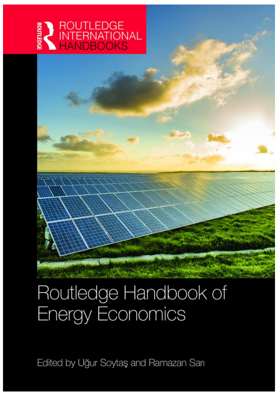

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Economic impacts of the energy transition

Christian Lutz and Ulrike Lehr

1 Introduction and background

The Paris Agreement against climate change was decided in December 2015 and came into force on 4 November 2016. Its central aim is to keep global temperature rise below 2°C above pre-industrial levels and to pursue efforts to limit the temperature increase even further to 1.5°C. Climate change mitigation that will meet the targets of the Paris Agreement requires a fundamental transformation of the global energy system. Renewable energy sources and energy efficiency are the two main pillars of this energy transition (ET). The expected investment needed for the energy transition is huge. A recent OECD et al. (2017) study calculates additional investment of USD 29 trillion against a reference case between 2015 and 2050 just to meet the 2°C target. This sounds like a huge number, but it has to be put into context. With global GDP reaching USD 75.5 trillion in 2016 according to the World Bank, the additional investment will be well below 1% of economic activity for the next decades. One key result of OECD et al. (2017), supported by other research, is that

> transformation of the energy system in line with the "well below 2°C" objective of the Paris Agreement is technically possible but will require significant policy reforms, aggressive carbon pricing and additional technological innovation. Around 70% of the global energy supply mix in 2050 would need to be low-carbon.
>
> *(OECD et al. 2017, p. 13)*

Large investment, aggressive pricing, and policy reforms raise the question of the macroeconomic effects of the energy transition. The scientific debate is still on. While some research highlights the costs of the energy transition; others concentrate on the benefits.

The remainder of this contribution therefore wants to shed some light on the economic dimension of the energy transition. It starts with the methodology of measuring the different effects of the energy transition. This helps to better understand the sophisticated modeling studies that try to quantify macroeconomic impacts of the energy transition. Different models lead to different results; therefore, they have to be interpreted carefully and put into context. The results depend on modeling scale (global, national, regional), time horizon, bottom-up consistency, and the underlying assumption on economic framework conditions and instruments of the energy transition.

2 Economic effects in the literature

The energy transition has effects on all sectors in the economy. It changes household demand as well as industrial demand and supply and will lead to a global structural change. The demand for new energy technologies and efficient equipment causes direct and indirect effects. New wind farms require wind turbines produced by the respective industry and thermal insulation requires triple panes with special glazing, insulation material, and new building material. Direct effects comprise these additional turnovers from additional demand. Indirect effects are caused along the supply chain up- and downstream (e.g. in the steel industry for the tower of the wind turbines or in services for project planning).

The substitution of investment and use of fossil fuels by renewables and energy efficiency offsets the positive impacts of the latter. Operation and maintenance will shift from conventional sources to energy transition technologies. Conventional energy sources will be substituted by renewables or by capital in the case of energy efficiency investment. Additional to the direct and indirect effects various second-round or induced effects can be observed. These induced effects include

- Price and income effects
- Changes in trade relations
- Various dynamic effects such as multiplier, learning, market and productivity effects that are difficult to quantify.

(see IEA-RETD 2011 and 2012; Lehr et al. 2012; IEA 2014a, Cambridge Econometrics et al. 2015; IRENA 2016).

Price effects result from economic instruments such as taxes, emission permits, or regulation. But the energy transition as such also changes relative prices: a more efficient use of energy leads to lower relative energy costs in production, consumption, or transport. Financing the additional costs for households or industry related to renewable energy or energy efficiency investment changes relative prices, too.

Private households as well as companies or the government have a certain budget to spend. For households, the disposable income reflects the budget constraint after the necessary expenditures for health care, taxes, and so forth are done. Higher prices for electricity will reduce consumption for other goods, as short-term price elasticity is low. Companies face similar constraints. However, reduced energy expenditures due to energy efficiency measures free additional budget for non-energy goods in both cases. In the long-term changes in relative prices play a decisive role for induced effects, especially regarding future behavior as they signal scarcity and drive technical change.

