	E	資源・エネルギー統計月報 (Monthly Report of Mineral Resources and Petroleum Products Statistics)	Ministry of Economy, Trade and Industry (METI)
	JPN-D10	E	電力需要実績 (Actual Electricity Demand)	Organization for Cross-regional Coordination of Transmission Operators (OCCTO)
	JPN-D11	p^E	消費者物価指数 (Consumer Price Index)	Ministry of Internal Affairs and Communications (MIC)
	JPN-D12	p^E	企業物価指数 (Producer Price Index)	Bank of Japan (BOJ)
	JPN-D13	p^E	企業向けサービス価格指数 (Service Producer Price Index)	Bank of Japan (BOJ)
	JPN-D14	V^E, E	貿易統計 (Trade Statistics of Japan)	Ministry of Finance (MOF)
Korea	D12, D14, and			
	KOR-D04	p^E, E	에너지통계월보 (Monthly Energy Statistics)	Korea Energy Economics Institute (KEEI)
	KOR-D05	E	간이 밸런스 (Simple Energy Balances)	Korea Energy Statistical Information System (KESIS)
	KOR-D06	E	광업제조업동향조사 (Monthly Survey of Mininig and Manufacturing)	Korean Statistical Information Service (KOSIS)
	KOR-D07	p^E	생산자물가지수 (Producer Price Indices)	Bank of Korea (BOK)
	KOR-D08	p^E	소비자물가지수 (Consumer Price Indices)	Bank of Korea (BOK)
	KOR-D09	p^E	수입물가지수 (Import Price Indices)	Bank of Korea (BOK)
	KOR-D10	V^E, E	해외무역통계 (Foreign Trade Statistics)	Korea International Trade Association (KITA)

Source: ECM_202403.

For domestic demand (E'_{ij} and E_{ij}), in countries where there are no monthly energy use data (such as Japan) or where there are statistics but no breakdown of demand for energy transformation (such as South Korea), provisional estimates are developed by multiplying the output of each sector (e.g., IP (Index of production/Industrial production/Indices of industrial production) and ISP (Index of services/Services production/Indices of tertiary production)) by the energy use coefficient for each product of the corresponding sector.[12] Supplemented by these output-based estimates, provisional estimates of the energy use matrix ($\hat{E}'_{ij}$ and $\hat{E}_{ij}$) are obtained.

For domestic supply (E_i), in countries where monthly data on domestic supply by energy type

[12] If an energy productivity improvement (EPI) is measured in terms of changes in the input coefficient for the relevant energy product in the sector concerned, an average rate of EPI based on the past trend is assumed to estimate energy consumption volumes. The household sector's output indicator is based on real household consumption in OECD's *Quarterly National Accounts* (D05 in Table 4) as a crude approximation in this paper, except for China.

are not available (such as Japan), domestic supply is determined from shipments of the energy product concerned (e.g., JPN-D06) and import data from trade statistics (e.g., JPN-D14). In countries where shipment data by energy type are unavailable (such as China), it is estimated using output volumes of IP/ISP (e.g., CHN-D05, D06, and D07), assuming a proportional relationship with shipments without adjusting for inventory changes.[13] Supplemented by these estimates, a provisional estimate of the row total of the energy use table ($\hat{E}_i$) is obtained.

Table 5: Data Used for Monthly Estimates (Cont'd)

Country	Data code	Variables	Data Name	Organization
U.S.	D12, D14, and			
	USA-D05	p^E, E	Monthly Energy Review	Energy Information Administration (EIA)
	USA-D06	p^E	U.S. Bioenergy Statistics	U.S Department of Agriculture (USDA)
	USA-D07	p^E	Producer Price Indexes	U.S Bureau of Labor Statistics (BLS)
	USA-D08	p^E	Consumer Price Index	U.S Bureau of Labor Statistics (BLS)
	USA-D09	E	Industrial Production and Capacity Utilization	Federal Reserve Board (FRB)
	USA-D10	E	US Monthly GDP (MGDP) Index	S&P Global
	USA-D11	E	Electricity Power Monthly	Energy Information Administration (EIA)
	USA-D12	V^E, E	International Trade Data	United States Census Bureau
France	D07, D08, D09, D10, D11, D12, D13, D14, and			
	FRA-D03	p^E, E	Conjoncture Mensuelle de l'énergie (Monthly Energy Review)	Ministry of Ecology Transition and Territorial Cohesion
	FRA-D04	p^E	Indice de Prix de Production de l'industrie Française pour le Marché Français (Producer Price Index in Industrial Production Sold in France)	The French National Institute of Statistics and Economic Studies
Germany	D07, D08, D09, D10, D11, D12, D13, D14, and			
	DEU-D05	p^E	Index der Erzeugerpreise Gewerblicher Produkte (Producer Price Index for Industrial Products)	Federal Statistical Office Germany (Destatis)
	DEU-D06	p^E	Index der Einfuhrpreise (Index of Import Prices)	Federal Statistical Office Germany (Destatis)
	DEU-D07	p^E	Gesamtausgabe der Energiedaten (Energy Data: Complete Edition)	Federal Ministry for Economic Affairs and Climate Action (BMWK)
	DEU-D08	V^E, E	Außenhandel (Foreign Trade)	Federal Statistical Office Germany (Destatis)
Italy	D07, D08, D10, D11, D12, D13, D14, and			
	ITA-D03	p^E	Prezzi alla Produzione dell'industria (Industrial Producer Price Index)	The National Institute for Statistics (Istat)
	ITA-D04	p^E, E	Statistiche Energetiche e Minerarie (Energy and Mining Statistics)	Ministry of Environment and Energy Security
	ITA-D05	E	Indice delle Vendite del Commercio al Dettaglio (Index of Retail Trade Sales)	The National Institute for Statistics (Istat)
UK	D07, D11, D12, D14, and			
	GBR-D04	p^E	Producer Price Inflation	Office for National Statistics (ONS)
	GBR-D05	p^E	Consumer Price Inflation	Office for National Statistics (ONS)
	GBR-D06	p^E	Domestic Energy Price Indices	Department for Energy Security and Net Zero
	GBR-D07	p^E	Monthly and Annual Prices of Road Fuels and Petroleum Products	Department for Energy Security and Net Zero
	GBR-D08	E	Index of Production	Office for National Statistics (ONS)
	GBR-D09	E	Index of Services	Office for National Statistics (ONS)
	GBR-D10	E	Energy Trends	Department for Energy Security and Net Zero
	GBR-D11	V^E, E	Trade Data	HM Revenue and Customs

Source: ECM_202403.

The volume balance for each product in each country is maintained according to our evaluation of the data accuracy in one of three assumptions:

a) with $\hat{E}_i$ as a constraint, the estimate is split into j-sectors using $\hat{E}'_{ij}$ and $\hat{E}_{ij}$,

b) with $\hat{E}'_{ij}$ and $\hat{E}_{ij}$ as constraints, $\hat{E}_i$ is defined as $\sum_j(\hat{E}'_{ij} + \hat{E}_{ij})$, and

c) with $\hat{E}_i$ and $\hat{E}_{ij}$ as constraints, the row sum ($\sum_j \hat{E}'_{ij}$) is split into j-sectors using $\hat{E}'_{ij}$.

The assumptions by product and country are shown in Table 6 in Appendix B.

The monthly preliminary estimates of energy prices by product are extended using available energy price statistics for Korea, the U.S., France, Germany, Italy, and the UK.[14] Due to differences in how each data set classifies energy sectors or uses, an effort has been made to closely match the

[13] The changes in energy inventory stocks are considered in our annual benchmark process described in Section 3.3.

[14] The monthly energy statistics of these countries are KOR-D04, USA-D05 and D06, FRA-D03, DEU-D07, ITA-D04, and GBR-D05 in Table 5. However, for products for which these statistics are unavailable or for the most recent months for which the latest estimates are unavailable, expanded estimates were made using PPI and CPI.

ECM sector classification (see Table 2). When such data are unavailable for China, Japan, and Germany, monthly estimates are extrapolated using the most detailed Producer Price Index (PPI) and Consumer Price Index (CPI).[15] There may be significant problems with viewing the available price indices as indicative of average price changes relative to total use by product, including price differences by sector, type of use, and time of day. Because of these problems, the preliminary monthly estimates will be benchmarked on a value basis in the year the SUT/IOT becomes available (see Section 3.3). The PPI and CPI estimates are subject to revision due to changes in the base year, and the ECM is revised retrospectively when the latest data becomes available.[16]

The purpose of the ECM is to evaluate the energy costs relative relationship to output (GDP). In the estimated results presented in Section 4, real PLI represents the relative price between energy use and output, while RUEC signifies the relative value between energy use and output. To incorporate significant trends in these measures, output is typically defined as the seasonally adjusted price and volume of GDP. Consequently, although energy statistics are often not seasonally adjusted, the corresponding energy use prices and volumes in ECM are also seasonally adjusted. For monthly data for which seasonally adjusted series, such as IP/ISP and CPI/PPI, are available, these are used, while those not seasonally adjusted, such as energy statistics, trade statistics, and some IP in China, are seasonally adjusted in ECM using the X-13ARIMA-SEATS (U.S. Census Bureau 2023).

3.3 Annual Benchmark

Annual benchmarking is conducted at several aggregate levels, based on detailed —but preliminary— monthly estimates of ECM's energy use tables developed in Section 3.2. The *World Energy Balances* (D01 in Table 4) published by IEA (2023a) provides the annual benchmark estimates for FEC volumes.[17] For example, the IEA published the latest data for the 2021 estimates in September 2023; the ECM monthly estimates from January to December 2021 are adjusted to the IEA's 2021 estimates by product as an annual total. Based on the revised estimates in December 2021, the recent estimates are revised from January 2022 to the latest date (i.e., December 2023 in ECM_202403). A similar process will be repeated next year when the new data of D01 is available.

After the annual benchmarking on a volume basis, annual benchmarking on a value basis is carried out. This process is similar to the base year estimation described in Section 3.1. Applying the annual benchmarking to the past would allow us to verify the accuracy of the ECM monthly preliminary estimates in Section 3.2 (before annual benchmarks). Some verification works from 2015 are provided for the German cases in Appendix C. Based on historical data, the monthly cost estimates derived from the current methodology provide a reliable approximation, with average error rates of about 2% in volume and 4% in value for Germany. While the accuracy is understandable during periods of lower price volatility, it's important to recognize that the error rate could be even higher during the critical

[15] The PPI and CPI are D10 for EU countries, CHN-D08–D12, JPN-D11–D14, KOR D07–D09, USA-D07–D08, FRA-D04, DEU-D05–06, ITA-D03, GBR D04–D05 in Table 5.

[16] Even in energy products, the impact of base year revision is not small. For example, in the German PPI for natural gas (352227100: Erdgas, bei Abgabe an Wiederverkäufer (Natural gas, when sold to resellers)), the 2015 base PPI shows an increase to 4.5 times from January 2021 to the peak in September 2022 but was revised to 3.6 times in the 2021 base PPI published in March 2024.

[17] In D01, time-series defects sometimes occur due to changes in statistical concepts. In this case, the ECM adjusted the past data to conform as closely as possible to the revised concept.

period in the 2022–2023 RUEC surge.

Finally, deviations from the annual national accounts are also adjusted in real and nominal terms of output. The ECM output measures rely on quarterly GDP estimates in each country. Quarterly GDP estimates do not necessarily coincide with the GDP estimates in the annual national accounts for each country, which are published with a time lag of more than one year. If adjusted quarterly GDP estimates are published with the annual national accounts, the ECM quarterly outputs are replaced, but if it is not published, the ECM output in nominal and real values are benchmarked against the annual GDP.

3.4 Forecasts

In the current ECM, our efforts continue to improve the accuracy of monthly preliminary estimates while continuing to verify them against past annual estimates. The role of forecasts is, therefore, limited. Although fairly simplified, a short-term outlook, which is 6–12 months ahead of the period of the latest observation, is constructed based on the available information in the U.S. EIA's *Short-Term Energy Outlook* (D14 in Table 5) for energy prices and the OECD's *Economic Outlook* (D06 in Table 4) for output growths. In ECM_202403, the forecast values are from January to December 2024 in the monthly estimates. In the estimation results in Section 4, dotted lines represent forecasted values.

4 Estimated Results

4.1 Energy Prices

Figure 1 provides the estimated monthly quality-adjusted and seasonally adjusted price changes of the final energy use at local currency units in each country, with the average price in 2015 set at 1.0. Since late 2020, high fossil fuel prices have significantly impacted the global economy due to the demand recovery following the COVID-19 pandemic. This situation has been further exacerbated by Russia's invasion of Ukraine in February 2022. Subsequently, energy prices in the U.S. started to decrease early in the second quarter of 2022. In contrast, Germany, Italy, and the UK experienced ongoing increases, reaching their peaks that were more than double that of 2015 in 2022. Although prices began to decline after that, they remained at 1.2 to 1.7 times the pre-pandemic levels (average price in 2015–2019) as of December 2023.

The factors contributing to energy price surges vary significantly among countries. Figure 2 provides the product and sector contributions in each country. The main difference between the U.S. and Germany, Italy, and the UK is the notable impact of electricity price spikes and those of natural gas. In the U.S., which relies on the domestic supply of natural gas, price increases were limited from mid-2022 compared to Europe,[18] which was forced to find alternatives to imports from Russia, as shown in Figure 29 in Appendix D.1. These increases were passed on to electricity prices. With the added impact of Germany's nuclear phase-out in 2023, electricity prices remained high. Another notable feature of the U.S. energy price increase is that price increases in the EITE industry have been

[18] Most energy price increases in the U.S. are attributable to petroleum products, with the transportation sector, particularly household gasoline consumption, making the largest contribution on a sectoral basis, as shown in the U.S. left chart of Figure 2.

very limited compared to other countries, as shown in Figure 2, the U.S. right chart. The strength of the U.S. industry supports households' energy consumption burdens through higher incomes.

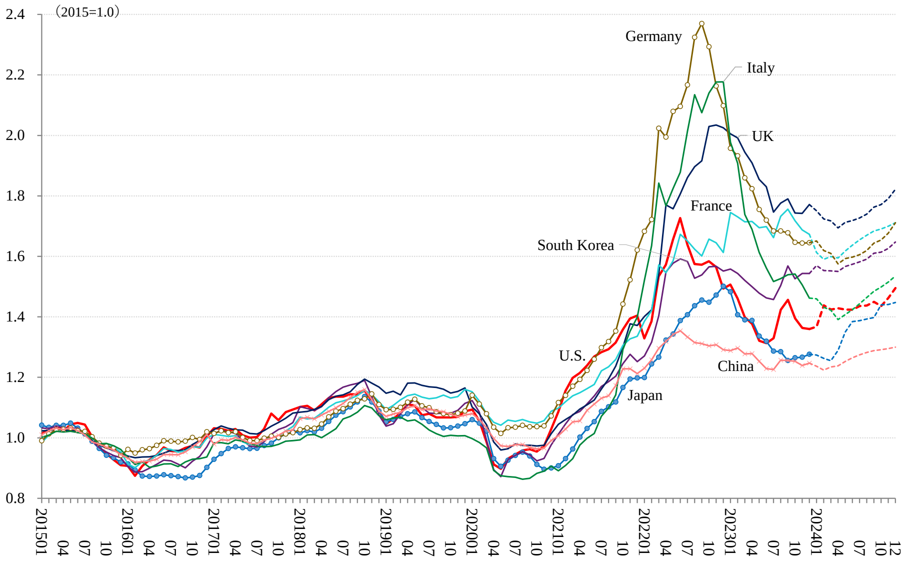

Figure 1: Energy Prices

Unit: Index (average price at local currency unit in 2015=1.0 in each country). Period: January 2015–December 2024. Source: ECM_202403. Notes: The dotted line represents forecasts for January–December 2024. Quality-adjusted energy price (P^E) is defined as the implicit Translog index in Eq. (4). The prices are seasonally adjusted and include taxes and subsidies.

With its heavy reliance on nuclear power, France was expected to be an exception to the post-pandemic energy price surges. Still, in 2022, half of its 56 reactors were temporarily shut down for inspection and repair.[19] To meet demand, Electricite de France (EDF) was forced to purchase electricity on the European market during a period of very high prices, costing the group an estimated EUR 29 billion and contributing to a record net loss (EBITDA) of EUR 17.9 billion for 2022 (MacLachlan 2023).[20] To pass on such price increases, EDF raised electricity prices in stages from the beginning of 2022 until 2023 (see Figure 2, left-hand chart for France). In Figure 2, the contribution of price increases due to electricity is divided into the impact of domestic and imported electricity. Germany and Italy have also seen electricity import prices contribute significantly to energy price increases. This indicates that they are forced to purchase higher-priced electricity during limited renewable energy generation and electricity shortages.

