Has Japan lost its position as a leader in energy efficiency?

GDP intensity should be utilised while understanding its characteristics

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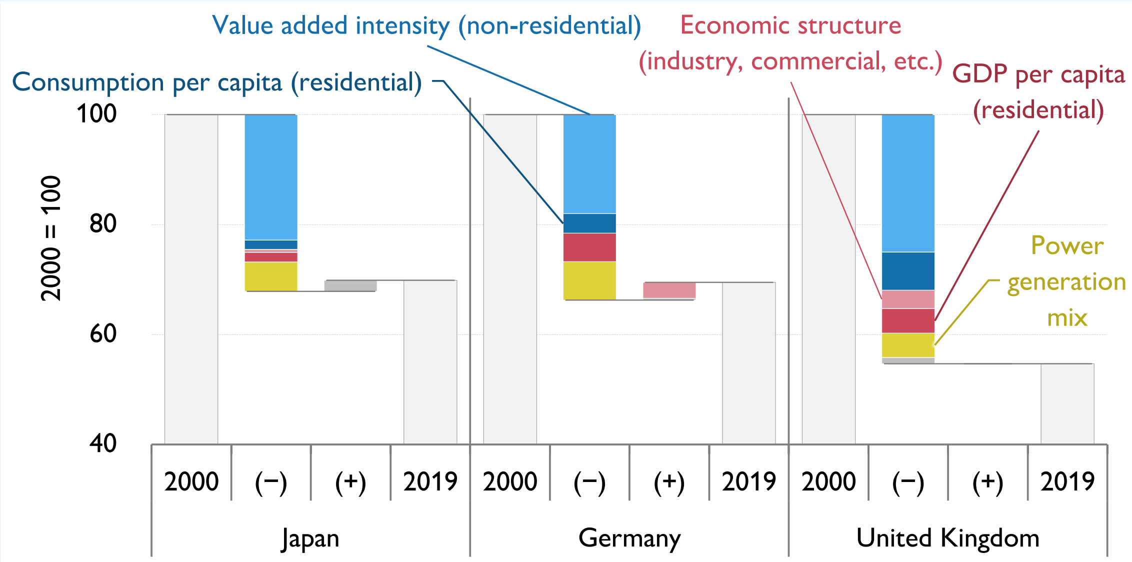
Summary

- Russia's invasion of Ukraine has raised the priority of energy security and heightened interest in energy efficiency. Under these circumstances, some consider that Japan has already lost its position as a leader in energy efficiency. When comparing energy efficiency in terms of GDP intensity – primary energy supply per unit of gross domestic product (GDP) – which is the primary macroscopic indicator of energy efficiency, Japan is falling behind the United Kingdom, Italy and Germany, and is almost on par with France among the Group of Seven (G7) countries.

- However, GDP intensity is greatly affected by the exchange rate. Even if all the constancy in substance, the gap between the United Kingdom as top runner and the other G7 countries, including Japan, will nearly halve, at most, just by switching to the next base year, which is expected to be 2020.

- Caution is also required when measuring progress in energy efficiency based on changes in GDP intensity, as it includes factors that are not inherently relevant to energy efficiency. The most significant contributor to the decrease in GDP intensity over the past two decades has been the reduction in energy consumption per unit of value added, which is a highly effective indicator of energy efficiency. However, GDP per capita, which has little relevance to actual energy efficiency, and changes in the power generation mix related to solar photovoltaics, wind and other primary electricity also made nonnegligible contributions to the decrease, with varying degrees in different countries.

Figure 1 | GDP intensity of primary energy supply and contributions to its changes



Keywords: energy efficiency, GDP intensity, exchange rate, primary electricity, decomposition analysis

An in-depth examination suggests that Japan's energy efficiency is not substantially inferior to that of Europe. However, the fact that Japan's advantage in energy efficiency is no longer immediately obvious may suggest that Japan needs to consider what else it can do as a world leader in energy efficiency, while also wholeheartedly commending Europe's progress.

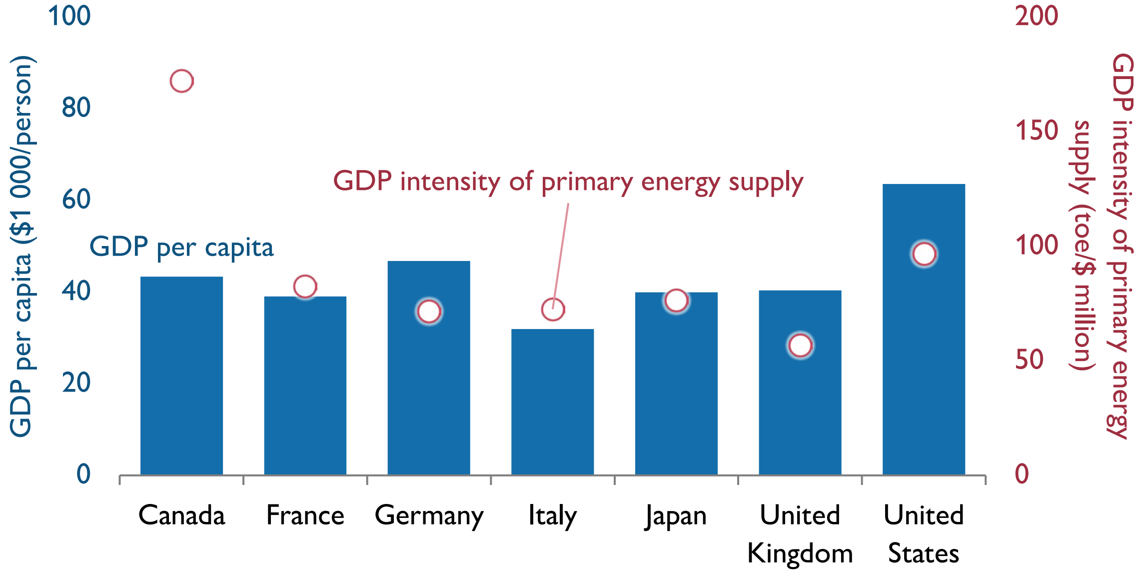
Energy efficiency in the spotlight and its macroscopic indicators

There are high expectations for low-carbon energy sources such as renewable energy and nuclear power as tools to tackle climate change issues. Perhaps because of these enormous expectations, energy efficiency has been slightly sidelined in some countries in Europe and elsewhere. However, Russia's invasion of Ukraine has raised the priority of energy security and supply stability, and attention to energy efficiency, as well as domestic energy sources, is growing. Japan has earned a reputation as a world leader in energy efficiency through its efforts since the oil crises. Energy efficiency has become the main area of Japan's international cooperation in the energy domain, and Japan's advanced energy efficiency technologies have helped maintain the country's presence. Given the recent situation, however, Japan may have already lost its lead in energy efficiency.

One widely known quantitative indicator used to assess the level of energy efficiency is energy consumption per activity (or energy service demand range). In fact, various indicators are used depending on the target and purpose. Examples of a microscopic indicator are car fuel efficiency (= energy consumption per distance travelled) and power generation efficiency (= energy consumption per amount of electricity generated). Indicators with a slightly broader scope include energy consumption per unit of crude steel production and energy efficiency of houses (energy consumption to maintain daily living). At the country level, the gross domestic product (GDP) intensity of primary energy supply is often used as a macroscopic indicator; it uses the GDP as the amount of activity and adopts the primary energy supply, which represents the country's total energy consumption, as the amount of energy consumption. This is an indicator that is both easy to understand and easy to use.

However, the GDP intensity of primary energy supply does not explicitly consider various factors that affect energy efficiency, such as economic and industrial structure, climate and geographic conditions of a country, and population distribution. Therefore, a simple comparison of countries based on this indicator is merely for convenience. In the following sections, we will analyse this energy efficiency indicator, with a focus on factors that deserve more caution in some cases. In doing so, we will examine Germany and the United Kingdom, which are frequently compared with Japan in the context of energy efficiency. A quantitative assessment of other Group of Seven (G7) countries with similar levels of economic development as Japan will also be provided.