Figure 1 suggests that Asian countries have successfully mitigated energy price increases. However, examining the product-specific contributions in Figure 2 shows little cause for optimism regarding Japan, Korea, and China's ability to curb these price hikes. In essence, the detrimental effects are merely being deferred.

Japan relies primarily on LNG imports, many of which are based on long-term contracts, which has helped mitigate the impact of higher spot prices relative to the European countries. However, it is

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[19] MacLachlan (2023) indicates that inspection and repair outages due to generic stress corrosion cracking (SCC), first discovered in October 2021, reduced the output of EDF's nuclear fleet by 81.7 TWh in 2022.

[20] In 2023, EDF returned to profitability (EUR 10.0 billion) after the French government completed the nationalization of the group, in a year marked by higher nuclear power output in the country, as reported by *The Wall Street Journal* (Orru 2024).

important to note that this energy price comparison is based on prices suppressed by subsidies. The impact of subsidies and governmental interventions to curb energy price surges appears to be substantial. According to Japan's ECM, which breaks down the impact of subsidies on energy prices by product, the analysis shows that in 2022, gasoline subsidies lowered the overall energy price by approximately 5%. Moreover, in 2023, the combined effect of gasoline, electricity, and gas subsidies reduced overall energy prices by about 9%.[21] These subsidies reached about 5 trillion yen (about 36 billion USD) in 2023 and have been criticized. But under Japan's current policy, the subsidies are supposed to last until April 2024, with further extensions being considered.[22] The forecasts shown in Figure 1 by the dotted line tend to increase from April 2024 due to the impact of the increase in the FIT surcharge for renewable energy and the phased subsidy reductions.

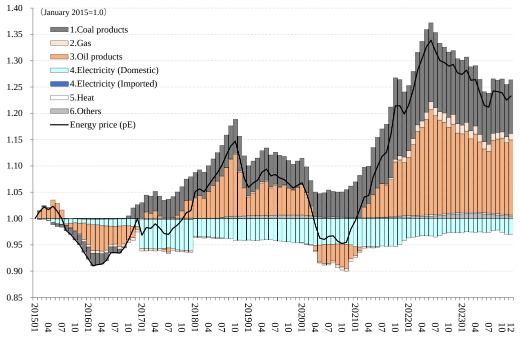
In addition to the impact of subsidies, the decline in electricity prices in Japan, particularly in 2022, includes the effects of insufficient price pass-through due to rising fossil fuel prices. Despite formal market liberalization, government intervention has consistently slowed the escalation of electricity prices. Following the Fukushima Daiichi nuclear power plant accident in 2011, Japan's largest electric power company, Tokyo Electric Power Company (TEPCO), is effectively under government control. Implementing an increase in residential electricity prices in 2022 was particularly difficult, with all major power companies recording large losses in the same year. While such domestic electricity price suppression measures are desirable for electricity consumers, there are concerns that they may jeopardize the stable supply of electricity in the long run.

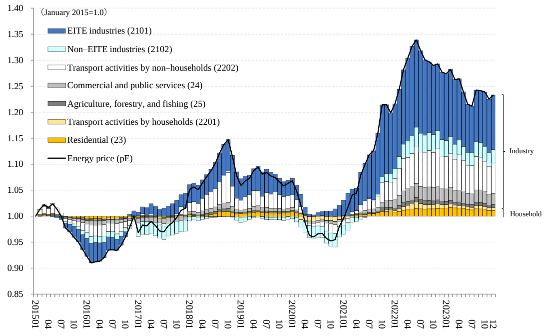
Similar trends are observed in South Korea. The state-owned enterprise, Korea Electric Power Corporation (KEPCO), which monopolizes the entire process of power generation, transmission, and distribution, incurred a substantial deficit of 32.6 trillion won (about 30 billion USD) in 2022 due to the inability to pass on the soaring fuel prices. In 2023, despite a reduction in the deficit through government-approved electricity tariff increases (see Figure 2, South Korea's left chart), KEPCO continued to record a deficit for the third consecutive period from 2021.

China restructured its national power sector, splitting the State Power Corporation into separate entities for power generation and transmission/distribution in late 2002. This resulted in the creation of two transmission and distribution companies and five major power generation companies. Despite the surges in coal and LNG prices, China has effectively contained the rise in electricity prices (Figure 2, China's left chart), making it the only one of the eight industrialized countries with no significant price increases in the post-pandemic period. This achievement can be attributed to the Chinese government's efforts to curb household burdens (see Figure 2, China's right chart) and policies to promote a significant uptake of electric vehicles (EVs). However, substantial concerns exist about the sustainability of the current suppressed electricity prices.

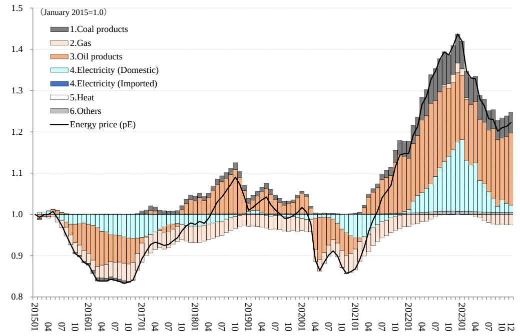
[21] The impact of electricity and gas subsidy addition is shown as the fault from January 2023 in Figure 2, Japan's right chart (sector decomposition).

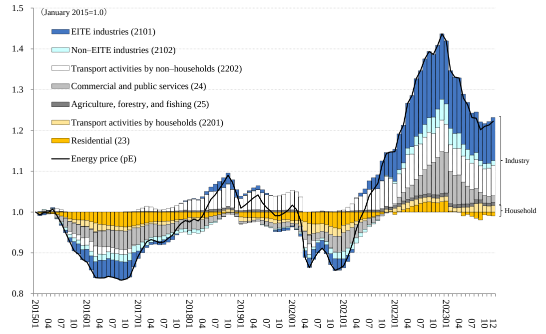
[22] The Japanese government has stated that it will extend subsidies on fuel oil prices beyond May. Figure 1 assumes that subsidies for electricity and gas are halved in May and zero after June and that subsidies for fuel oil are halved from May to September and zero after October.



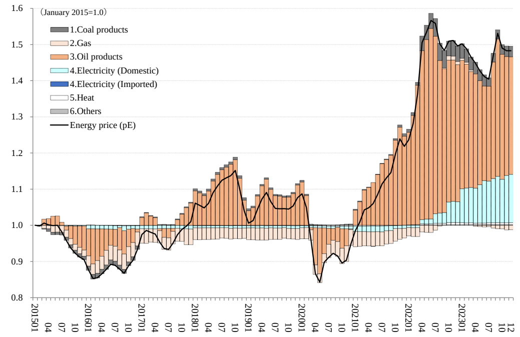


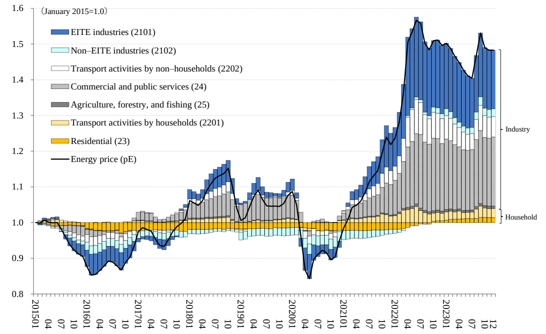
(China) Product decomposition Sector decomposition



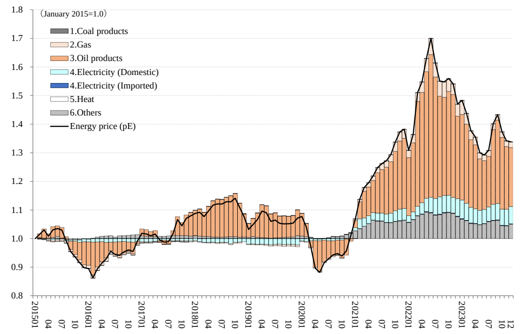


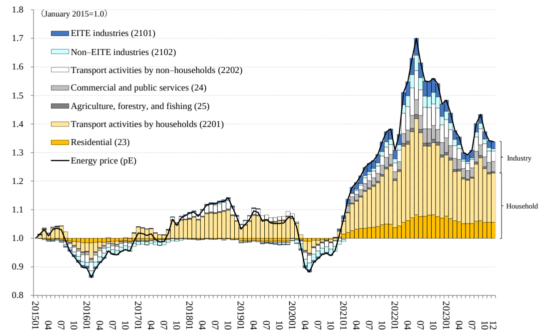
(Japan) Product decomposition Sector decomposition





(South Korea) Product decomposition Sector decomposition

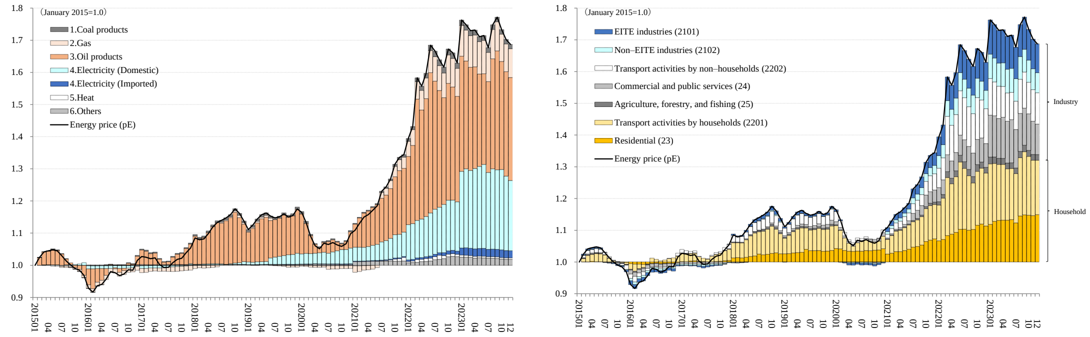




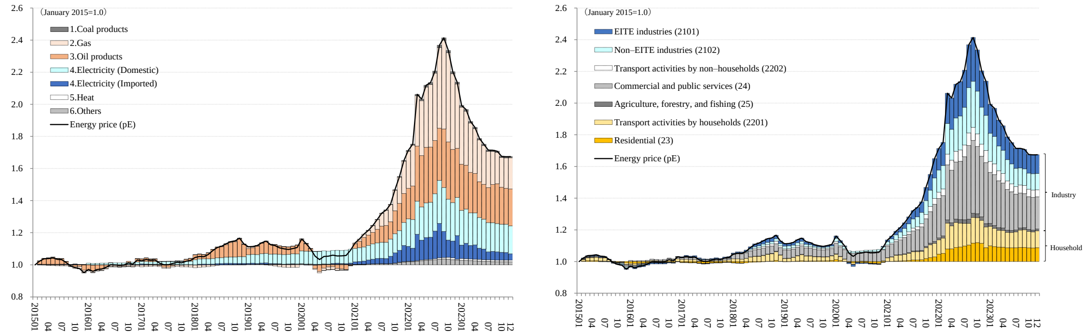
(the U.S.) Product decomposition Sector decomposition

Figure 2: Sources of Energy Price Changes

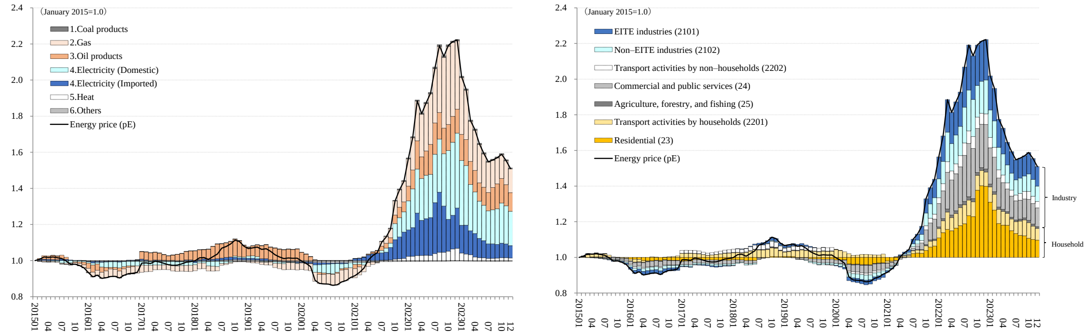
Unit: Index (price at local currency unit in January 2015=1.0 in each country). Period: January 2015–December 2023. Source: ECM_202403. Note: The prices are seasonally adjusted and include taxes and subsidies.



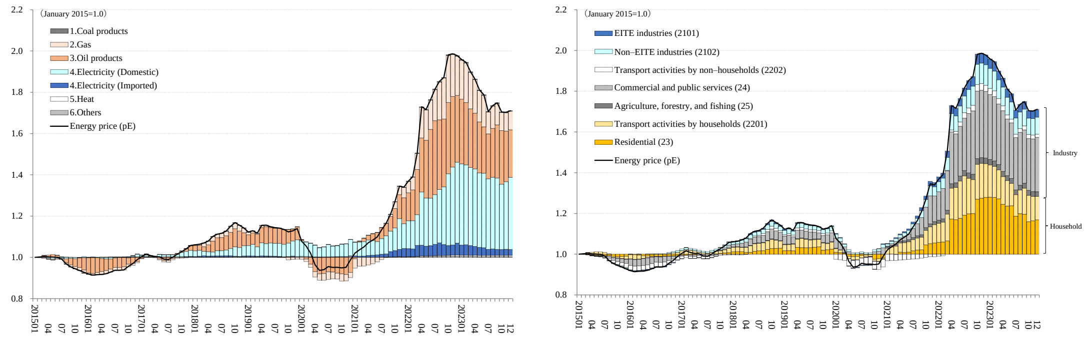
(France) Product decomposition Sector decomposition



(Germany) Product decomposition Sector decomposition



(Italy) Product decomposition Sector decomposition



(the UK) Product decomposition Sector decomposition

Figure 2: Sources of Energy Price Changes (Cont'd)
Unit: Index (prices in each country in January 2015=1.0). Period: January 2015– December 2023. Source: ECM_202403. Note: The prices are seasonally adjusted and include taxes and subsidies.

4.2 Real PLI

As a real energy cost burden relative to output price, this section provides the quarterly estimates of the real PLI, and Section 4.3 discusses the RUEC.[23] The real PLIs for overall final energy use and industry electricity use are shown in Figure 3 and Figure 4, respectively, with the U.S. level set at 1.0 each quarter from 2015 to 2023. The real PLI provides a highly stable trend independent of exchange rate fluctuations and indicates international price differentials in real terms. A notable feature is the extremely advantageous position of the U.S. among major industrialized countries in terms of prices of final energy use (Figure 3) and industry electricity (Figure 4).

While China's nominal PLI for final energy use is comparable to that of the U.S. until the pre-pandemic period, post-pandemic measures to contain price increases have allowed China to achieve similar or lower prices than the U.S. after 2022, shown in Figure 12 for energy use and Figure 13 for industry electricity in Appendix A. However, in real terms, the output prices generated by production in China are much cheaper than in the U.S., as shown in Figure 48 in Appendix D.3. When interpreted as real energy prices, China bears an energy price burden about twice that of the U.S. in Figure 3 as one unit of output still generates only a smaller value. The substantial burden seen in the real PLI indicates that China is also facing difficulties in bearing additional energy costs on its energy transition path.

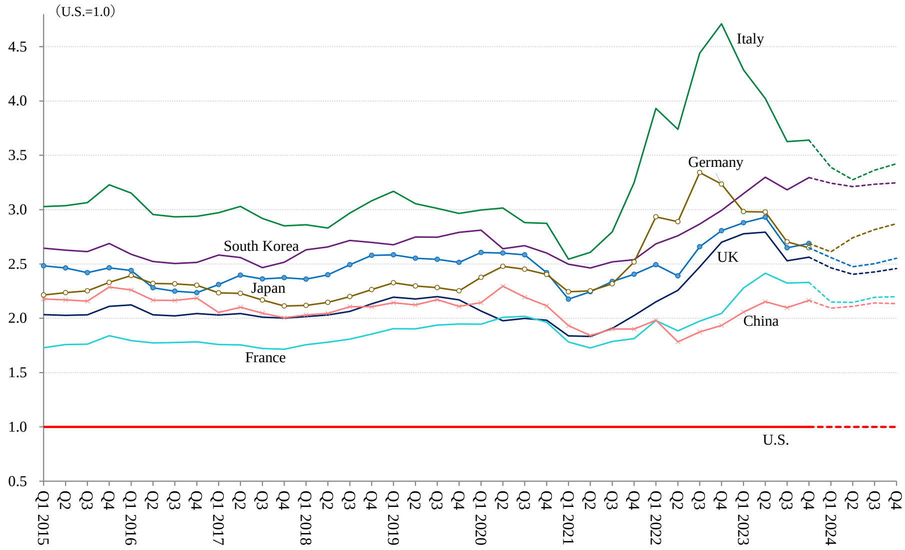


Figure 3: Real PLI for Energy Use

Unit: Index (the U.S. REP in each period=1.0). Period: Q1 2015–Q4 2024. Source: ECM_202403. Notes: The dotted line represents forecasts for Q1–Q4 in 2024. The quality-adjusted price of final energy use is defined in Eq. (4), and the real PLI is defined in Eq. (11). The nominal PLI for final energy use is provided in Figure 12 in Appendix A, and that for output is in Figure 48 in Appendix D.3. The prices are seasonally adjusted and include taxes and subsidies.

The widening gap in real PLI relative to nominal PLI for final energy use is similar in South Korea. The nominal PLI is at the same level as in Japan (Figure 12), but the real PLI is higher, reflecting

[23] The nominal PLI measured monthly in ECM is discussed in Appendix A, with nominal exchange rate fluctuations in our observation period. In addition, the time-series changes in prices and volumes in each country and the nominal PLI by product are provided in Appendix D.1 and D.3, respectively.

a lower nominal PLI for output (Figure 48). Conversely, in the UK, the gap in real PLI for final energy use is smaller than in nominal PLI and the same level as in Japan, due to higher nominal PLI for output, indicating a higher price pass-through capacity.

Figure 4 compares real PLI, focusing on industrial electricity usage.[24] The overall trend mirrors that of Figure 3 for overall final energy use. However, noteworthy changes include the elevated position of the UK, attributed to suppressed electricity prices in Japan during the post-pandemic period. In South Korea and China, particularly in the post-pandemic period in China, industrial electricity price spikes are restrained, and the gap with the U.S. remains largely within a factor of two.

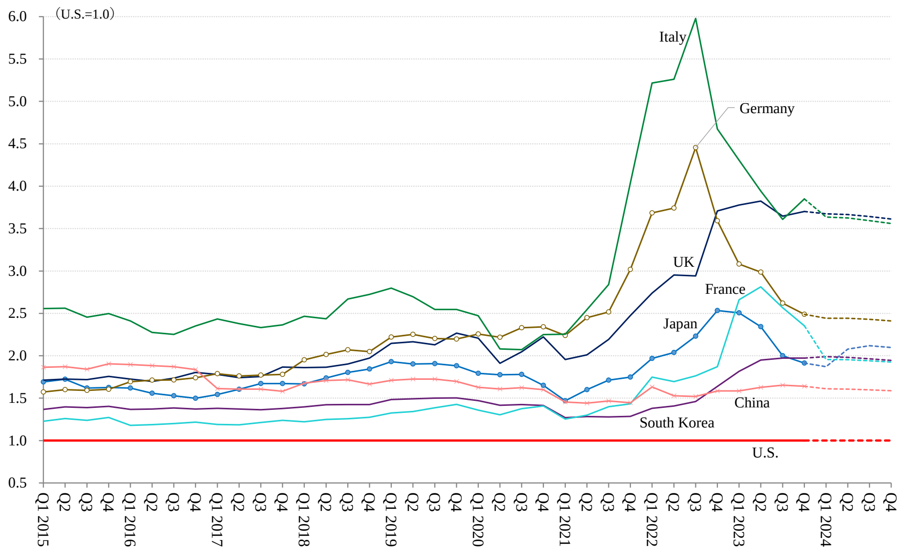


Figure 4: Real PLI for Industry Electricity Use

Unit: Index (the U.S. REP in each period=1.0). Period: Q1 2015–Q4 2024. Source: ECM_202403. Notes: The dotted line represents forecasts for Q1–Q4 in 2024. See footnote 24 for industry definition. Electricity includes 402. Autoproducer electricity. The prices are seasonally adjusted and include taxes and subsidies.

Industry electricity price spikes in Germany were considerably influenced by the domestic post-pandemic correction of the electricity price burden. Figure 5 shows the HI-ratio, which indicates the difference between household and industrial average electricity prices, independently from the exchange rate fluctuations. Countries with a HI-ratio greater than 1.0 indicate that the average household-use electricity price is higher than the average industry electricity price, meaning that the industrial electricity burden is relatively reduced.

Before the pandemic, this was the case in all countries except China and South Korea, as shown in Figure 5. Electricity policies are such that industry is burdened less, and households bear more of the cost, as in Germany, France, and Japan, where the HI ratio was above 1.8. However, after late 2021, the inclined burden by households is unacceptable, reflecting high electricity prices, and the industrial burden is also expanding in these countries.

[24] The industry is defined roughly corresponding to economic statistics in Figure 4 and Figure 5. As shown in Table 2, it is defined as the aggregate sector of 21. Industries, 2202. Transport activities by non-households, 24. Commercial and public services, and 25. Agriculture, forestry, and fishing.

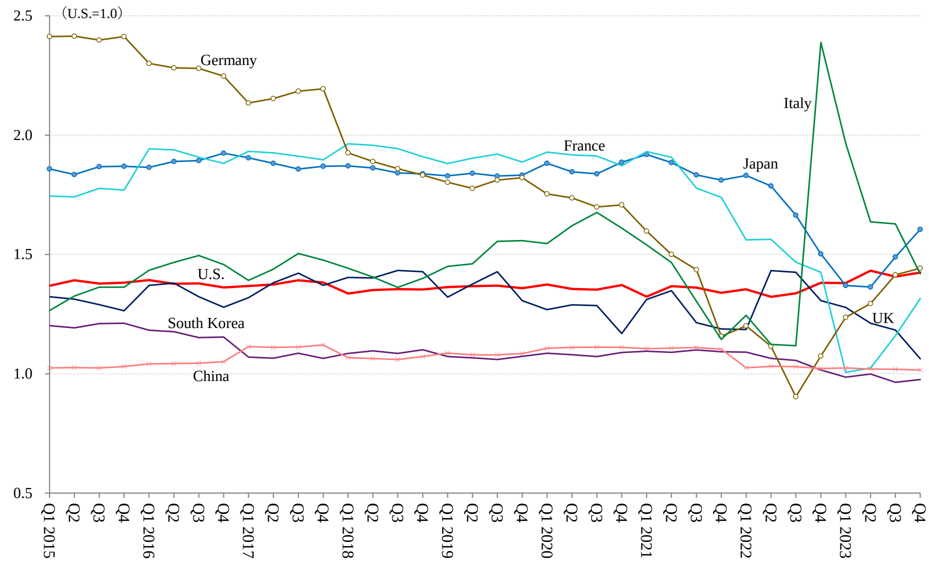


Figure 5: HI-Ratio of Electricity Price

Unit: Index (industry electricity use price in each period=1.0). Period: Q1 2015–Q4 2023. Source: ECM_202403. Notes: See footnote 24 for industry definition. Electricity is defined includes 402. Autoproducer electricity. The prices are seasonally adjusted and include taxes and subsidies.

4.3 RUEC

4.3.1 Post-Pandemic RUEC Surge

The RUEC is the share of the total final energy cost to GDP at current prices, as defined in Eq. (2) in Section 2.1. Figure 6 compares RUEC disparities among eight countries, suggesting different difficulties in advancing the energy transition initiatives. In particular, the post-pandemic RUEC surge and its recovery are illustrated in Figure 7 as a change from the pre-pandemic RUEC average.

Compared to the real PLI in Figure 3 in Section 4.2, the RUEC is a measure of overall cost burden that further reflects differences in industrial structure and (gross) energy productivity across countries. Countries with a higher output share of EITE manufacturing and lower energy productivity have a higher RUEC rank than the real PLI. The first observation from the RUEC comparison, China and South Korea have ranked significantly higher in the pre-pandemic period. The higher RUECs in China and South Korea suggest that their economies are more vulnerable to rising energy prices than other industrialized countries. In other words, even on a long-term energy transition path, it is more difficult to take steps that would raise electricity and energy prices, including the cost of intermittent renewable backup sources.

On the other hand, the UK, which has the lowest GDP share of manufacturing,[25] has reduced its RUEC to a level close to that of the U.S. and France, compared to a higher gap in real PLI in Figure 3. In the UK, despite ranking relatively low in RUEC, navigating the energy transition remains challenging amid macroeconomic and fiscal constraints. Hughes (2024) advocates for a pragmatic approach, stating, "Rather than pretense and muddle, it would be better to extend the period and pace

[25] According to OECD's *Annual National Accounts* and official national accounts in each country, the manufacturing GDP share in the UK is 9.3% in 2022, compared to 10.3% in the U.S., 10.7% in France, 19.4% in Japan, 20.4% in Germany, South Korea in 28.0% in the same period and 27.5% in China in 2021.

of the energy transition to match the resources that can realistically be afforded.”

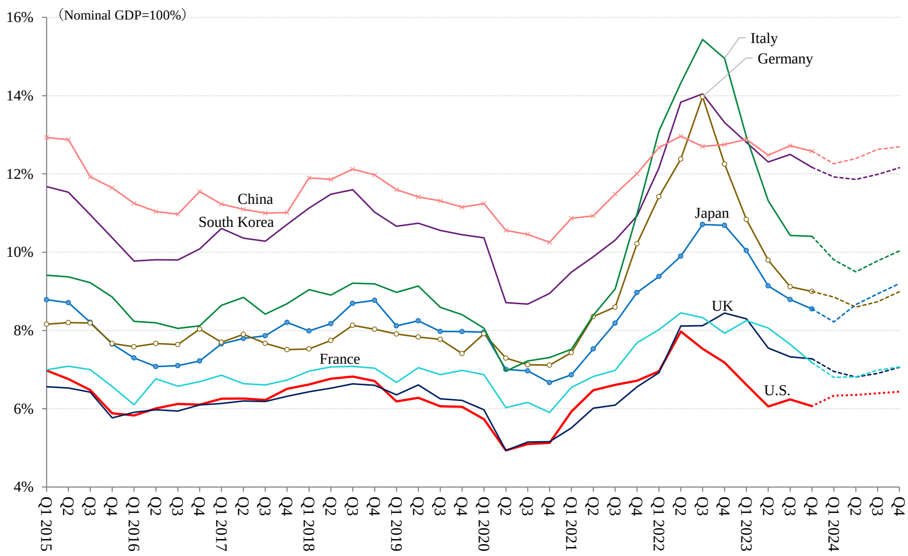


Figure 6: RUEC

Unit: Share (GDP at current market prices in each period=100% in each country). Period: Q1 2015–Q4 2024. Source: ECM_202403. Notes: The dotted line represents forecasts for Q1–Q4 in 2024. The prices are seasonally adjusted and include taxes and subsidies. The volumes are seasonally adjusted.

The second observation from the RUEC comparison is that all countries except China experienced a sharp increase in RUEC between 2021 and 2022 and a recovery from late 2022 to 2023. The numbers after the country name in Figure 7 indicate the peaks of the post-pandemic RUEC surges and the recovered level as of the fourth quarter of 2023 relative to the pre-pandemic level (averages in 2015–2019). The post-pandemic RUEC surge has greatly increased the vulnerability of national economies to energy price volatility. Section 4.3.2. discusses the economic consequences. By the fourth quarter of 2023, RUEC had been successfully contained in all countries to within 5% to 19% of pre-pandemic levels (except for the U.S., which is rather below). The sources of RUEC recovery are discussed in Section 4.3.3.

The third observation from the post-pandemic RUEC surges is the notable increases in Germany and Italy. After the pandemic, Italy experienced a noteworthy rise in RUEC starting in early 2021, surpassing South Korea in the fourth quarter of 2021 and China in the first quarter of 2022, as shown in Figure 6. Meanwhile, Germany outpaced China and approached South Korea’s level in the third quarter of 2022. The RUECs in Germany and Italy peaked in the third quarter of 2022 and gradually declined through the end of 2023. As a comparison of peak levels of RUEC surges, Germany and Italy have risen to 1.79 and 1.76 times the pre-pandemic level, respectively, as shown in Figure 7, while other countries except China are from 1.24 to 1.34 times their pre-pandemic levels.

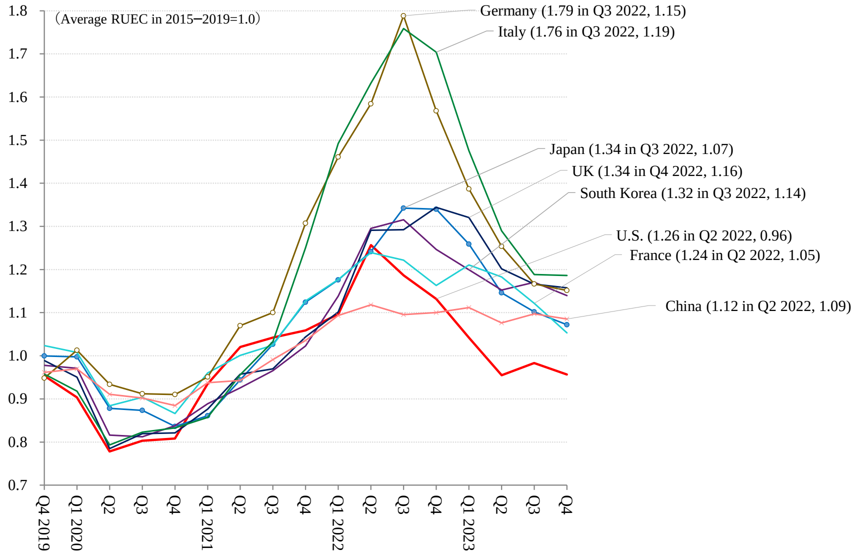


Figure 7: Post-Pandemic RUEC Surge

Unit: Index (average RUEC in 2015–2019=1.0 in each country). Period: Q4 2019–Q4 2023. Source: ECM_202403. Notes: The counts after the country name indicate the peaks in RUEC surges and the recovered level as of Q4 2023 relative to the pre-pandemic level. The prices are seasonally adjusted and include taxes and subsidies. The volumes are seasonally adjusted.

4.3.2 Economic Impacts of RUEC Surge

This section discusses the economic impact of the post-pandemic RUEC surges. Figure 8 compares changes in RUEC and economic growth between the pre-pandemic and the RUEC-surge periods. The x-axis in this figure represents the RUEC, starting from the 2015–2019 average and concluding at the 2022–2023 average. The y-axis depicts economic growth rates, beginning with the average annual growth rate from 2015–2019 and concluding with the growth rate from 2022–2023.

Various factors influence the economic growth rate, so comparing RUEC and economic growth rates provides only a crude tendency. For example, in Germany, Italy, and the UK, the RUEC increased significantly from the pre-pandemic to the post-pandemic (indicated by the arrows to the right in Figure 8). At the same time, the economic growth rates in Germany and the UK experienced a significant decline (pointing downward). Conversely, although RUEC increased significantly in Italy, economic growth only slowed modestly compared to pre-pandemic levels. Italy implemented policies such as a substantial expansion of fiscal spending to bridge the demand-supply gap during the pandemic,[26] making it difficult to discern the impact of RUEC on observed economic growth. It is understood that adverse effects may be deferred to the future.

In Asia, the pronounced slowdown of the Chinese economy against the backdrop of the U.S.-China decoupling was evident, perhaps more so than was reflected in GDP statistics. Despite the limited increase in China's RUEC, growth was trending down. South Korea experienced a slowdown

[26] The exceptionally strong performance of Italy can be largely attributed to the 'super bonus,' a generous tax break for improving the energy efficiency of the housing stock introduced in 2020 under then-Prime Minister Giuseppe Conte. To grasp the magnitude of this measure, *Financial Times* (Romei 2024) indicates that Italian investment, including housing, has surged by 30% compared to pre-pandemic levels (the fourth quarter of 2019), marking the fastest pace of growth since comparable records began in 2000. Eurostat data further illustrates that while construction output in December 2023 experienced a 13% decline in Spain, a 7% decrease in Germany, and remained unchanged in France, Italy witnessed a remarkable 40% increase compared to the same month in 2019. Prime Minister Giorgia Meloni, who has led the country since October 2022, suspended this system completely at the end of 2023.

in growth because of its RUEC surge associated with China's great economic slowdown. While Japan experienced the RUEC surge, the continued negative interest rate policy from January 2016 to March 2024 and the substantial yen depreciation (Figure 14) contributed to the modest recovery of economic growth from pre-pandemic levels.[27] As noted in Section 4.2, the real PLI for final energy use in Asian countries was accompanied by policy measures to contain price increases, particularly in electricity prices. This helped to mitigate the RUEC surge and minimized the short-term impact on economic growth. However, despite their temporary effectiveness, they postponed the fundamental challenge of achieving a more substantial reduction in energy prices.