Figure 2 | GDP per capita and GDP intensity of primary energy supply [2020]



Source: Calculated based on the IEA "World Energy Balances", the OECD "National Accounts" and the World Bank "World Development Indicators"

Energy efficiency levels are affected by exchange rates

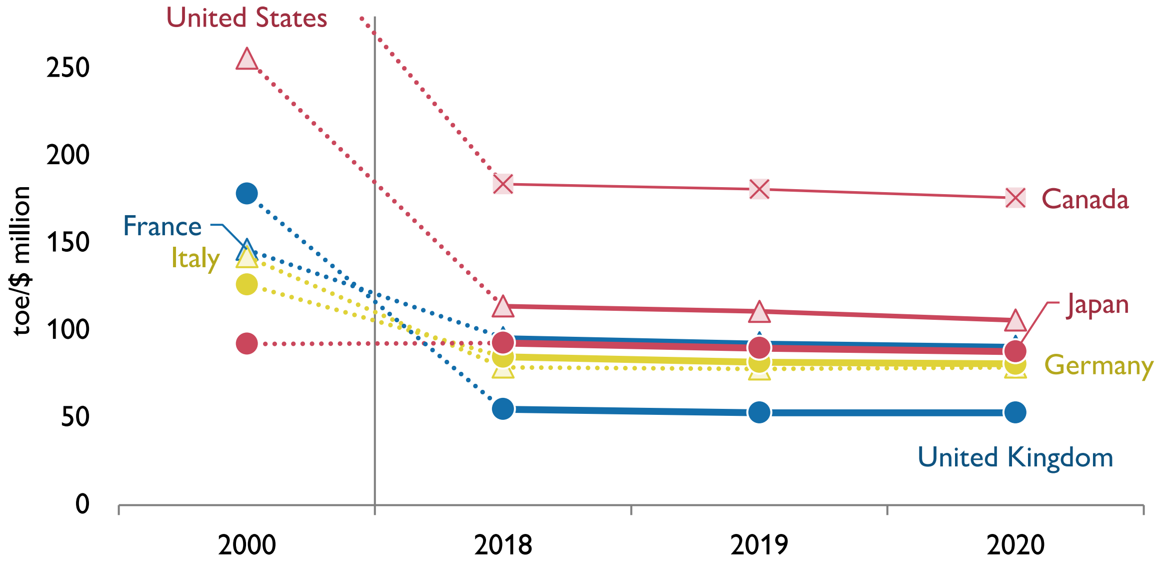
Japan has been one of the world's leaders in terms of the GDP intensity of primary energy supply. Recently, however, some say that Japan is no longer a leader in energy efficiency. For example, according to the International Energy Agency (IEA)'s statistics[1], Japan was the most energy efficient of the G7 in 2000, but in recent years it has not only fallen behind the United Kingdom, Italy and Germany, but is now almost matched by France (Figure 3).

This seems to be one of the reasons for claiming that Japan is no longer a leader in energy efficiency. However, it is important to remember that statistical data must be handled with a full understanding of its background.

When comparing the GDP intensity of primary energy supply between countries, it is necessary to decide what series to use as the denominator GDP. Often, the exchange rate used to convert that GDP into a common currency – usually the United States dollar – becomes a point of debate. For an arbitrary single year comparison, the natural solution may be to use the nominal GDP and the exchange rate for that year. For a multi-year comparison, the real GDP and exchange rate for a predetermined year are usually used. There is no set standard for which year to select for the exchange rate, but the base year for the real GDP is usually adopted. This base year for the real GDP is often a year ending in 5 or 0, such as 2015 or 2020. Therefore, exchange rates also tend to be based on a year ending in 5 or 0.

[1] "Energy Balances of OECD Countries, 1999-2000" and "World Energy Balances 2022", the first editions that carried the data for 2000 and 2020, respectively.

Figure 3 | GDP intensity of primary energy supply



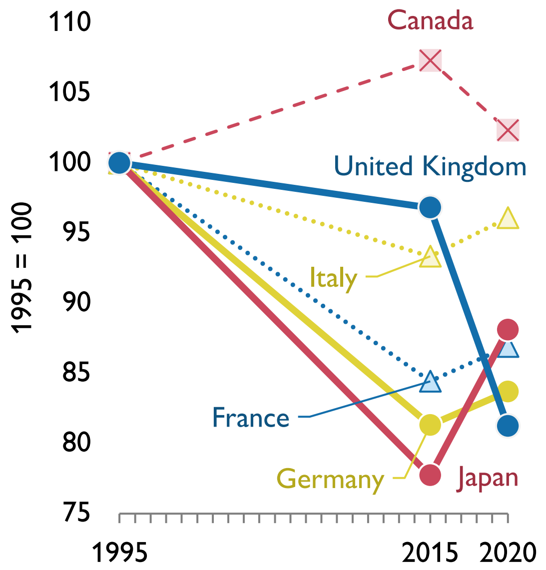
Note: The figures for 2000 are based on 1995 prices; the figures for 2018-2020 are based on 2015 prices.
Source: IEA "Energy Balances of OECD Countries, 1999-2000" and IEA "World Energy Balances 2022"

However, under the floating exchange rate system with free movement of capital and an independent monetary policy, there is no guarantee that the exchange rate for a year ending in 5 or 0 is reasonable in terms of energy economics[2]. For example, the values for the year 2000 in Figure 3 adopt the 1995 exchange rates, while the 2018-2020 values adopt the 2015 exchange rates. During that 20-year period, except for the United States with the United States dollar as its local currency, the currencies of five countries except Canada depreciated against the United States dollar (Figure 4). In other words, while exchange rates serve to enhance the energy efficiency of the five countries for the 1995-based indicator, for the 2015-based indicator, this enhancement effect is cancelled because of the switch in the base year for the exchange rates. The yen was at its highest during that time period in 1995 at ¥94/$ but was at its lowest during the time period at ¥121/$ in 2015; its fluctuation was the largest among the currencies. Therefore, among countries Japan suffered the largest deterioration (increase) of GDP intensity of primary energy supply due to the switch in the base year.

In 2020, the expected next base year for the IEA statistics, the yen and the euro appreciated against the dollar compared with 2015, while the British pound fell in value due to the negative economic impacts of Brexit at the end of January that year. Even if all the constancy in substance, the gap in the GDP intensity of primary energy supply between the United Kingdom as top runner and other countries will almost halve from the current value simply because of the change in the base year[3] (Figure 5).

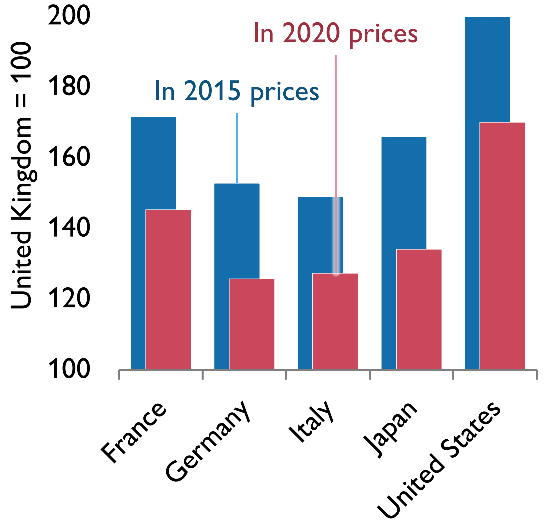
[2] This is the effect of the trilemma of international finance, in which it is impossible to fully achieve stable or fixed exchange rates as a policy target while there is free movement of capital and independence of monetary policy.
[3] When the base year changes, the GDP intensity of primary energy supply does not change at the same rate as the exchange rate because changes in the GDP deflator also come into play.

Figure 4 | Exchange rate against the United States dollar



Note: The larger the value, the stronger the country's currency.
Source: Calculated based on the OECD "National Accounts"

Figure 5 | GDP intensity of primary energy supply [2020]



Source: Calculated based on the IEA "World Energy Balances" and the OECD "National Accounts"

As the exchange rate, it is also possible to use the purchasing power parity (PPP) rate instead of the market rate. For example, Suehiro (2007) suggests using either the market rate or the PPP rate depending on the energy consumption sector[4]. However, adopting the PPP rate is not a perfect solution either and can give rise to new problems[5]. In any case, there is a risk in discussing the superiority or inferiority of energy efficiency based on the GDP intensity of primary energy supply without considering the impact of exchange rates.

Box 1 | Was it only the strong pound that made the United Kingdom the top runner?

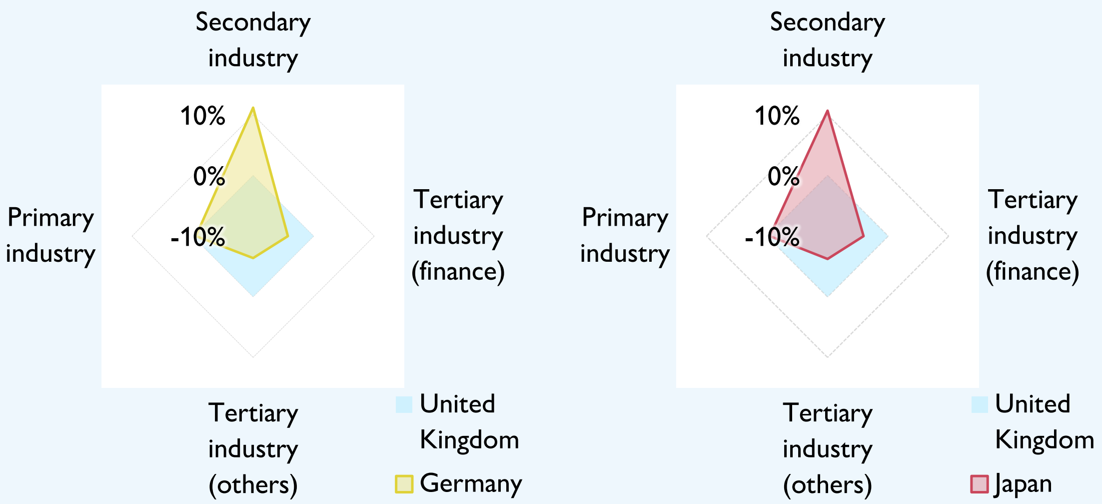
It is not only energy efficiency in the narrow sense that defines the GDP intensity of primary energy supply. As described above, the exchange rate is a major factor when making international comparisons. Climate conditions also affect the GDP intensity through the amount of energy consumption in the buildings sector.

In addition, industry, commercial, etc., and non-energy use sectors reflect the economic and industrial structure of a country. In terms of value added by industry, the United Kingdom has the largest tertiary industry in terms of share, particularly the non-energy-intensive finance sector, among the G7 countries. In contrast, for Germany and Japan, the importance of the energy-intensive secondary industry is relatively high (Figure 6). These differences manifest particularly in final energy consumption, which accounts for about 70% of the primary energy supply.

[4] SUEHIRO Shigeru, "Energy Intensity of GDP as an Index of Energy Conservation" (June 2007)

[5] These include the definitional aspect, that is, which goods are adopted in calculating the PPP rate and how accurately the quality of the goods are adjusted, and the phenomenological aspect in which the currencies of countries with less economic development and trade deficits tend to be overvalued.

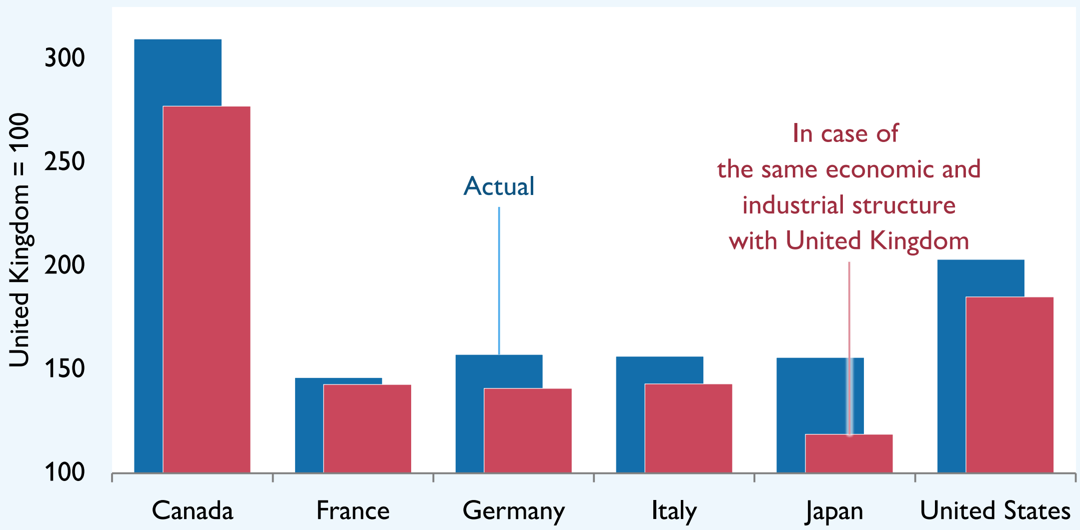
Figure 6 | Composition of value added [2019, compared with the United Kingdom]



Note: In 2015 prices
Source: Calculated based on the OECD "National Accounts"

If Germany and Japan had the same composition of value added by industry, in other words, the same economic and industrial structure, as the United Kingdom, their GDP intensity of final energy consumption would be 10% and 24% lower than they really are[6] (Figure 7). This will narrow the gaps with the United Kingdom considerably.

Figure 7 | GDP intensity of final energy consumption if the economic and industrial structure was the same as the United Kingdom [2019]



Source: Calculated based on the IEA "World Energy Balances" and the OECD "National Accounts"

In reality, not all countries can have a similar economic and industrial structure to the United Kingdom's – if every country specialised in services and finance, the world economy would not be viable. While

[6] The final energy consumption per unit of value added for each industry is calculated based on actual values of each country.

the economic and industrial structure has a significant impact on energy consumption, it is not explicitly considered when simply comparing GDP intensities; this should be kept in mind.

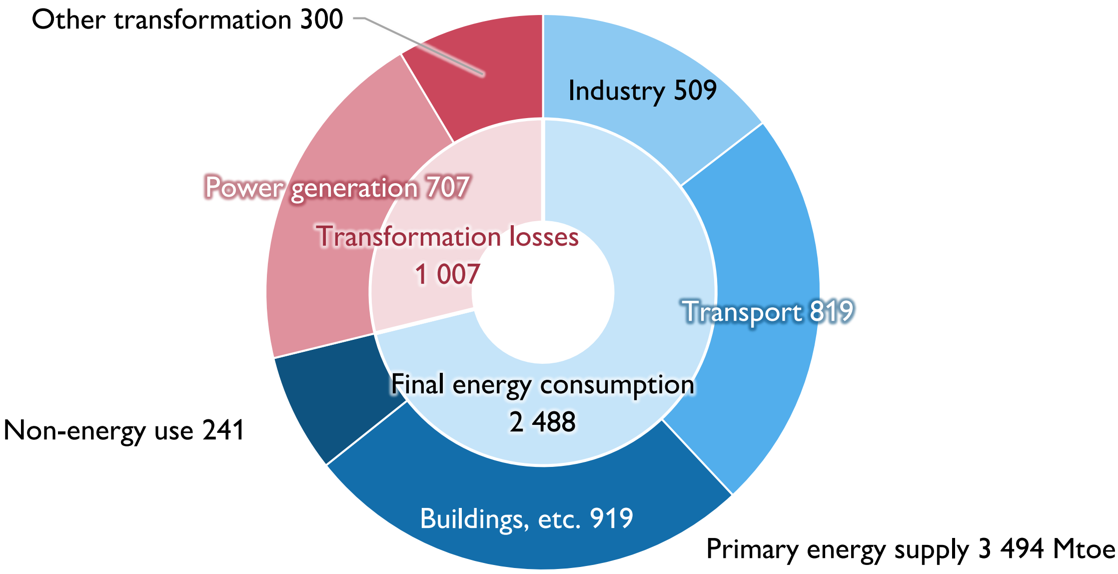
Caution warranted when evaluating progress in energy efficiency