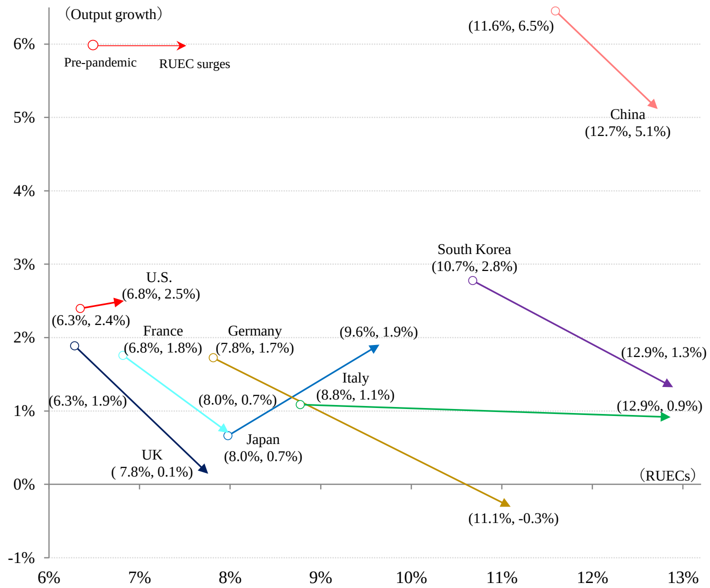


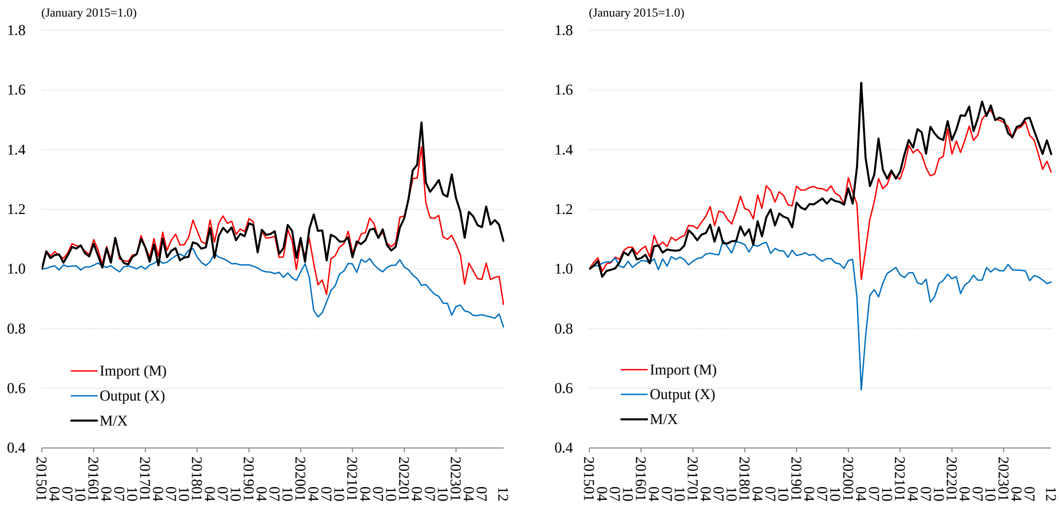
Figure 8: Post-Pandemic RUEC Surge and Economic Growth

Unit: %. Period: Q1 2015–Q4 2023. Sources: ECM_202403 for RUEC and the official annual national accounts for economic growth. Note: The x-axis is the RUEC share, with the starting point being the 2015–2019 average and the end point being the 2022–2023 average; the y-axis is the economic growth rate, with the starting point being the average annual growth rate from 2015 to 2019 and the endpoint being the growth rate from 2022 to 2023.

The impact of RUEC peaks can be observed more directly at the industry level. Here, we focus on Germany, where the RUEC has recorded the most rapid rise in Figure 7. Figure 9 presents the import and output volume indices for EITE and non-EITE manufacturing in Germany.[28] While the non-EITE manufacturing shows a slight decline to levels comparable to pre-pandemic production in the right chart of Figure 9, the EITE manufacturing experiences an accelerated decline in its output with an import spike from early 2022 after the initial recovery from the pandemic outbreak in the left chart of Figure 9. By the end of 2023, this decline led to stagnation, exceeding the level equivalent to the downturn caused by the pandemic outbreak in 2020.

[27] However, it's important to note that Japan's economic growth rate was the lowest among the eight industrialized countries before the pandemic, averaging 0.8% from 2015 to 2019. Nomura (2023, Chapters 2 and 5) indicates that since the 2010s, policies aimed at conserving energy consumption and reducing CO2 emissions have accelerated the hollowing out of production in energy-intensive goods.

[28] Statistisches Bundesamt (2024) discussed the importance of energy-intensive industries in Germany in the context of declining production in those industries, as discussed in this paper. In 2021, these industries required around 77% of the total amount of energy used in industry, generated 17% of GDP at factor costs and employed around 15% of the workforce in industry.



(EITE Manufacturing) (Non-EITE Manufacturing)

Figure 9: Import-Output Ratio in EITE and Non-EITE Manufacturing in Germany
Unit: Index (import and output volumes in January 2015=1.0). Period: January 2015–December 2023. Source: Our computation is based on Statistisches Bundesamt (Destatis) *German National Accounts* (DEU-D02), *Cost Structure Survey in Manufacturing, Mining and Quarrying* (DEU-D03), *Indices of Production in Manufacturing* (D08 in Table 5), *Index of import prices* (DEU-D06), *Foreign Trade* (DEU-D08).

Figure 10 shows the industry contributions in the production volume change in the German EITE manufacturing. The iron and steel manufacturing has hesitated to recover domestic production in the post-pandemic. From the mid-2022 peak of RUEC (Figure 7), chemical manufacturing, a cornerstone of the German economy, has declined its production significantly.[29] This decline can be attributed to the rapid increase in natural gas prices in Germany resulting from the loss of affordable gas supply from Russia,[30] exacerbated by the economic slowdown in China, a key trading partner. The paper and paper products manufacturing also witnessed substantial declines in production from mid-2022. Furthermore, production reductions extended to the glass and glass products and cement manufacturing sectors from mid-2023 onwards.

Germany's RUEC also declined considerably to about 15% above the pre-pandemic level in the fourth quarter of 2023, as shown in Figure 7. However, this has not led to a recovery in EITE manufacturing production by the fourth quarter of 2023 in Figure 10.[31]

[29] The largest chemical company in Germany, BASF, is investing €10 billion to construct a factory in China. According to the news release on January 18 (BASF 2024), BASF plans to power the entire Zhanjiang Verbund site with 100% renewable energy by 2025. The new Verbund site will be BASF's largest investment, with around €10 billion upon completion. It will be operated under the sole responsibility of BASF and will be the company's third-largest Verbund site worldwide, following Ludwigshafen, Germany, and Antwerp, Belgium.

[30] Holger Schmieding, chief economist at Berenberg Bank, asserts, "Germany is paying the price for its energy policies," highlighting that "the perception of Germany's underlying strength may also have contributed to the misguided decisions to exit nuclear energy, ban fracking for natural gas and bet on ample natural gas supplies from Russia." (Mchugh 2023).

[31] Cable (2024) reports that the manufacturing PMI (Hamburg Commercial Bank's preliminary composite Purchasing Managers' Index) dropped to a three-month low of 45.7 in March 2024, down from 46.5 in February. This figure fell well below the expectations outlined in the Reuters poll, which had forecasted an increase to 47.0. Cyrus de la Rubia, chief economist at Hamburg Commercial Bank, said, "If you were hoping for a recovery in the manufacturing sector in the first quarter, it's time to throw in the towel."

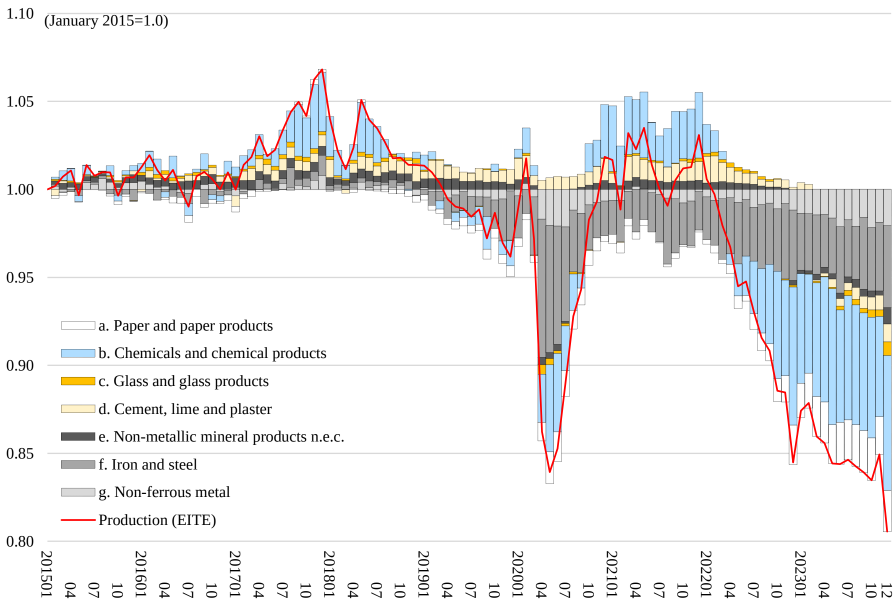


Figure 10: Decline in EITE Manufacturing Output in Germany

Unit: Index (output in January 2015=1.0). Period: January 2015–December 2023. Source: Our computation is based on Statistisches Bundesamt (Destatis) *German National Accounts* (DEU-D02), *Cost Structure Survey in Manufacturing, Mining and Quarrying* (DEU-D03), and *Indices of Production in Manufacturing* (D08 in Table 5). Note: The industry contribution is based on the Translog index using the previous year's output value share.

4.3.3 Sources of RUEC Recovery

RUEC was generally returned to within 19% of pre-pandemic levels by the end of 2023 in Figure 7, but this rebound leaves traces of structural challenges. Figure 11 decomposes the changes in RUEC, with the level in the first quarter of 2015 set as 1.0, into contributions from energy price and volume and output price and volume. A notable aspect is that about half of Japan's RUEC recovery by the fourth quarter of 2023 is attributed to a decrease in energy use. However, this reduction in energy use is not driven by a desirable improvement in energy productivity but rather by an undesirable decrease in output through deindustrialization.[32] Consequently, Japan's real GDP growth has remained stagnant since the pre-pandemic period (see Figure 36 in Appendix D.2), and industrial hollowing out has contributed to deflationary pressures, which have suppressed the rise of the GDP deflator. The reduction effect of RUEC due to the expansion of nominal output has been significantly limited in Japan.

A similar, albeit more moderate than in Japan, downward trend in final energy use is observed in the European countries from 2022 in Figure 11. The cause of the decrease in these countries is more likely due to deindustrialization, as observed in Germany in Section 4.3.2 than to the desired technical energy productivity gains. Further measurements to analyze the causes of the decrease in energy use associated with industrial hollowing out is another future task in the multilateral ECM.

[32] The Japan Business Federation (Keidanren 2023) analyzes three factors that contribute to changes in CO2 emissions by industries. These factors are a) changes in output volumes, b) changes in CO2 emission coefficients (transition to low-carbon energy), and c) changes in energy productivity improvement. The factor decomposition shows that, of the CO2 emission reductions in industries from fiscal 2013 to 2022, a substantial 76 percentage points is attributable to the decline in output (a). The low-carbonization of energy through the expansion of renewable energy and the restart of nuclear power plants (b) accounts for 19 percentage points. In comparison, the effects of energy productivity improvement (c) contribute only five percentage points.

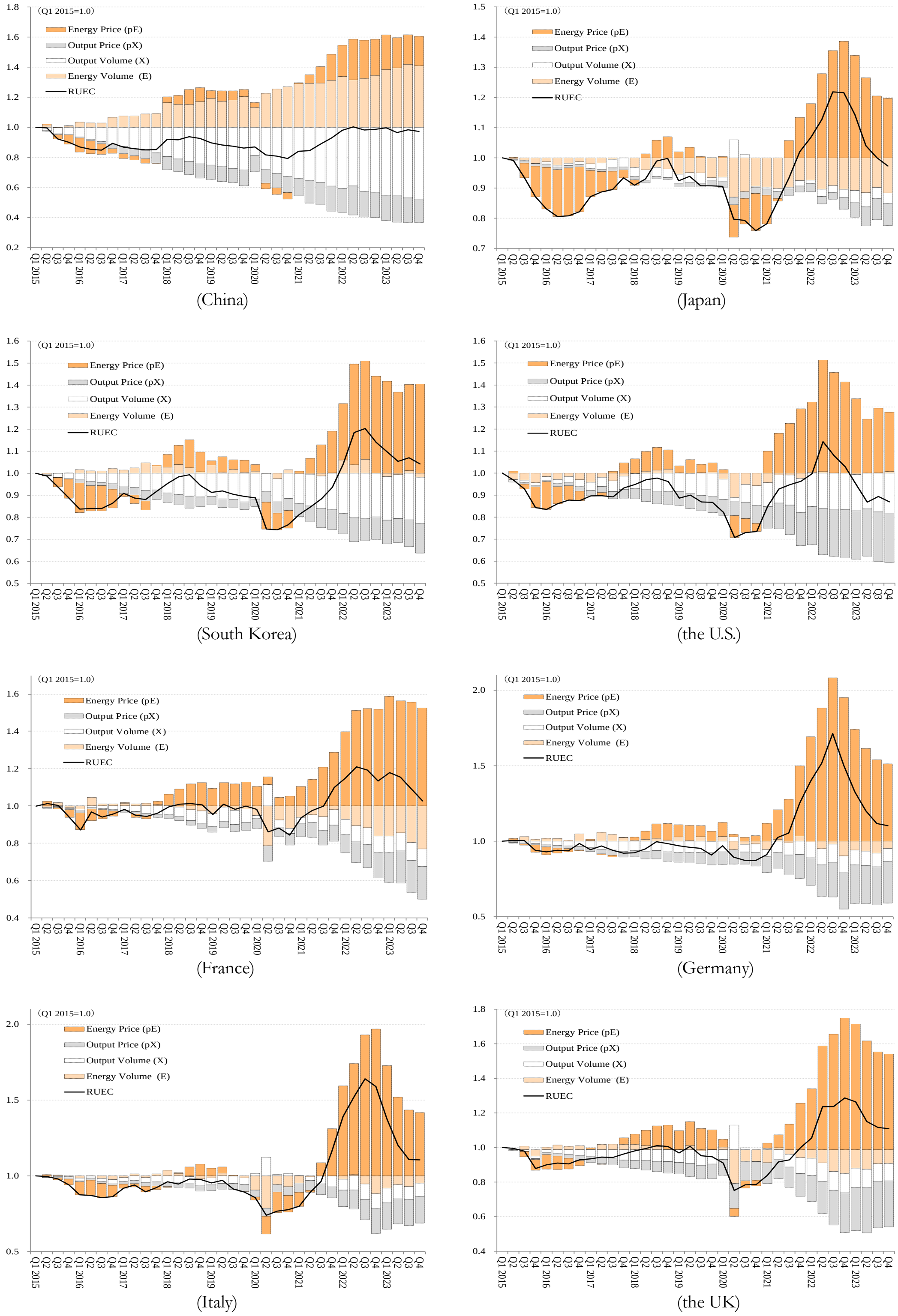


Figure 11: Sources of RUEC Changes

Unit: Index (RUEC in Q1 2015=1.0). Period: Q1 2015–Q4 2023. Source: ECM_202403. Notes: The prices are seasonally adjusted and include taxes and subsidies. The volumes are seasonally adjusted.

5 Conclusion

The situation in each country in the long-term energy transition is fluid, and it is unclear to what extent the public will accept the direct burden of higher energy costs and the indirect burden of stagnating economic growth and incomes. This paper developed the multilateral ECM (Energy Cost Monitoring) to capture high-frequency indicators of the real price and cost differentials for final energy use across eight industrialized countries. This initial estimate serves as a valuable starting point, providing insights into international real energy cost differentials within 1–2 months of the release of quarterly GDP figures for each country. While the estimates will be revised as more statistics become available and the current measurement framework is refined, the findings of this paper can be summarized in the following three points.