In the previous sections, we described how exchange rates have a major impact on the *level* of GDP intensity of primary energy supply, which is used to evaluate energy efficiency, and its comparison between countries. In addition to this, attention must also be paid to certain factors when evaluating the progress of energy efficiency in terms of the *change* in the GDP intensity. In the following section, we assess what factors cause changes in the GDP intensity of primary energy supply by dividing the primary energy supply into its components: (1) final energy consumption, which represents the amount of energy actually used by end users, and (2) transformation loss, which is the amount of energy lost in transforming energy sources into other forms usable by end users.

Final energy consumption

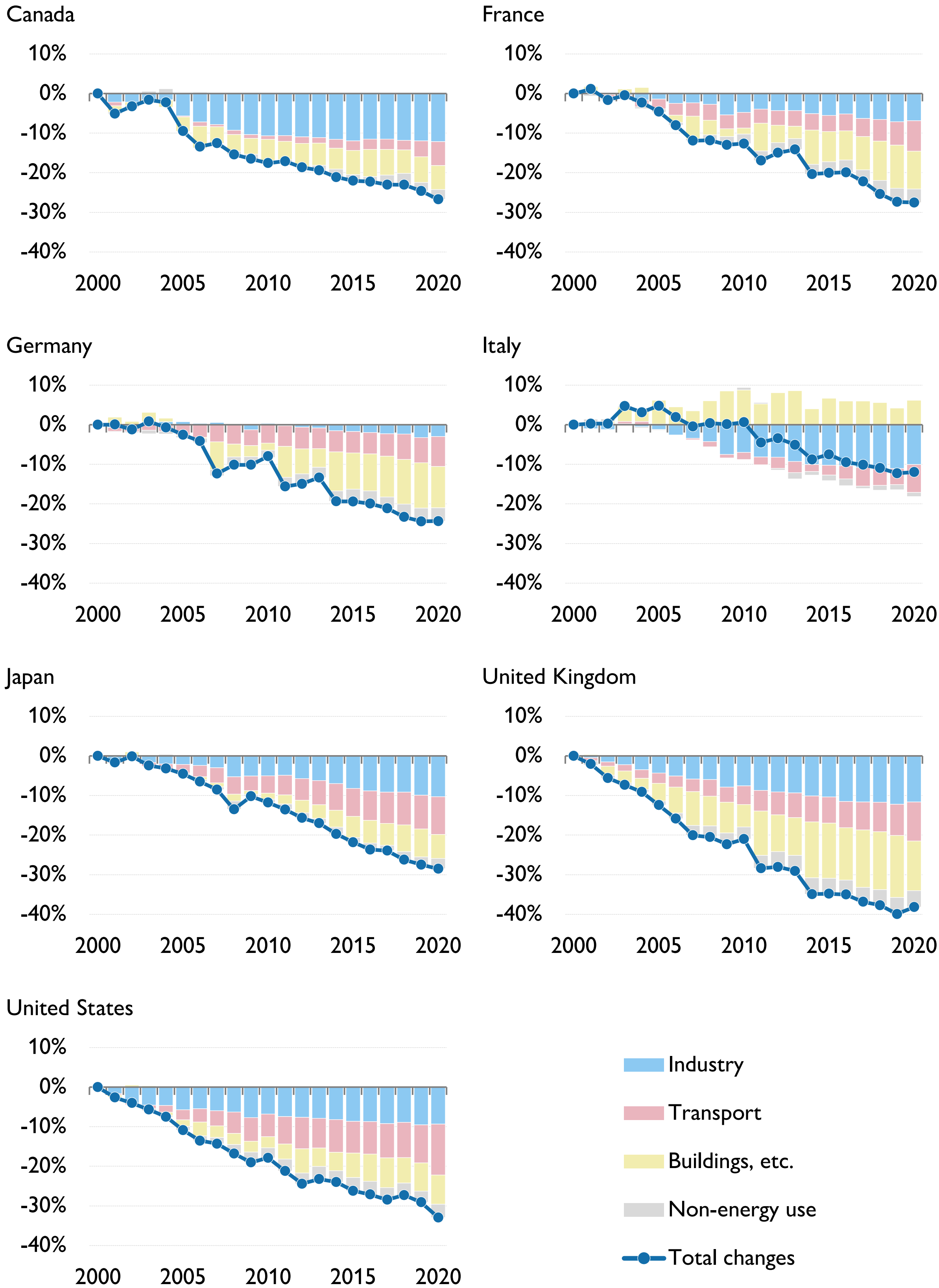
Areas of final energy consumption can be classified broadly into industry (mining, construction and manufacturing), transport, buildings, etc. (residential, commercial, agriculture, forestry and fisheries, and unclassified), and non-energy use sectors (Figure 8). The GDP intensity of final energy consumption has been decreasing for the past two decades in all G7 countries, and energy efficiency is considered to be improving also at the end-user level (Figure 9). In particular, North America has made significant progress in energy efficiency, though it still lags behind Europe and Japan in terms of energy efficiency levels. The United Kingdom and Germany, which are considered to be ahead of Japan in energy efficiency level, have made notable progress in energy efficiency in the buildings, etc., which drove the decrease in their GDP intensity of final energy consumption.

Figure 8 | Primary energy supply of G7 [2020]



Source: IEA "World Energy Balances 2022"

Figure 9 | Sector-based contribution to changes in GDP intensity of final energy consumption [vs. 2000]



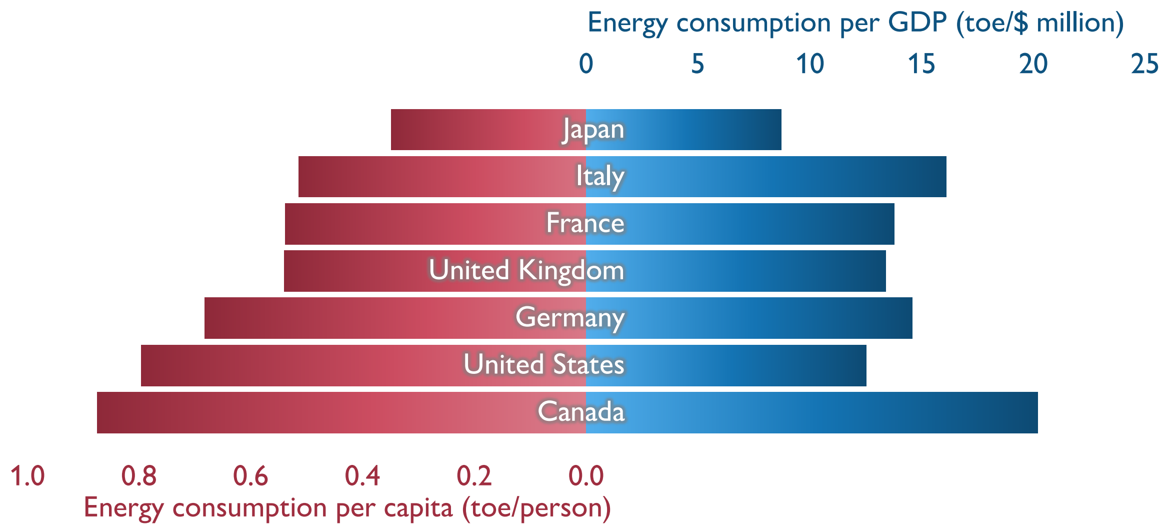
Source: Calculated based on the IEA "World Energy Balances" and the OECD "National Accounts"

The final energy consumption for industry[7], commercial, agriculture, forestry and fisheries, and non-energy use (chemicals industry) represents the amount of energy consumed finally for production activities in each sector/industry. Therefore, it would make sense to consider the amount of value added for each sector/industry as its amount of activity, and to use the energy consumption per unit of value added as an energy efficiency indicator.

In contrast, household energy consumption is not used for production activities. Households consume energy to satisfy the energy services they need for their daily lives. In emerging and developing economies, it is common for the amount of energy consumption to increase as income rises and living standards improve. However, advanced and other economies that already enjoy generally advanced living conditions are less likely to increase their energy consumption, which is a necessity, to even higher levels with an increase in income. Household energy consumption depends primarily on the temperature, stay-at-home rate, which has changed dramatically with the pandemic measures (COVID-19), and the energy efficiency of appliances and houses, which is directly related to energy efficiency at the microscopic level.

If we measure the energy efficiency in residential sector using energy consumption per GDP, the most efficient country is Japan, followed by the United States (Figure 10). However, as the United States is not generally regarded as highly advanced in terms of energy efficiency, this approach is rather unconvincing. For a comparison of G7 countries with similar economic development levels, energy consumption per capita appears to be a more credible indicator for residential energy efficiency than that per GDP. It should be noted, however, that both indicators are not adjusted for different climate conditions.

Figure 10 | Residential sector energy consumption per capita and per GDP [2020]



Source: Calculated based on the IEA "World Energy Balances", the OECD "National Accounts" and the World Bank "World Development Indicators"

Transport sector is both industry and residential sectors in nature. Freight transport, which involves energy consumption for the transportation of goods, may be closer to industry than residential. Passenger transport, on the other hand, consists largely of energy consumption by people's own cars ("personal cars"), which

[7] In principle, in the following section, industry consists of the following categories: mining, construction, primary metals, chemicals, non-metallic minerals, transport equipment, metal machinery and other machinery, food, paper, pulp and printing, textiles, and other manufacturing sectors. The reason for this treatment is because the OECD "National Accounts" does not categorise the value added data for primary metals for Japan into steel and non-ferrous metals.

are rarely related to production activities. Here, energy used for transport is assumed to be widely used to support the country's economic and social activities, and therefore, we regard energy consumption per unit of GDP as an energy efficiency indicator. In addition, for convenience, the same treatment is applied to the unclassified and non-energy use (other than chemicals), for which usage scenes are hard to specify.

According to the above, the GDP intensity of final energy consumption can be expressed as follows:

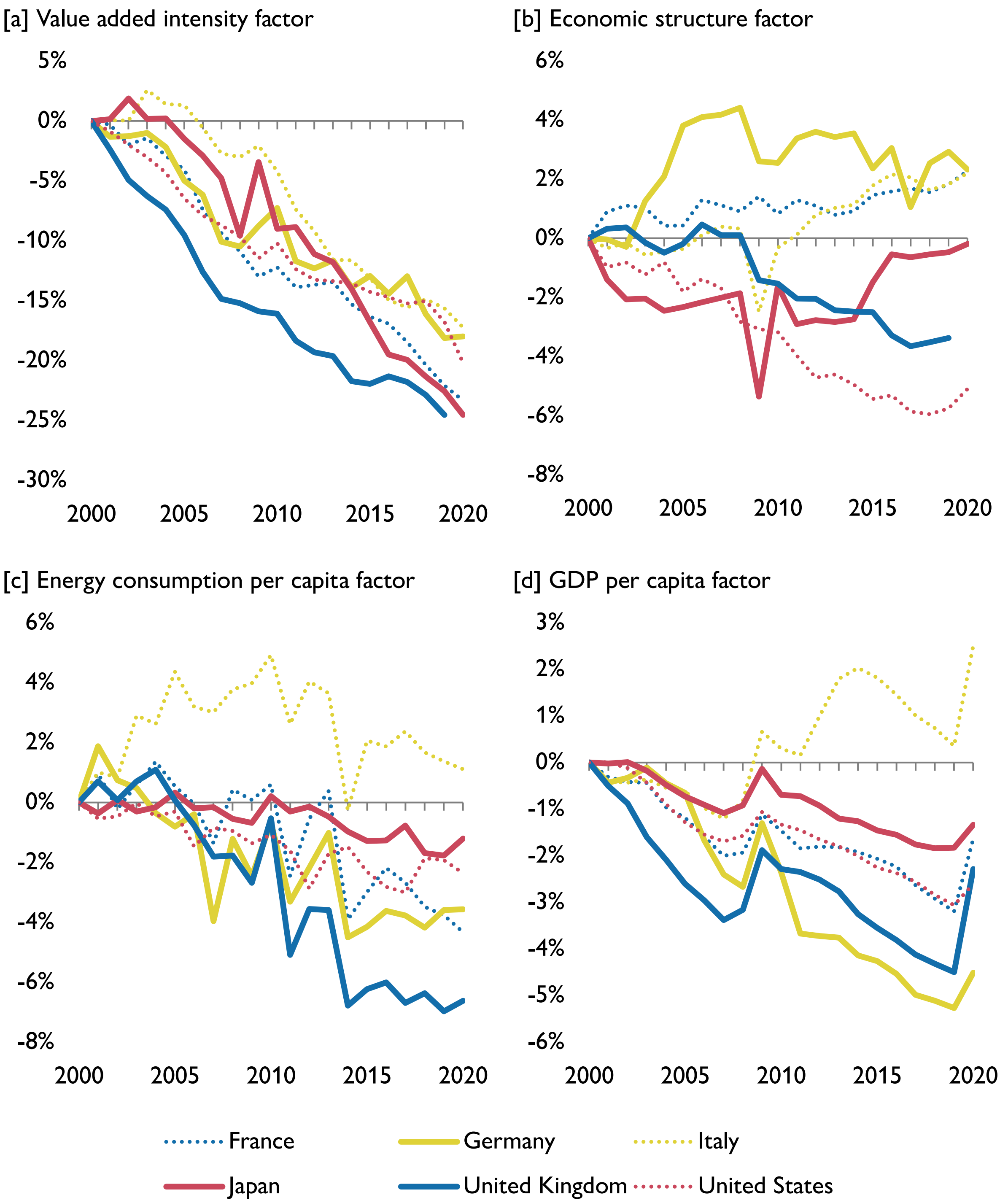
$$\frac{\text{Final energy consumption}}{\text{GDP}} = \sum_{i\in\text{Industry, commercial, agriculture, forestry and fisheries, non-energy use (chemical)}} \frac{\text{Energy consumption}_i}{\text{Value added}_i} \times \frac{\text{Value added}_i}{\text{GDP}} + \frac{\text{Energy consumption}_{\text{Residential}}}{\text{Population}} \times \left(\frac{\text{GDP}}{\text{Population}}\right)^{-1} + \sum_{i\in\text{Trasnsport, unclasiffied, non-energy use (other than chemical)}} \frac{\text{Energy consumption}_i}{\text{GDP}}.$$

Based on the equation above, changes in the GDP intensity of final energy consumption can be decomposed and reorganised into the following four factors: [a] "value added intensity factor", which is the contribution from the energy consumption per unit of value added (or GDP) and is a good indicator of energy efficiency (applied to industry, transport, commercial, agriculture, forestry and fisheries, non-energy use, and unclassified); [b] "economic structure factor", which is the contribution from the value added ratio of each industry against GDP and represents the economic and industrial structure (for industry, commercial, agriculture, forestry and fisheries, and non-energy use (chemical)); [c] "energy consumption per capita factor" (for residential), and [d] "GDP per capita factor" (for residential). Then, the change in the GDP intensity of final energy consumption was decomposed into the above factors for the G7 countries except Canada[8] (Figure 11).