Firstly, international comparisons of the real Price Level Index (PLI) for overall final energy use and the Real Unit Energy Cost (RUEC) reveal that China and South Korea exhibit greater vulnerability to energy price fluctuations than other industrialized countries. Policy suppression of nominal energy prices, such as electricity, in both countries is sometimes understood to provide sufficient room to absorb the additional costs of the energy transition. However, higher RUECs indicate that these countries face formidable challenges in advancing the energy transition. Even if other industrialized nations shoulder a significant burden to decrease the CO2 emission intensity of electricity, China and South Korea may be constrained to implementing cost-effective measures. Consequently, this dynamic could promote the growth of energy-intensive industries in these countries, exacerbating carbon leakage.

Second, there were significant increases in real energy prices in Germany, Italy, and the UK after the pandemic. Germany's RUEC spiked to 1.79 times pre-pandemic levels at its peak in the third quarter of 2022, exceeding the high RUEC in China. This rapid increase in RUEC has coincided with a 20% reduction in output in Germany's energy-intensive and trade-exposed (EITE) manufacturing by the fourth quarter of 2023. Although RUEC has gradually declined from the fourth quarter of 2022 to 15% above pre-pandemic levels as of the fourth quarter of 2023, the downward trend in German EITE manufacturing output has not diminished. This sustained production decline poses a long-term challenge to German economic growth, even though the RUEC surge has eased.

Third, in Japan and other Asian countries, explicit energy subsidies and government interventions have effectively mitigated the post-pandemic RUEC surges, contrasting the notable increases in RUEC observed in Germany. However, unlike China and South Korea, where power companies are nationalized, Japan has simultaneously pursued electricity liberalization, posing challenges to investments in new nuclear and thermal power facilities. This has sparked concerns about power supply stability. Instead of the visible trajectory of soaring energy prices and RUECs and the hollowing out of EITE manufacturing seen in Germany, Japan has promoted hollowing out through policy interventions to curtail production in various sectors to reduce CO2 emissions since before the pandemic. The increased risk of a disrupted stable electricity supply casts an even deeper shadow over future production. The current energy transition path cannot be secured without a review of energy policy to ensure that economic growth is not sacrificed.

References

BASF (2024) "A Smart Factory for Smart Materials: BASF Celebrates the Inauguration of its TPU Plant at the Zhanjiang Verbund Site," News release, January 18.

BEIS (2023) "Digest of UK Energy Statistics," Department for Business, Energy & Industrial Strategy, July 27. (accessed on March 8, 2024)

Birol, Fatih (2023) "Where Things Stand in the Global Energy Crisis One Year On," International Energy Agency, February 23.

Cable, Jonathan (2024) "Euro Zone Business Activity Close to Stabilising in March, PMI Survey Shows," *Reuters*, March 21.

EIA (2023) *Annual Energy Outlook 2023*, U.S. Energy Information Administration, March.

European Commission (2014) *Energy Economic Developments in Europe*, European Economy 1, Brussels: European Commission.

Eurostat (2022) "Energy Balances", December.

Hughes, Gordon (2024) "Financing the Energy Transition: Do the Numbers Add Up?" The Global Warming Policy Foundation, Briefing 68, March.

IEA (2020) "World Energy Balances 2020 Edition Database Documentation," International Energy Agency.

IEA (2023a) *World Energy Balances*, International Energy Agency, August.

IEA (2023b) *World Energy Outlook 2023*, International Energy Agency, October.

Keidanren (2023) "Keidanren Carbon Neutral Action Plan: Vision Toward Carbon Neutrality in 2050 and Follow-up Results for FY2023: General Summary (FY2022 Results) [Preliminary]," November 6.

MacLachlan, Ann (2023) "Dealing with Cracking in the French Nuclear Fleet," Nuclear Engineering International, July 5.

Mchugh, David (2023) "Germany Went from Envy of the World to the Worst-Performing Major Developed Economy. What happened?" AP (Associated Press).

Nahm, Jonas M., Scot M. Miller, and Johannes Urpelainen (2022) "G20's US$14-trillion Economic Stimulus Reneges on Emissions Pledges," *Nature*, 603, March 2.

Nomura, Koji (2023) *Energy Productivity and Economic Growth—Experiences of the Japanese Industries, 1955–2019*, Springer.

Nomura, Koji, and Sho Inaba (2023) "Development of High-Frequency Indicators of Real Unit Energy Cost in Japan," *RCGW Discussion Paper,* 68, Research Center of Global Warming, Research Institute of Capital Formation, Development Bank of Japan, March. (in Japanese)

Orru, Mauro (2024) "France's EDF Swings to Profit After Nationalization," *The Wall Street Journal*, February 16.

Romei, Valentina (2024) "Italy: Europe's Unlikely Outperformer," *Financial Times*, March 8.

Statistisches Bundesamt (2024) "Bedeutung der Energieintensiven Industriezweige in Deutschland (Importance of Energy-intensive Industries in Germany)," Bundesministerium des Innern und für Heimat. (in German) (accessed on March 8, 2024)

U.S. Census Bureau (2023) "X-13ARIMA-SEATS Seasonal Adjustment Program," July 10.

Wilkes, Willian (2023) "German Energy Reprieve Too Little, Too Late to Save Factory Jobs," *Bloomberg*, February 4.

World Bank (2020) *Purchasing Power Parities and Real Expenditures of World Economies: Summary of Results and Findings of the 2017 International Comparison Program*, Washington, D.C.: World Bank.

Appendix

A Nominal PLI

This paper considered the disparity in energy prices as real compared to output prices. One of the reasons for doing so is that understanding the trend of disparities based on nominal energy prices becomes difficult due to fluctuations in exchange rates. Figure 12 and Figure 13 present the monthly nominal PLIs for (quality-adjusted) final energy use and industry electricity use, respectively, with the U.S. level set at 1.0 each month from January 2015 to December 2023. These nominal PLIs are comparable to the real PLIs in Figure 3 and Figure 4, respectively, discussed in Section 4.2.

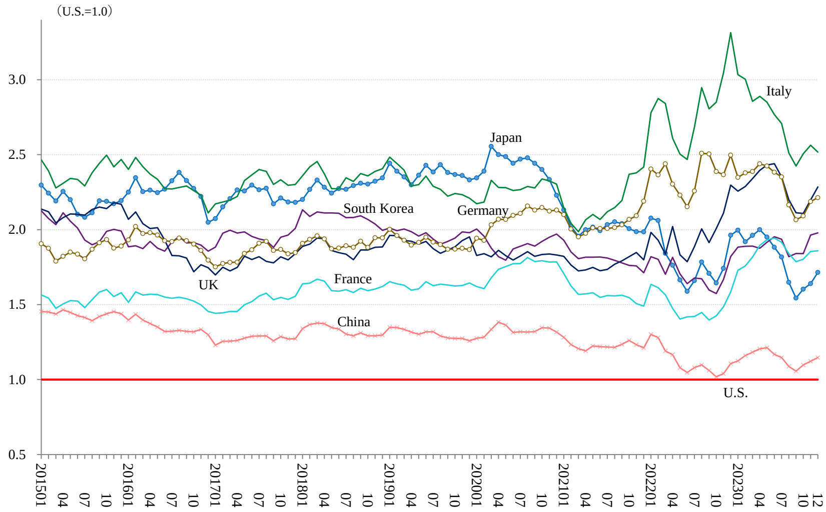


Figure 12: Nominal PLI for Energy Use

Unit: Index (the U.S. prices in each period=1.0). Period: January 2015–December 2023. Source: ECM_202403. Notes: The nominal PLI for final energy use is measured based on Eq. (10). The real PLI for final energy use is provided in Figure 3 in Section 4.2. The nominal PLIs for energy uses for industry and household uses are presented in Figure 38 and Figure 39, respectively, in Appendix D.3. The prices are seasonally adjusted and include taxes and subsidies.

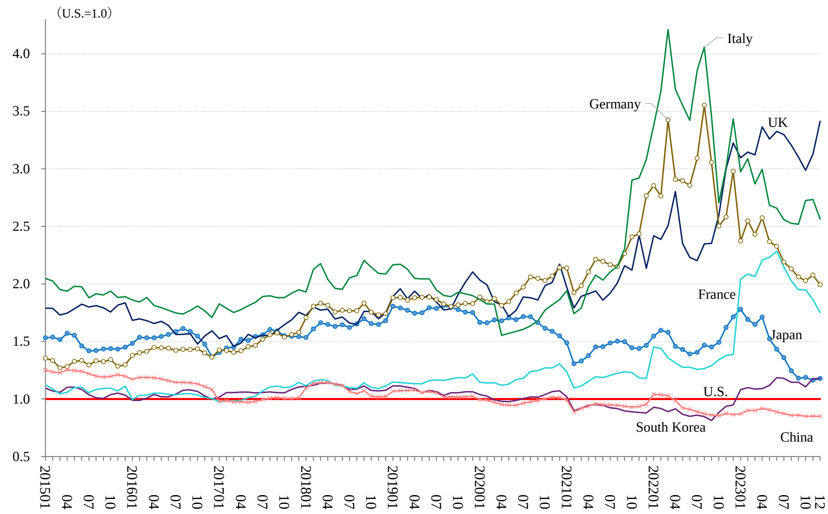


Figure 13: Nominal PLI for Industry Electricity Use

Unit: Index (the U.S. prices in each period=1.0). Period: January 2015–December 2023. Source: ECM_202403. Notes: The nominal PLI is measured based on Eq. (10). Electricity includes 402. Autoproducer electricity. The real PLI for industry electricity is provided in Figure 4 in Section 4.2. The nominal PLIs for electricity for the whole economy and household are presented in Figure 42 and Figure 43, respectively, in Appendix D.3. The prices are seasonally adjusted and include taxes and subsidies.

The nominal PLIs are sensitive to changes in market exchange rates. If the home country's exchange rate depreciates, it leads to an increase in imported fossil fuel prices. However, the increase in domestic electricity prices can remain more moderate, reflecting the stable prices of domestic energy sources such as nuclear and renewables. Therefore, domestic electricity prices are evaluated as becoming cheaper relative to a reference product (measured as the market exchange rate), thus the nominal PLI for electricity decreased. As depicted in Figure 14, the euro experienced a significant depreciation against the US dollar from early 2021 through October 2022. Despite the impact of currency depreciation, the European countries' PLIs for energy use increased by approximately 30% in Figure 12, and the PLIs for industrial electricity use doubled from pre-pandemic levels in Figure 13. It's worth noting that these price increases were underestimated due to the weakened euro.

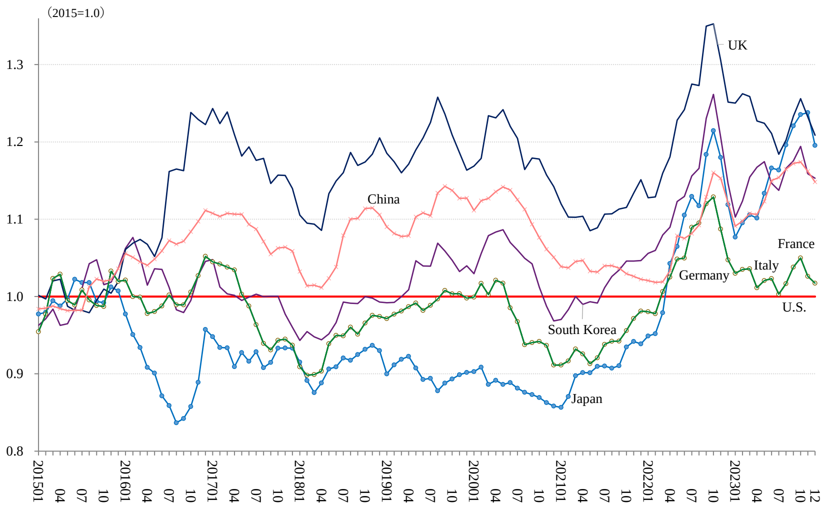


Figure 14: Nominal Exchange Rate

Unit: Index (averages in 2015=1.0 in each country). Period: January 2015–December 2023. Source: IMF *International Financial Statistics*.

During the same period from early 2021 to October 2022, Asian countries also faced similar currency depreciation. From December 2022 to January 2023, while European and Asian countries started to correct their currency's depreciation against the U.S. dollar, Asian countries have again experienced sharp currency depreciation since early 2023, shown in Figure 14. As a result, the nominal PLIs for energy use in Figure 12 and for industry electricity use in Figure 13 have been declining in Asian countries, especially in Japan, against the U.S. These trends differ significantly from real PLIs in Section 4.2. To avoid the complexities arising from exchange rate fluctuations and to account for the price pass-through in output price, a comparison using real PLIs would be more appropriate.

B Volume Balance Assumption

As noted in Section 3.2, the volume balancing by product in each country is based on the following assumptions:

a) with $\hat{E}_i$ as a constraint, the estimate is split into j-sectors using $\hat{E}'_{ij}$ and $\hat{E}_{ij}$,

b) with $\hat{E}'_{ij}$ and $\hat{E}_{ij}$ as constraints, $\hat{E}_i$ is defined as $\sum_j(\hat{E}'_{ij} + \hat{E}_{ij})$, and

c) with $\hat{E}_i$ and $\hat{E}_{ij}$ as constraints, the row sum ($\sum_j \hat{E}'_{ij}$) is split into j-sectors using $\hat{E}'_{ij}$.[33]

Table 6 provides the assumptions by product (domestic production and imports separately) in each country in ECM_202403. When monthly data with balanced domestic supply and demand are available, as in the U.S. EIA (USA-D05 in Table 5), they are evaluated as "ab" in this table. As discussed in Section 3.3, since preliminary figures based on monthly statistics are subject to annual benchmarking corrections, the data accumulation and our examination (as conducted in Appendix C) are to improve the accuracy of future estimates.

Table 6: Balancing Assumptions by Product and Country

	Domestic products								Imported products							
ECM products	CHN	JPN	KOR	USA	FRA	DEU	ITA	GBR	CHN	JPN	KOR	USA	FRA	DEU	ITA	GBR
101. Coal	a	a	c	ab		a	a	a	a	b	c	ab	a	a	a	c
102. Coal coke	a	b	c	a	a	a	a	b	a	b	a	a	a	a	a	c
103. Coal gas	(a+b)/2	b	b	a	a	b	b	a								
104. Peat and peat products																
105. Oil shale and oil sands																
200. Natural gas	a	a	c	ab		a	a	a	a			ab	a	a	a	c
301. Crude,NGL and feedstocks	a	a	b	a	a	b	a	a	a	b	a	a	a	a	a	a
302. Liquefied petroleum gases	a	a	a	ab	a	a	a	a	a	a	c		a	a	a	a
303. Motor gasoline excl. biofuels	a	a	(a+b)/2	ab	(a+b)/2	a	a	b	a	a	a	ab	(a+b)/2	a	a	b
304. Jet fuel	b	a	a	ab	a	a	a	a	a	a		ab	a	a	a	a
305. Kerosene	a	a	a	ab		b	a	a	a	a	b	ab	a	a	a	a
306. Gas/diesel oil	a	a	a	ab	(a+b)/2	a	a	a	a	a	a	ab	a	a	a	a
307. Fuel oil	a	a	c	ab	a	a	a	c	a	a	c	ab	a	a	a	c
308. Naphtha	a	b	c	ab	a	a	a	a	a	b	c	ab	a	a	a	a
309. Lubricants	b	a	a	ab		b	a	a	a	a	a	ab	a	a	b	a
310. Other oil product	a	b	c	ab	(a+b)/2	a	a	c	a	a	a	ab	(a+b)/2	a	a	c
401. Electricity	a	a	c	ab	a	a	a	a	a			ab	a	a	a	a
402. Autoproducer electricity	b	a	b	ab	b	b	b	b								
500. Heat	b	a	(a+b)/2	a	b	a	b	b								
601. Waste	b	b	b	ab	b	b	b	b								
602. Biofuels	b	b	b	ab	b	a	a	a		b	a	ab	a	a	a	a
603. Nuclear	b	b	b	b	b	b		b								
604. Hydro	b	b	b	ab	b	b	b	b								
605. Geothermal	b	b	b	ab	b	b	b	b								
606. Solar photovoltaics	b	b	b	ab	b	b	b	b								
607. Solar thermal	b	b	b	ab	b	b	b	b								
608. Tide, wave and ocean	b		b		b			b								
609. Wind	b	b	b	ab	b	b	b	b								
610. Other sources			b													

Source: ECM_202403. Note: The 'ab' indicates data where domestic supply and demand are balanced, and '(a+b)/2' means that the average of a and b was used as the constraint.

C Verification

ECM_202403 provides monthly estimates from January 2021 to December 2023, while the IEA's *World Energy Balances* (D01 in Table 4), which is the latest currently available, is used as a benchmark to maintain consistency for the estimated annual energy use volume in 2021. The data after January 2022, connected after the 2021 annual benchmark, are called preliminary estimates in the ECM. The accuracy of the ECM measurement framework can be confirmed by applying the methodology used to obtain preliminary estimates to historical benchmark estimates (D01 from 2015 to 2020) and comparing them to subsequently published benchmark estimates (D01 from 2016 to 2021).