Although Japan is said by some to be trailing the United Kingdom and Germany in energy efficiency, its value added intensity factor has been growing faster than those countries since the beginning of the 2010s, partly due to the electricity saving efforts following the Great East Japan Earthquake (Figure 11a). Its downward contribution surpassed that of Germany in 2013 and has come very close to that of the United Kingdom since 2016. Some attribute any "lack of progress in Japan's energy efficiency" to industry and the production sector, but such criticism is not valid.

[8] Canada was excluded because the OECD "National Accounts" does not contain the industry-based value added data for Canada prior to 2011. In addition, the United Kingdom was included in the analysis only through 2019 because the data for 2020 were not available.

Figure 11 | Contribution by factor to change in GDP intensity of final energy consumption [vs. 2000]



Source: Calculated based on the IEA "World Energy Balances", the OECD "National Accounts" and the World Bank "World Development Indicators"

The economic structure factor has a relatively large downward contribution in the United Kingdom (and the United States), where the manufacturing sector has declined and the service sector has expanded (Figure 11b). In contrast, in Germany, expansion of the energy-intensive industries has made an upward contribution. This may have a bearing on the recent direction of green transformation, but it must be noted that the economic structure factor's contribution to energy efficiency is purely the *result* of the change in the economy; changing the economic and industrial structure to improve energy efficiency is reversing this cause-effect relationship by nature. It would make sense to create new industries conducive to green transformation and the spillover effects will help revitalise the economy. However, putting too much weight on economic reform to achieve energy efficiency and decarbonisation may lead to the inappropriate exclusion of energy-intensive industries and carbon leakage, which could worsen the overall energy efficiency and hamper climate action. It is necessary to consider the possibility[9].

The energy consumption per capita factor tends to show a downward contribution except for Italy, indicating substantial progress in household energy conservation (Figure 11c). In the United Kingdom and Germany, high energy consumption due to their cold climates coupled with faster progress in energy efficiency than Japan has resulted in a significant downward contribution. Japan's energy consumption per capita is small to begin with, but its downward contribution was smaller in Japan than in Europe and the United States, even though the Top Runner program that began at the end of the 1990s should have had an effect. Japan is currently focusing on improving the energy efficiency of homes, but it may be worth considering the scope for further improvements.

One possible pitfall is the GDP per capita factor. GDP per capita itself has little meaning as a factor for energy efficiency. Nonetheless, when dealing explicitly with energy consumption per capita in residential sector, the GDP per capita factor is inherently present in the GDP intensity of final energy consumption as an energy efficiency indicator, though seldom noticed. This requires attention. Because Japan's economic growth is slow, the country enjoys only a limited downward contribution from an increase in GDP per capita compared to Germany and the United Kingdom (Figure 11d). Again, however, even if the GDP intensity of final energy consumption decreases thanks to the downward contribution of the GDP per capita factor, it does not mean that energy efficiency has fundamentally improved. In 2020, the GDP per capita factor recorded the greatest upward contribution since the 2008 financial crisis and the European debt crisis in all countries as their economies declined sharply due to COVID-19. Needless to say, this does not mean that their energy efficiency has deteriorated.

Transformation loss

The type of energy transformation that suffers the greatest transformation loss in terms of both amount and rate loss is power generation. In thermal power generation, approximately 60% of the energy input is lost during transformation. In comparison, the loss rate for other types of transformation is generally small, with only about 10% for coke production, which ranks second after power generation. Therefore, in this paper, we broadly classified transformation loss into power generation loss and other transformation loss. The GDP intensity of transformation loss was expressed by the following equation and was analysed:

$$\frac{\text{Transformation loss}}{\text{GDP}} = \frac{\text{Power generation loss}}{\text{GDP}} + \frac{\text{Other transformation loss}}{\text{GDP}},$$

[9] For example, the draft Basic Policy for the Realization of GX of the GX Implementation Council includes a clause that reads, "...promote industrial structural transformation and fundamental energy efficiency on both the supply and demand sides, including the manufacturing industry, such as steel, chemical, and others...". The goals to be set may differ greatly depending on what is considered as the scope of industrial structural transformation.

$$\frac{\text{Power generation loss}}{\text{GDP}} = \frac{\text{Final energy consumption}}{\text{GDP}} \times \frac{\text{Final electricity consumption}}{\text{Final energy consumption}} \times \frac{\text{Total electricity generated}}{\text{Final electricity consumption}} \times \sum_{i \in \text{Type of power generation}} \frac{\text{Electricity generated}_i}{\text{Total electricity generated}} \times \frac{\text{Power generation loss}_i}{\text{Electricity generated}_i},$$

$$\frac{\text{Other transformation loss}}{\text{GDP}} = \frac{\text{Final energy consumption}}{\text{GDP}} \times \frac{\text{Other transformation loss}}{\text{Final energy consumption}}.$$

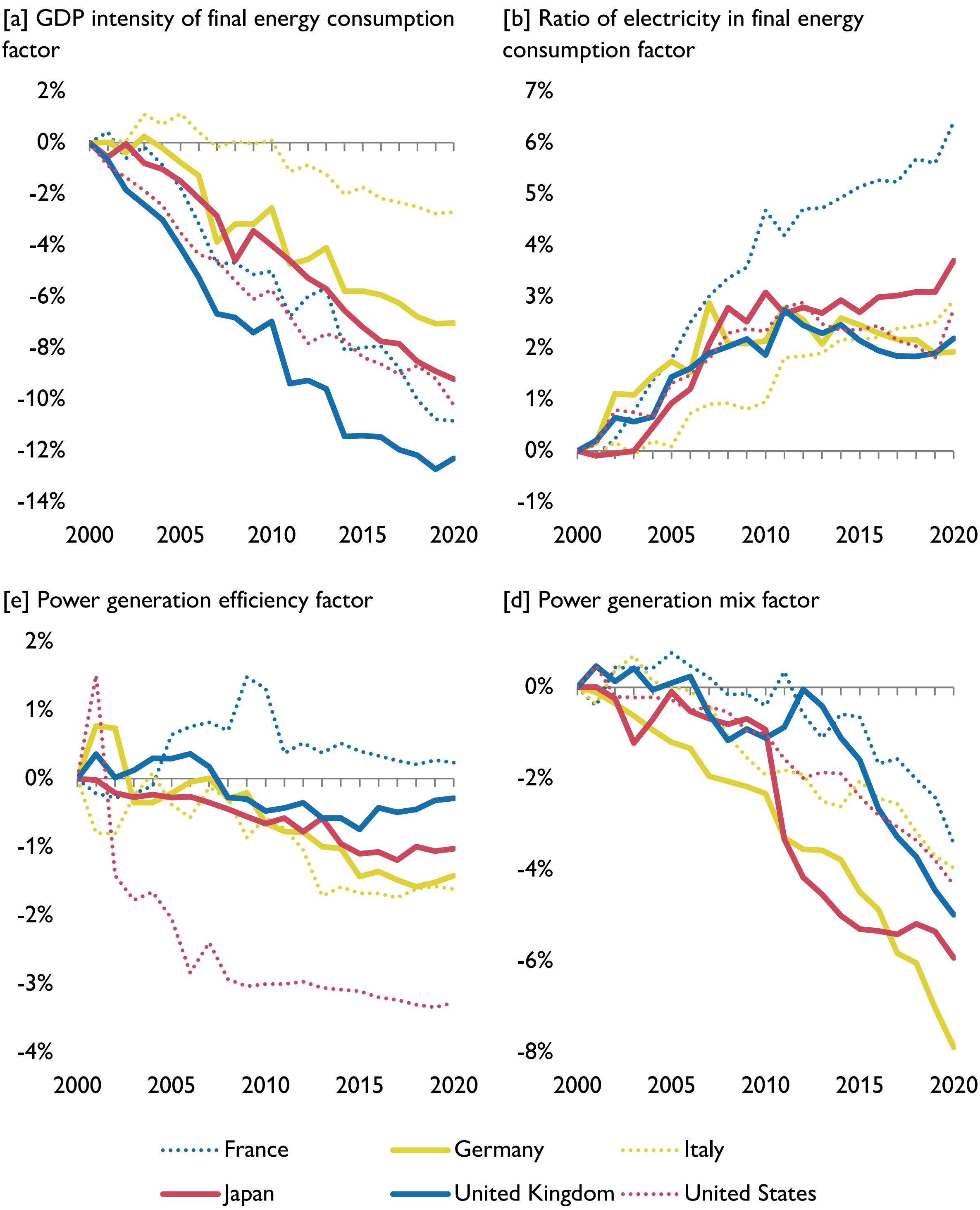
If we focus on the change in GDP intensity of transformation loss, as in the previous section, changes in the GDP intensity of transformation loss can be broken down and reorganised into the following six factors: [a] "GDP intensity of final energy consumption factor" (for power generation and other transformation); [b] "ratio of electricity in final energy consumption factor"; [c] "ratio of power transmission/distribution loss and own use, etc. factor"; [d] "power generation mix factor"; [e] "power generation efficiency factor", and [f] "other transformation efficiency factor". Figure 12 shows the main contributors to the change identified above.