Figure 15 shows the errors with the annual volume benchmarks from 2016 to 2021 for the past preliminary estimates for the German case. The numbers in parentheses in the left panel are the mean absolute percentage error (MAPE); the first series is the MAPE for the first year of the preliminary

[33] If the row sum as a residual is negative, the assumption-a is used.

estimates (average from 2016 to 2021), and the second series is the MAPE for the second year of the preliminary estimates (average from 2017 to 2021). Regarding the aggregate FEC, the MAPE for the first year is 1.8%. For the second year, it is 2.6% with a slight expansion, confirming that the preliminary estimates in volumes show a certain degree of accuracy in Germany.

After benchmarking on a volume basis, the ECM conducts a benchmark on a value basis against available economic statistics, i.e., SUT/IOT, for some available products. Figure 16 presents the errors with the annual value benchmarks, Statistisches Bundesamt Use Table (DEU-D01 in Table 4), from 2016 to 2020 in Germany. As shown in the left panel of Figure 16, the MAPE is 3.8% in the first year and 3.7% in the second year, as the sum of the products benchmarked in value terms. This is after benchmarking on a volume basis, which may include the effects of divergence in statistical concepts between energy and economic statistics, along with energy price estimation errors. While the accuracy is understandable during periods of lower price volatility, it's important to recognize that the error could be even higher during the critical period in the 2022–2023 RUEC surge.

There may be significant problems in viewing the available price indexes as an indication of average price changes relative to total use by product, such as price differences by sector and time of day. In addition, the timing of subsidies may not be appropriate, such as when they begin or end. There is a 2–3-year time lag between the release of SUT/IOT (the 2021 estimates of DEU-D01 are scheduled to be released in Summer 2024). To compensate for this, the ECM also adjusts for some specific products, such as household electricity use, using the German national accounts for 2021–2022 (DEU-D02).

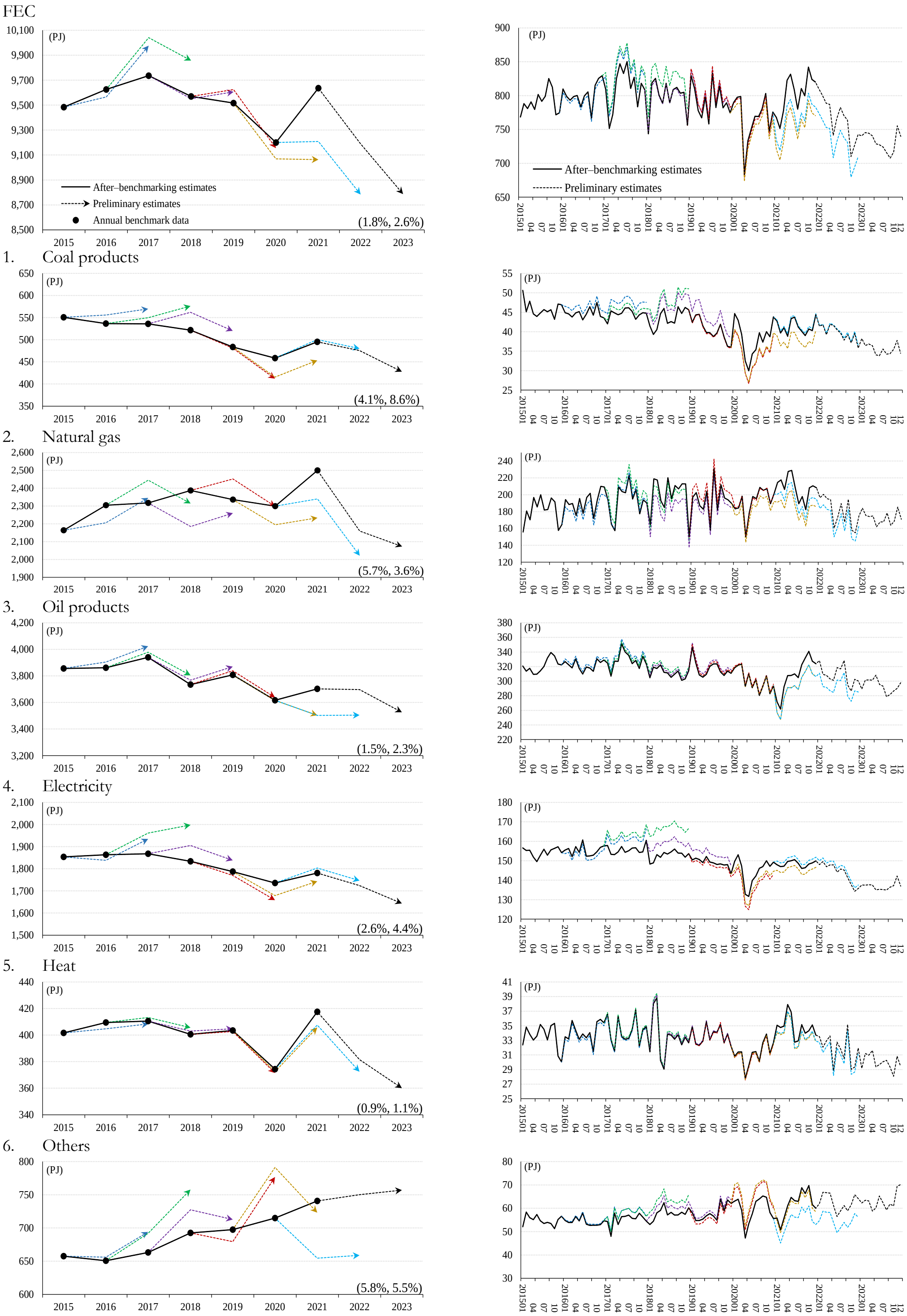


Figure 15: Annual Volume Benchmark in Germany

Unit: PJ. Period: 2015–2023. Source: ECM_202403. Note: The figures in parentheses in the left panel are the mean absolute percentage error (MAPE); the first series is the MAPE for the first year of the preliminary estimates (six-year average of 2016–2021), and the second series is the MAPE for the second year of the preliminary estimates (five-year average of 2017–2021).

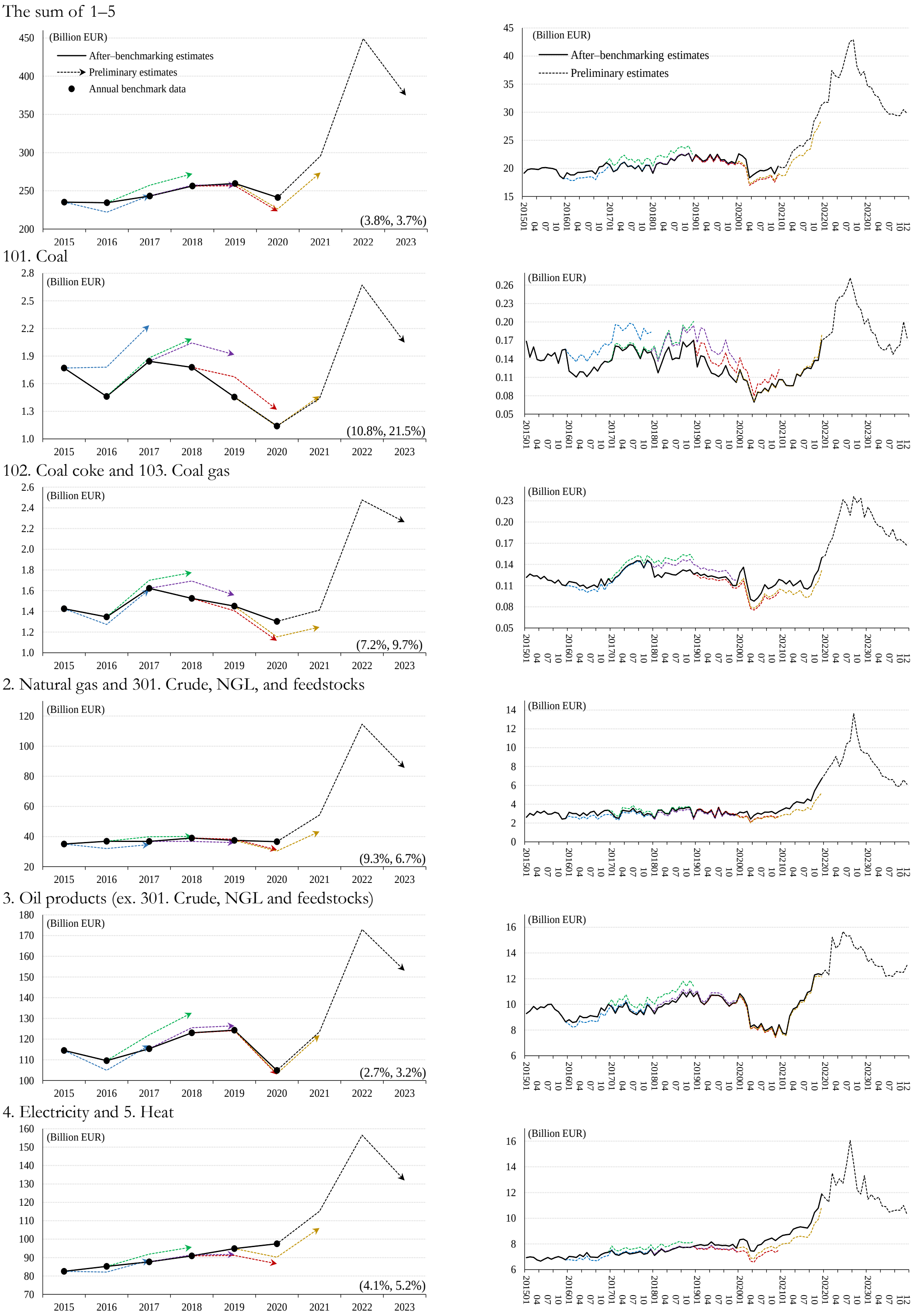


Figure 16: Annual Value Benchmark in Germany

Unit: Billion EUR. Period: 2015–2023. Source: ECM_202403. Note: The figures in parentheses in the left panel are the mean absolute percentage error (MAPE); the first series is the MAPE for the first year of the preliminary estimates (five-year average of 2016–2020), and the second series is the MAPE for the second year of the preliminary estimates (four-year average of 2017–2020).

D Supplementary Figures

D.1 Energy Prices, Volumes, and Costs

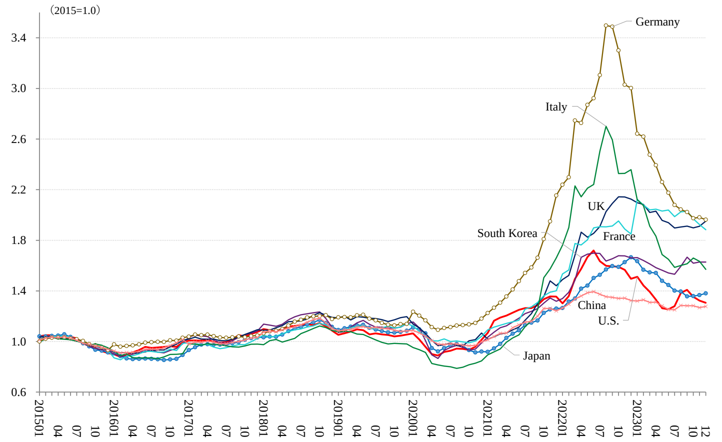


Figure 17: Industry Energy Prices

Unit: Index (price at local currency unit in 2015=1.0 in each country). Period: January 2015–December 2023. Source: ECM_202403. Note: The prices are seasonally adjusted and include taxes and subsidies.

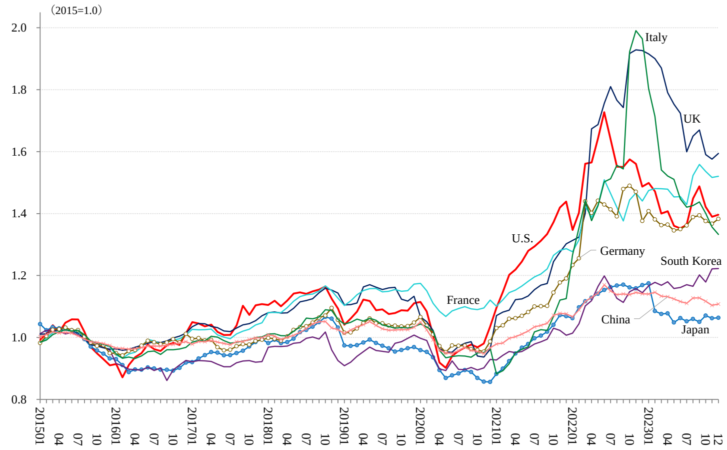


Figure 18: Household Energy Prices

Unit: Index (price at local currency unit in 2015=1.0 in each country). Period: January 2015–December 2023. Source: ECM_202403. Note: The prices are seasonally adjusted and include taxes and subsidies.

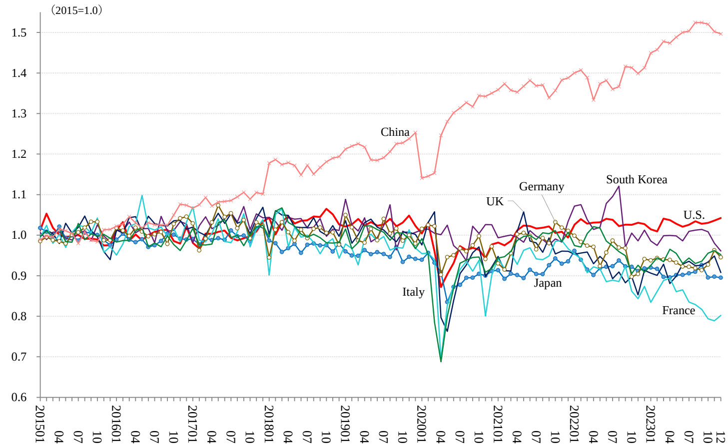


Figure 19: Energy Use Volumes

Unit: Index (quality-adjusted final energy use in 2015 =1.0 in each country). Period: January 2015–December 2023. Source: ECM_202403. Notes: The volume is defined as the Translog index. The volumes are seasonally adjusted.

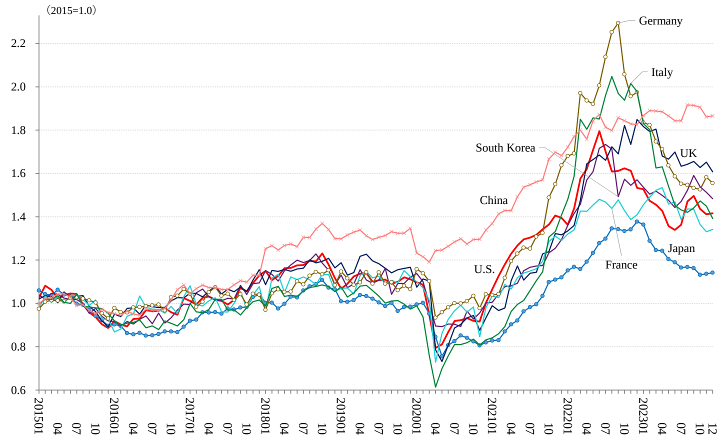


Figure 20: Energy Use Costs

Unit: Index (cost at local currency unit in 2015=1.0 in each country). Period: January 2015–December 2023. Source: ECM_202403.
Note: The costs are seasonally adjusted and include taxes and subsidies.

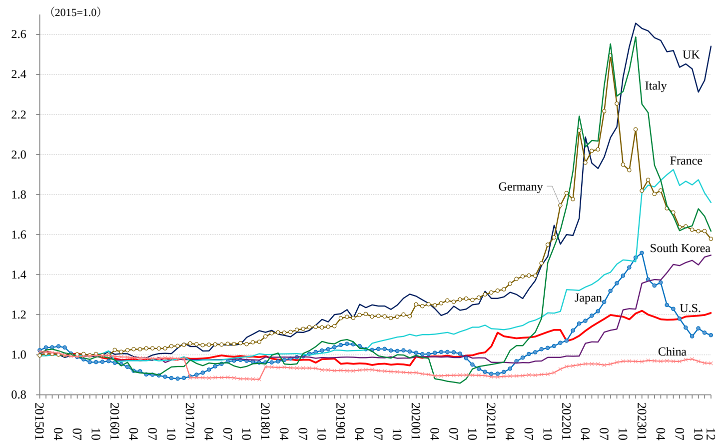


Figure 21: Electricity Prices

Unit: Index (price at local currency unit in 2015=1.0 in each country). Period: January 2015–December 2023. Source: ECM_202403.
Notes: Energy price is defined as the implicit Translog index. The prices are seasonally adjusted and include taxes and subsidies.

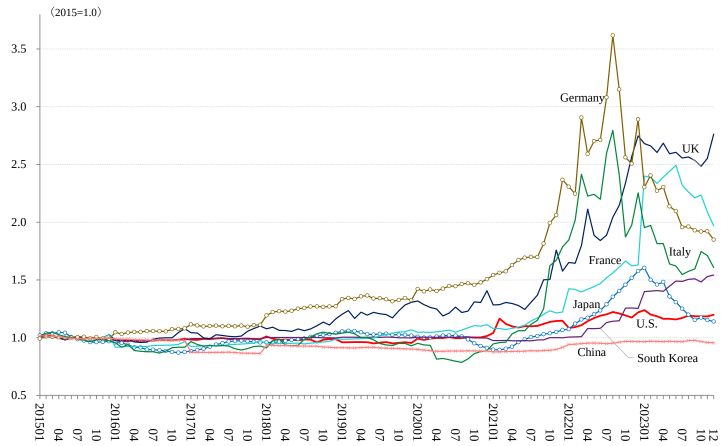


Figure 22: Industry Electricity Prices

Unit: Index (price at local currency unit in 2015=1.0 in each country). Period: January 2015–December 2023. Source: ECM_202403.
Note: The prices are seasonally adjusted and include taxes and subsidies.

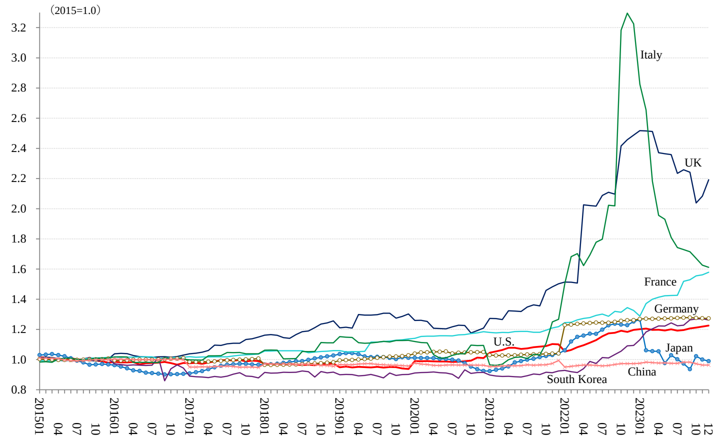


Figure 23: Household Electricity Prices

Unit: Index (price at local currency unit in 2015=1.0 in each country). Period: January 2015–December 2023. Source: ECM_202403. Note: The prices are seasonally adjusted and include taxes and subsidies.

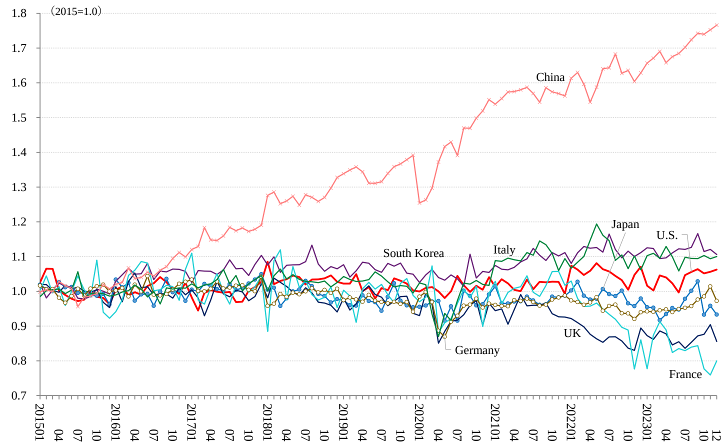


Figure 24: Electricity Use Volumes

Unit: Index (volume in 2015 =1.0 in each country). Period: January 2015–December 2023. Source: ECM_202403. Notes: The volume is defined as the Translog index. The volumes are seasonally adjusted.

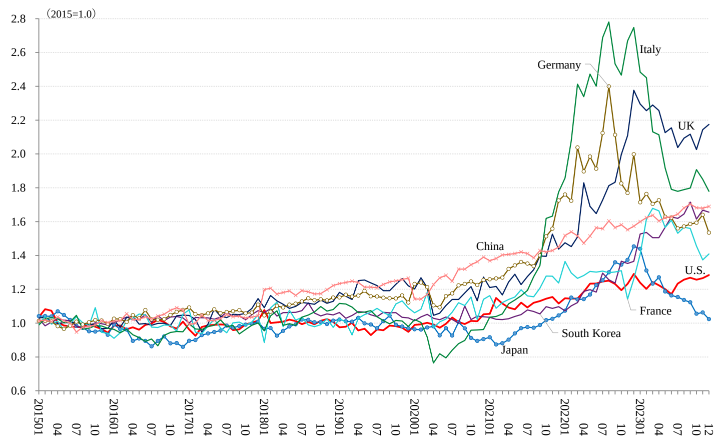


Figure 25: Electricity Use Costs

Unit: Index (cost at local currency unit in 2015=1.0 in each country). Period: January 2015–December 2023. Source: ECM_202403. Note: The prices are seasonally adjusted and include taxes and subsidies.

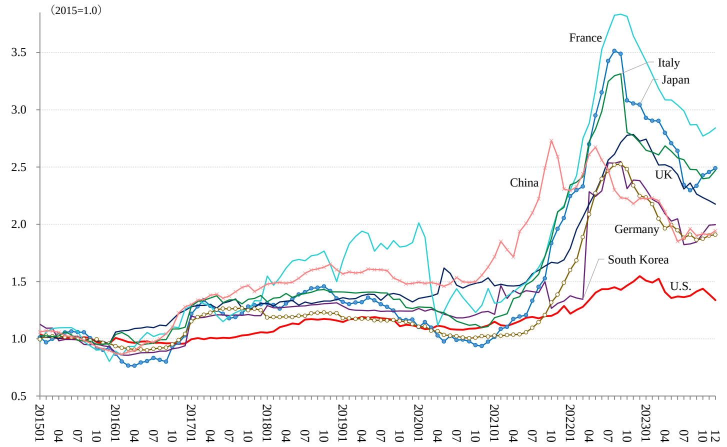


Figure 26: Coal Products Prices

Unit: Index (price at local currency unit in 2015=1.0 in each country). Period: January 2015–December 2023. Source: ECM_202403. Notes: The price is defined as the implicit Translog index. The prices are seasonally adjusted and include taxes and subsidies.

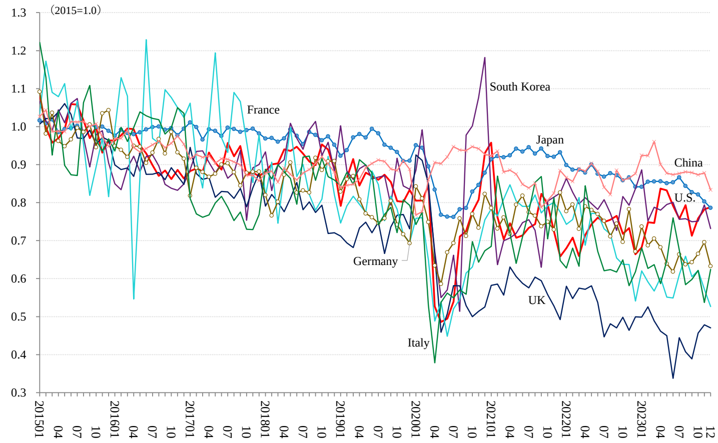


Figure 27: Coal Products Use Volumes

Unit: Index (volume in 2015 =1.0 in each country). Period: January 2015–December 2023. Source: ECM_202403. Notes: The volume is defined as the Translog index. The volumes are seasonally adjusted.

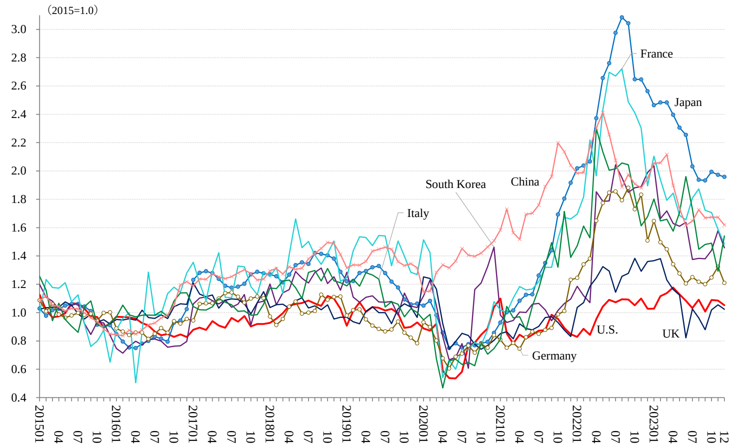


Figure 28: Coal Products Use Costs

Unit: Index (cost at local currency unit in 2015=1.0 in each country). Period: January 2015–December 2023. Source: ECM_202403. Note: The prices are seasonally adjusted and include taxes and subsidies.

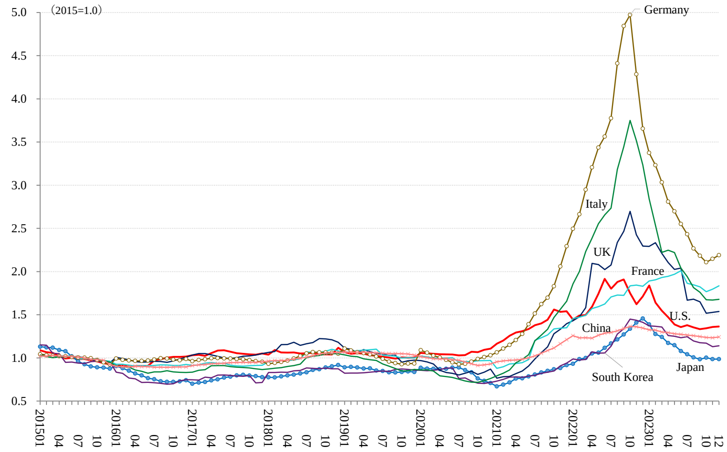


Figure 29: Gas Prices

Unit: Index (price at local currency unit in 2015=1.0 in each country). Period: January 2015–December 2023. Source: ECM_202403. Notes: The price is defined as the implicit Translog index. The prices are seasonally adjusted and include taxes and subsidies.

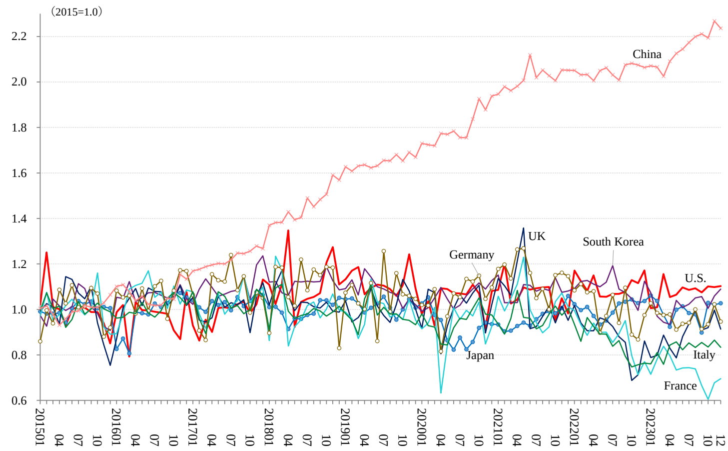


Figure 30: Gas Use Volumes

Unit: Index (volume in 2015 =1.0 in each country). Period: January 2015–December 2023. Source: ECM_202403. Notes: The volume is defined as the Translog index. The volumes are seasonally adjusted.

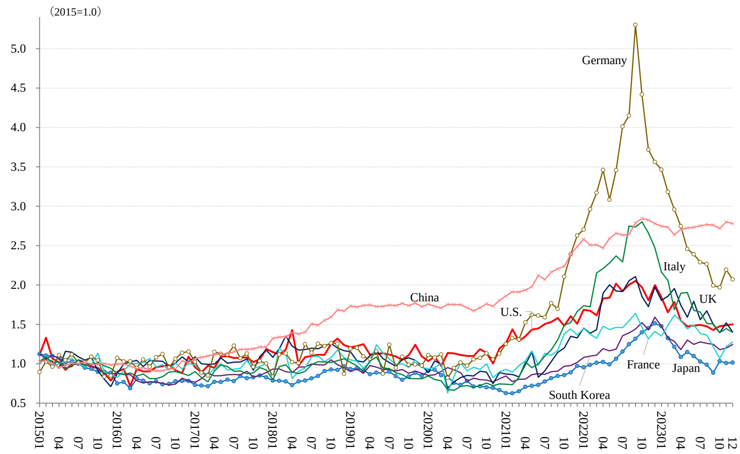


Figure 31: Gas Use Costs

Unit: Index (cost at local currency unit in 2015=1.0 in each country). Period: January 2015–December 2023. Source: ECM_202403. Note: The prices are seasonally adjusted and include taxes and subsidies.

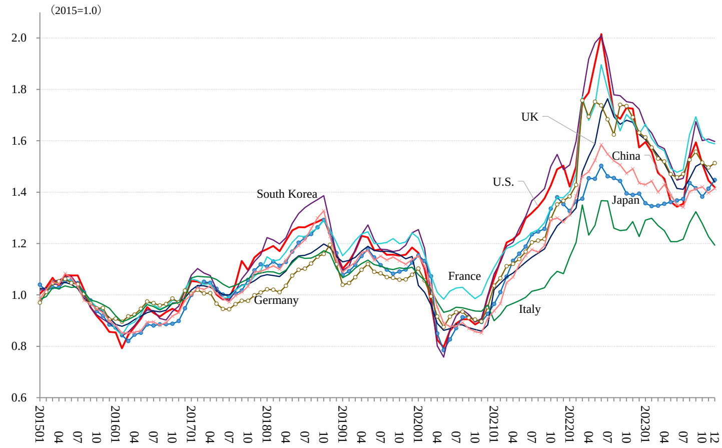


Figure 32: Oil Products Prices

Unit: Index (price at local currency unit in 2015=1.0 in each country). Period: January 2015–December 2023. Source: ECM_202403. Notes: The price is defined as the implicit Translog index. The prices are seasonally adjusted and include taxes and subsidies.

Figure 33: Oil Products Use Volumes

Unit: Index (volume in 2015 =1.0 in each country). Period: January 2015–December 2023. Source: ECM_202403. Notes: The volume is defined as the Translog index. The volumes are seasonally adjusted.

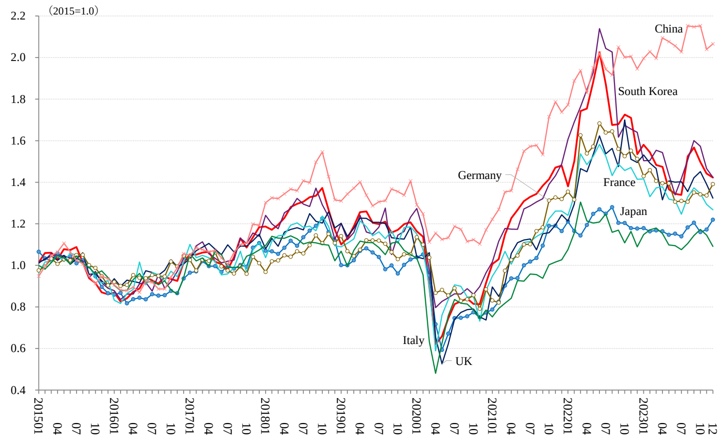


Figure 34: Oil Products Use Costs

Unit: Index (cost at local currency unit in 2015=1.0 in each country). Period: January 2015–December 2023. Source: ECM_202403. Note: The prices are seasonally adjusted and include taxes and subsidies.

D.2 Output Prices, Volumes, and Values

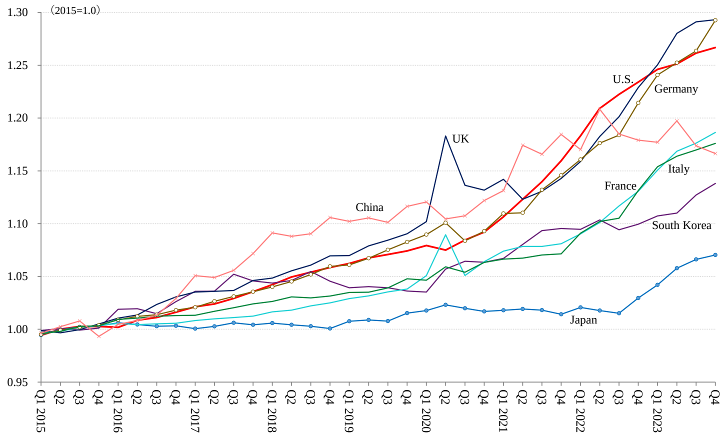


Figure 35: Output Prices

Unit: Index (price at local currency unit in 2015=1.0 in each country). Period: Q1 2015–Q4 2023. Sources: Quarterly national accounts in each country. Note: The prices are seasonally adjusted.