The GDP intensity of final energy consumption strongly reflects the gaps in the rate of progress in energy efficiency between countries shown in Figure 9, with the United Kingdom seeing the largest downward contribution to its GDP intensity of transformation loss (Figure 12a). Furthermore, the contribution of the GDP intensity of final energy consumption becomes larger when the transformation loss is large. Being a major nuclear power producer, France is the only G7 country whose transformation loss exceeds half of its primary energy supply, due in part to the assumed efficiency of nuclear power generation (see below), resulting in the second largest downward contribution of its GDP intensity after the United Kingdom.

Electrification is expanding as societies become more sophisticated, making the ratio of electricity the only factor with an upward contribution in all countries (Figure 12b). The ratio of electricity is certain to increase going forward, as electrification with low-carbon electricity is viewed as a means to combat climate change. This makes it important to control the deterioration of energy efficiency caused by electrification. Japan has the fastest rate of electrification, with France ranked second. France, however, has a far higher upward contribution of ratio of electricity to its GDP intensity of transformation loss than other countries at 6.4%, due to its high ratio of transformation loss to primary energy supply.

Improving power generation efficiency is one of the key measures for energy conservation. In reality, however, the reduction in the GDP intensity of transformation loss that can be achieved by improving the power generation efficiency is not markedly large (Figure 12c). This is because it is not easy to greatly enhance the efficiency of power generation even with advanced technology, unless very old equipment is being replaced. In addition, the limited share of new installed power generation plants in the existing stock – especially in countries with slow power generation growth – also limits the downward contribution.

Figure 12 | Contribution to change in GDP intensity of transformation loss [vs. 2000]



Source: Calculated based on the IEA "World Energy Balances" and the OECD "National Accounts"

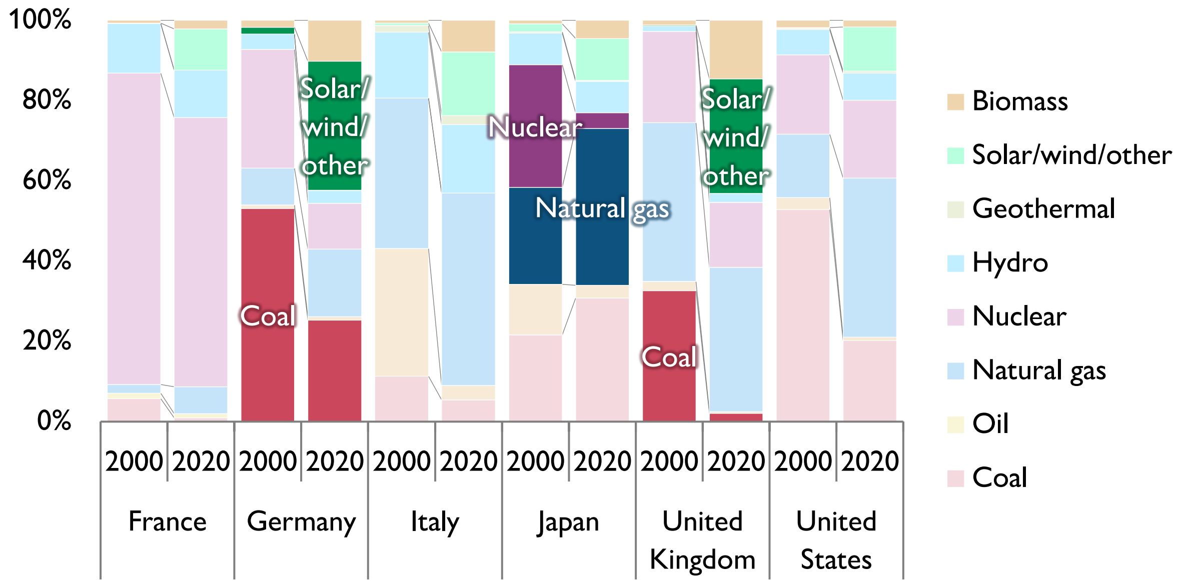
The power generation mix factor represents, for example, the reduction in transformation loss achieved by replacing low-efficiency coal-fired power generation with high-efficiency natural gas-fired power generation. However, the handling of primary electricity must be considered. The IEA's energy balance table assigns predetermined generation efficiency to power generation by nuclear, hydro and solar/wind/other, for which the amount of energy input cannot be measured directly; the amount of energy input is calculated backward from the assumed power generation efficiency and the amounts of electricity generated (Table 1). The power generation efficiency for the quickly expanding solar/wind/other and hydro is 100%, in other words, transformation losses are treated as 0%. This means that if thermal power generation is replaced by these, the calculated transformation loss will be drastically reduced. In other words, the power generation mix factor is a combination of both factors that are truly relevant and those that are relevant only in rules and calculations.

Table 1 | Assumed power generation efficiency of primary electricity in IEA statistics

Nuclear	Hydro	Geothermal	Solar/wind/other
33%	100%	10% in principle	100%

Germany and the United Kingdom (Figure 13), where solar photovoltaic (PV) and wind power generation combined now account for about 30% of total electricity generated, are seeing a significant downward contribution of the power generation mix factor (Figure 12d). Japan has also recorded a major downward contribution since 2011, largely due to the growth of solar PV power generation as well as the replacement of nuclear power generation, which was shut down after the Great East Japan Earthquake, with thermal power generation (whose average efficiency is about 45%). Meanwhile, the Kishida administration has reversed Japan's post-Earthquake nuclear policy and proposed the active use of nuclear power generation. If this policy is implemented, the power generation mix factor will serve to increase the GDP intensity of transformation loss.

Figure 13 | Power generation mix



Source: IEA "World Energy Balances"

Primary energy supply

Given that the GDP intensity of final energy consumption and of transformation loss can be broken down into the aforementioned factors, we can deduce that the GDP intensity of primary energy supply is also a combination of factors that are truly relevant to energy efficiency and those that are not (Table 2).