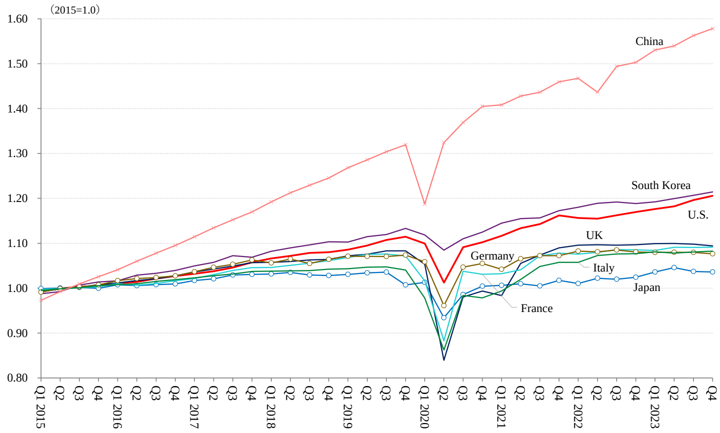


Figure 36: Output Volumes

Unit: Index (volume in 2015 =1.0 in each country). Period: Q1 2015–Q4 2023. Source: Quarterly national accounts in each country. Note: The volumes are seasonally adjusted.

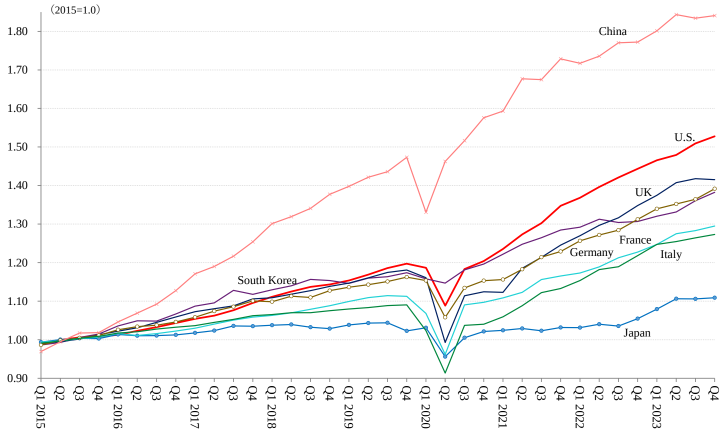


Figure 37: Nominal Outputs

Unit: Index (nominal value at local currency unit in 2015=1.0 in each country). Period: Q1 2015–Q4 2023. Source: Quarterly national accounts in each country. Note: The values are seasonally adjusted.

D.3 PLI

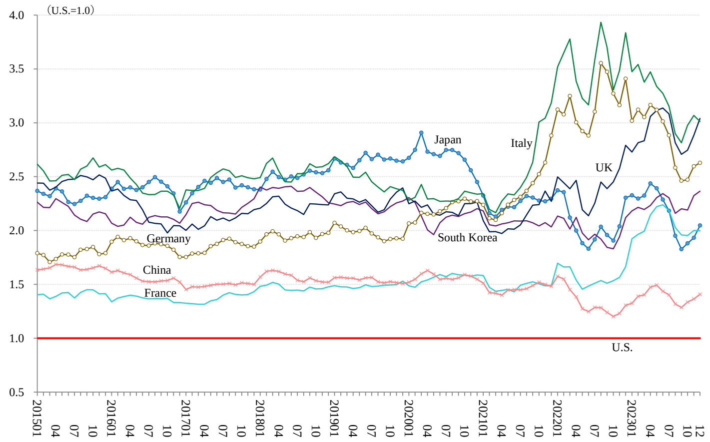


Figure 38: Nominal PLI for Industry Energy Use

Unit: Index (the U.S. price in each period=1.0). Period: January 2015–December 2023. Source: ECM_202403. Notes: The PLI is defined as the implicit Translog price index of the energy prices for each product by industry. The prices are seasonally adjusted and include taxes and subsidies.

Figure 39: Nominal PLI for Household Energy Use

Unit: Index (the U.S. price in each period=1.0). Period: January 2015–December 2023. Source: ECM_202403. Notes: The PLI is defined as the implicit Translog price index of the energy prices for each product by household. The prices are seasonally adjusted and include taxes and subsidies.

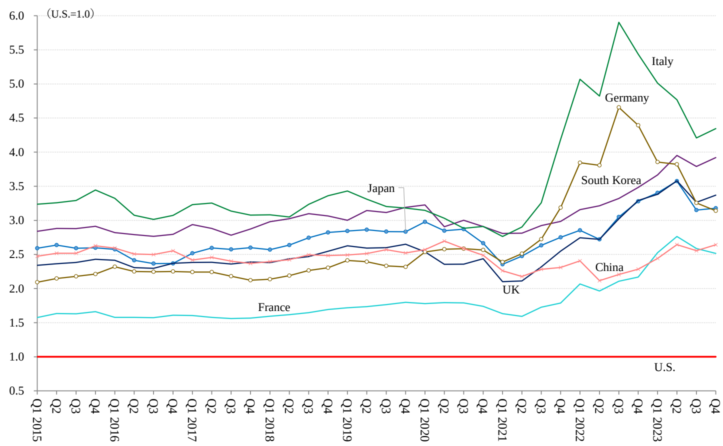


Figure 40: Real PLI for Industry Energy Use

Unit: Index (the U.S. REP in each period=1.0). Period: Q1 2015–Q4 2023. Source: ECM_202403. Notes: The quality-adjusted energy use is defined in Eq. (4), and real PLI is defined in Eq. (11). The prices are seasonally adjusted and include taxes and subsidies.

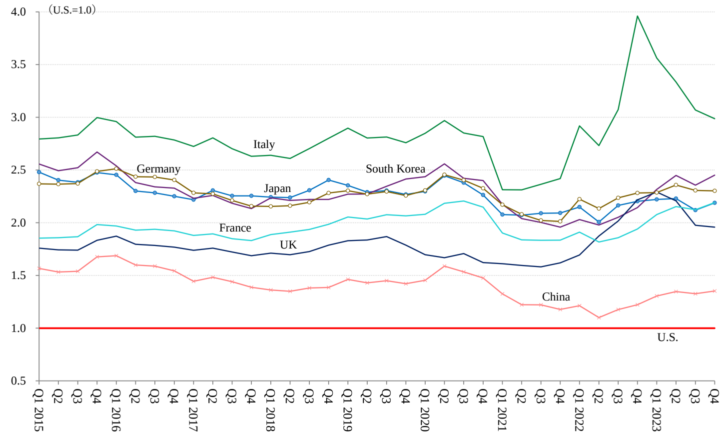


Figure 41: Real PLI for Household Energy Use
Unit: Index (the U.S. REP in each period=1.0). Period: Q1 2015–Q4 2023. Source: ECM_202403. Notes: The quality-adjusted energy use is defined in Eq. (4), and real PLI is defined in Eq. (11). The prices are seasonally adjusted and include taxes and subsidies.

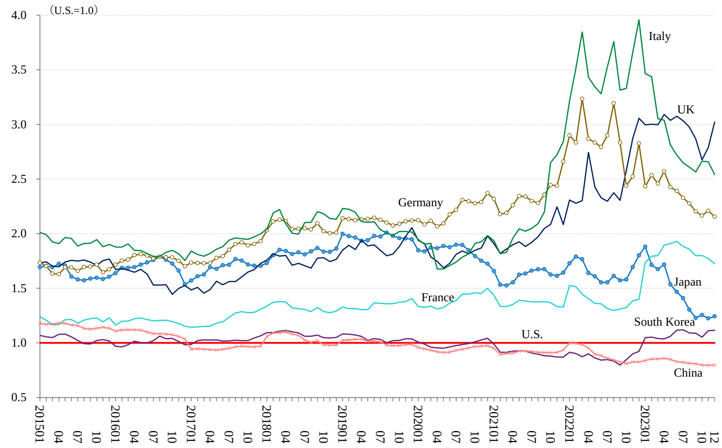


Figure 42: Nominal PLI for Electricity Use
Unit: Index (the U.S. price in each period=1.0). Period: January 2015–December 2023. Source: ECM_202403. Note: The prices are seasonally adjusted and include taxes and subsidies.

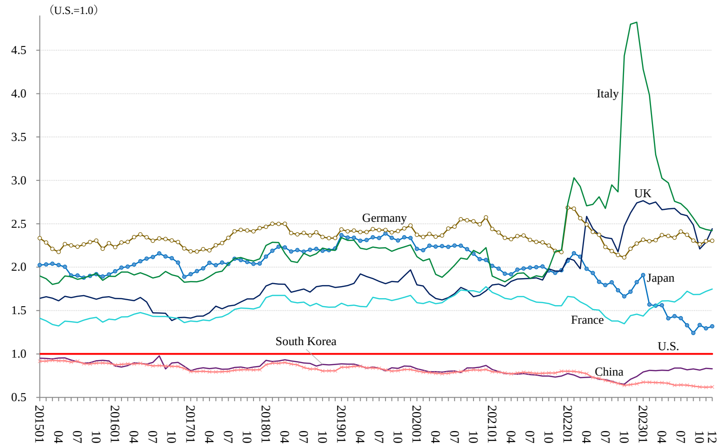


Figure 43: Nominal PLI for Household Electricity Use
Unit: Index (the U.S. price in each period=1.0). Period: January 2015–December 2023. Source: ECM_202403. Notes: The prices are seasonally adjusted and include taxes and subsidies.

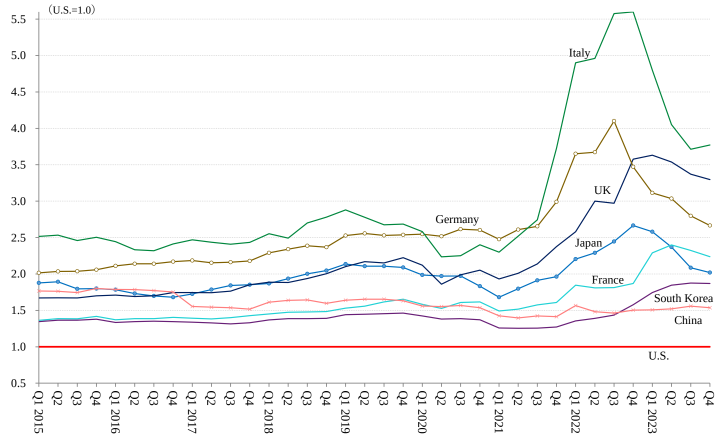


Figure 44: Real PLI for Electricity Use

Unit: Index (the U.S. REP in each period=1.0). Period: Q1 2015–Q4 2023. Source: ECM_202403. Notes: Real PLI is measured based on Eq. (11). The prices are seasonally adjusted and include taxes and subsidies.

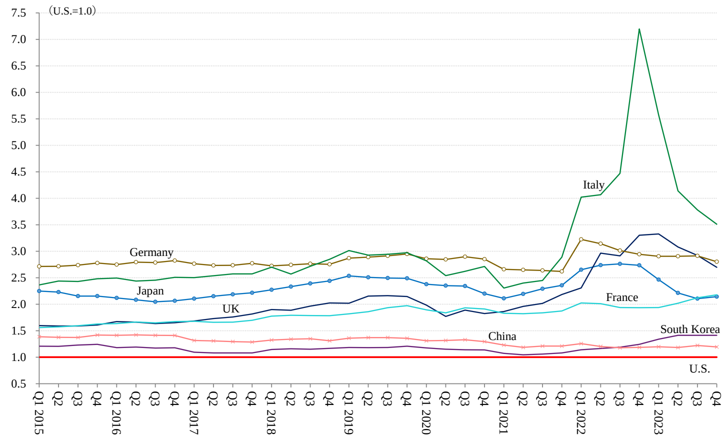


Figure 45: Real PLI for Household Electricity Use

Unit: Index (the U.S. REP in each period=1.0). Period: Q1 2015–Q4 2023. Source: ECM_202403. Notes: The prices are seasonally adjusted and include taxes and subsidies.

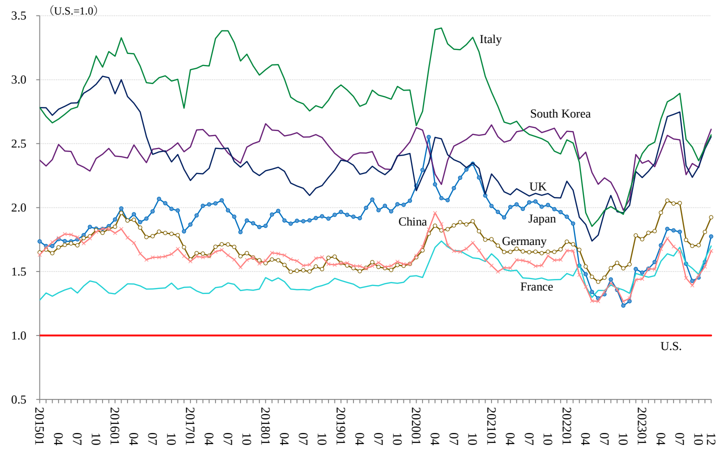


Figure 46: Nominal PLI for Industry Oil Products Use

Unit: Index (the U.S. price in each period=1.0). Period: January 2015–December 2023. Source: ECM_202403. Notes: The PLI is defined as the implicit Translog price index of the energy prices for each product. The prices are seasonally adjusted and include taxes and subsidies.

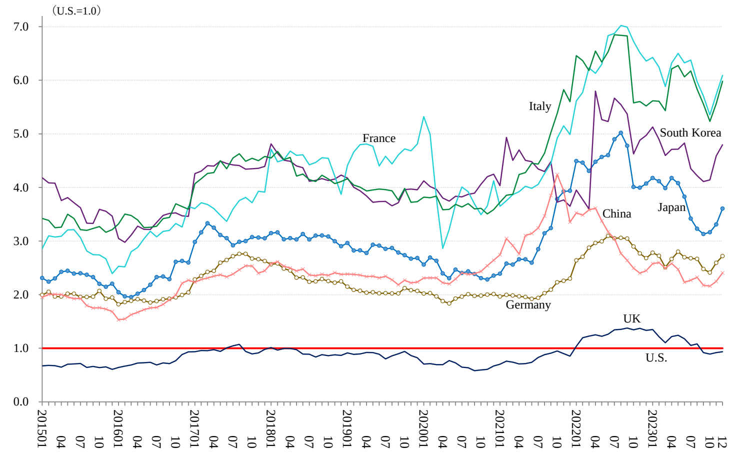


Figure 47: Nominal PLI for Industry Coal Products Use

Unit: Index (the U.S. price in each period=1.0). Period: January 2015–December 2023. Source: ECM_202403. Notes: The PLI for energy use is defined as the implicit Translog price index of the energy prices for each product of FEC. The prices are seasonally adjusted and include taxes and subsidies.

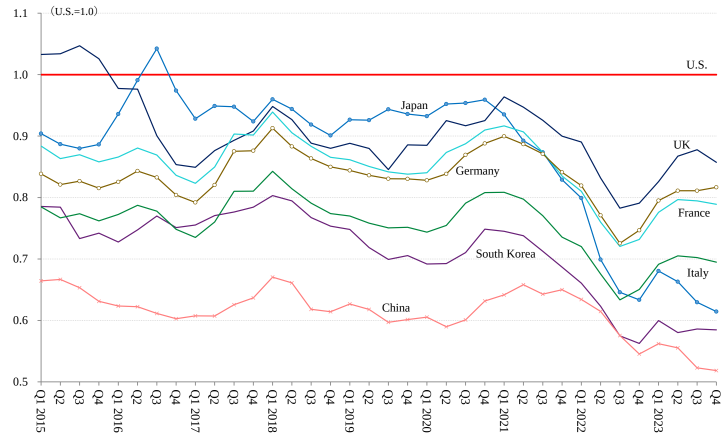


Figure 48: Nominal PLI for Output

Unit: Index (the U.S. price in each period=1.0). Period: Q1 2015–Q4 2023. Sources: the ICP's 2017 round (World Bank 2020) and the extended quarterly estimates in ECM_202403.