Table 2 | Contributors to the GDP intensity of primary energy supply

	Contributors to the GDP intensity of final energy consumption	Contributors to the GDP intensity of transformation loss
Factors that are fundamentally relevant to energy efficiency	● Value added intensity (Scope: all except residential) ● Energy consumption per capita (Scope: residential)	● Ratio of power transmission/distribution loss and own use, etc. ● Power generation mix (except for primary electricity) ● Power generation efficiency ● Other transformation efficiency
Factors with intermediate implications	● Economic structure (Scope: industry, commercial, etc., agriculture, forestry and fisheries, and non-energy use)	● Ratio of electricity in final energy consumption
Factors with little fundamental relevance	● GDP per capita (Scope: residential)	● Power generation mix (for primary electricity)
Factors with mixed implications		● GDP intensity of final energy consumption (see left column)

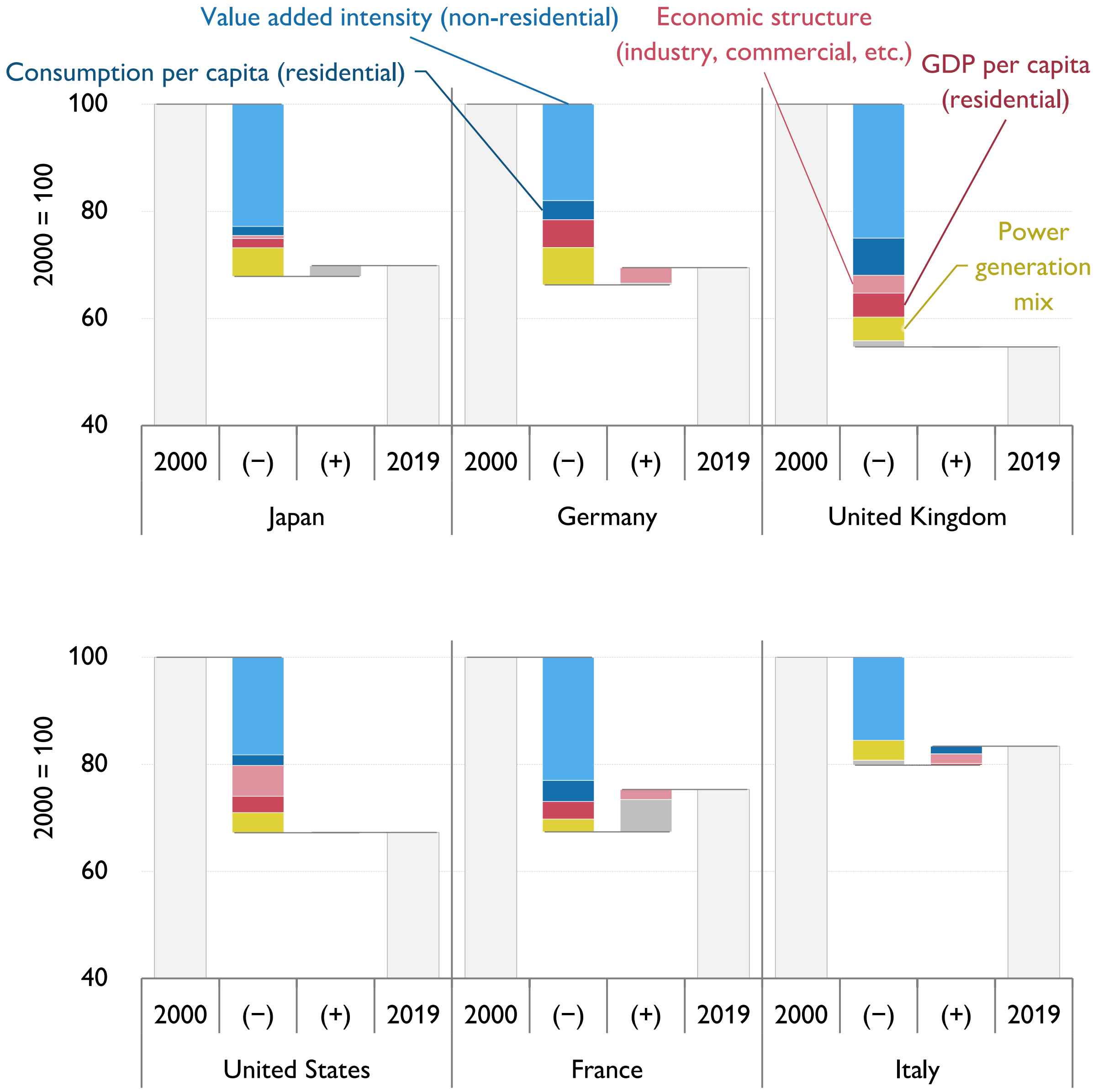
With this in mind, the contribution of each factor to the change in GDP intensity of primary energy supply was recalculated by combining the results of previous analyses and the outcome was charted as shown in Figure 14.

By the value added intensity factor, the factor most fundamentally relevant to energy efficiency, Japan reduced its GDP intensity of primary energy supply more than Germany did, although not by as much as the United Kingdom. Nevertheless, Japan lagged behind Germany in the reduction rate of the GDP intensity of primary energy supply. One reason is the difference in the negative contribution of another fundamental energy efficiency factor, the energy consumption per capita for households. When discussing energy efficiency, the focus tends to be on industry, mainly manufacturing, but our finding is a warning that such focus is not sufficient.

The United Kingdom is undergoing a remarkable economic shift from manufacturing to an information- and service-based industry, and the country is transforming its economic and industrial structure into a non-energy intensive one. As a result, its economic structure factor drove down the GDP intensity of primary energy supply on a scale second only to that of the United States. However, it is inherently inappropriate to treat the economic structure factor as if it were a controllable means of energy efficiency; it is energy that serves the economy, and not the other way round.

For Japan, which is suffering from low economic growth, GDP per capita had a contribution of only one-third that of Germany and 40% that of the United Kingdom, slowing the rate of progress in overall energy efficiency. However, like the economic structure factor, the GDP factor per capita factor is a *result* of economic growth, and it would be illogical to strive for economic growth with the aim of its downward contribution to energy intensity. Thus, the contribution of this factor that have little fundamental relevance for energy efficiency may be rather discarded.

Figure 14 | GDP intensity of primary energy supply and contributions to its changes



Source: Calculated based on the IEA "World Energy Balances", the OECD "National Accounts" and the World Bank "World Development Indicators"

The negative contribution from the power generation mix factor was smaller for Japan than for Germany but was bigger than for the United Kingdom. However, if we look at the largest changes in the power generation mix, Germany and the United Kingdom have replaced coal with solar PVs and wind, which are assumed to have no transformation loss, whereas Japan has replaced nuclear power, whose assumed power generation efficiency is lower than that of thermal power, with natural gas, meaning that the actions of these countries have completely different implications in terms of low-carbonisation (Figure 13). The power generation mix factor varies greatly depending on the assumed power generation efficiency of primary electricity, which is "plastic". This makes it difficult to treat the power generation mix factor as a measure of energy efficiency in these days when efforts to low carbonisation are being made and the introduction of solar PVs and wind is progressing rapidly. For example, if geothermal, which is assigned an assumed power generation efficiency of only 10% in principle, replaces other power sources, the GDP intensity of primary energy supply will actually worsen.

What the GDP intensity of primary energy supply tells us

The GDP intensity of primary energy supply is used frequently and is adopted as an energy efficiency indicator because it is intuitive, easy to understand, and requires little data for calculation. However, it is an indicator that disregards various factors that actually affect energy efficiency. It also contains elements that appear irrelevant to the evaluation of energy efficiency, with an influence that cannot be ignored.

The GDP intensity of primary energy supply is a particularly convenient indicator, and its use should not be ruled out. However, when grasping the real picture of energy efficiency targets through international comparisons, running a plan-do-check-act (PDCA) cycle for progress in energy efficiency by monitoring the changes over time, and projecting the future by extrapolation, it is essential to understand the characteristics and limitations of this indicator.

An in-depth examination suggests that Japan's energy efficiency is not substantially inferior to that of Europe. However, the fact that Japan's advantage in energy efficiency is no longer immediately obvious suggests that Japan needs to consider what else it can do as a world leader in energy efficiency, while also wholeheartedly commending Europe's progress.

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