Income effects result from changes in income of households and companies. Additional demand, as described above, leads to additional employment and income in energy transition industries. Aggregate compensation of employees increases, who will spend the additional amount according to their marginal propensity to consume. This spending triggers effects for other producers of goods and services. Negative income effects are also possible, if conventional utility companies face reduced turnover, prices, and profits due to an increase in renewable power generation.

Foreign trade effects arise from the reduction of imports of fossil fuels and from trade in goods for renewables and energy efficiency. An example is mass production of solar panels in China, which are exported all over the world. The largest manufacturer for wind turbines is the Danish Vestas (WPM 2017), followed by the German-Spanish Siemens Gamesa and the wind sector of General Electric from the United States. Countries such as Denmark that have started the energy transition early, can hope for first-mover advantages in terms of additional exports for their goods and services on markets lagging behind. Discussing the effects from trade with energy transition goods leads to a discussion on who keeps the economic benefits from the energy transition. The largest physical potentials for electricity generation from renewable energy are found in developing countries in Africa and Asia where the establishment of own energy transition industries creates new paths for economic development.

In a long-term perspective, different dynamic effects play a role. Multiplier effects describe the relation between macroeconomic impulses such as higher demand for initially more expensive electric cars and various induced effects. Learning effects, often described as global learning curves for technologies such as solar PV, show the correlation between global capacity installed and cost reductions (learning by doing) or global research efforts and cost reductions (learning by searching). On the electricity markets, additional capacity with low variable costs such as wind or solar PV influences the wholesale price with impacts for all producers. The latter effects are very difficult to model endogenously in macroeconomic models. Typically, they will be treated in electricity market models that are soft linked to macroeconomic models. Table 6.1 summarizes the different effects.

An impact study can look at gross or net impacts (IEA-RETD 2012). Gross impact studies try to measure the relevance of the energy transition for the economy as a whole in terms of employment, production, or investment. They often only include direct investment but sometimes embrace indirect effects of investment as well as O&M and substitution effects. Net employment impact studies compare the effects from additional efforts towards the energy transition to the results in a world without these efforts.

The recent report by UN Environment, Frankfurt School-UNEP Collaborating Centre and Bloomberg New Energy Finance (2018) "finds that all investments in renewables totaled USD

Table 6.1 Overview of effects of the energy transition (ET)

	Effects	*Additional*	*Reduced*
Investment	Direct and indirect	Investment in ET	Reduced investment in conventional energy (CE)
Operation and maintenance (O&M)	Direct and indirect	O&M of ET technologies	Reduced O&M of CE technologies
Substitution/Savings	Indirect and induced	Additional use of ET sources	Reduced use of CE sources
Price	Direct, indirect and induced	Lower prices due to ET	Higher prices due to ET
Income	Induced	Higher income due to ET	Lower income due to ET
Foreign trade	Induced	Higher exports of ET technologies	Lower exports of energy/CE technologies
Dynamic	Induced	Multiplier, learning, market, productivity effects	

Source: IEA-RETD (2011, 2012); Lutz and Breitschopf (2016).

279.8 billion (excluding large hydro)" in 2017. These investments added 157 gigawatts to global power capacity in 2017, up 14% from the 138 gigawatts added the year before. According to that source, investment in renewables capacity was more than twice that in fossil fuel generation; the corresponding new capacity from renewables was equivalent to 69% of all new power, the highest to date. In 2016, global investment in energy efficiency increased by 9% to USD 231 billion (IEA 2017a). This increase coincided with a slowdown in investment on the supply side of the energy system. Energy efficiency investment now represents 13.6% of the USD 1.7 trillion invested across the entire energy market (IEA 2017b). Critics of the energy transition emphasize the cost side of financing this investment (e.g. Andor et al. 2017), if it is not market but policy driven.

IRENA (2018) informs in annual reports about global renewable energy employment, reaching 10.3 million jobs in 2017, up from 7.1 million jobs in 2012. These analyses are based upon a comprehensive annual desk research exercise and can be seen as gross effects. IRENA (2018) reports job losses in conventional energy industries, especially in the coal, oil, and gas industries due to substitution, as a first approach to net effect estimation. They summarize, however, that "project-level data indicates that, on average, renewable energy technologies create more jobs than fossil-fuel technologies".

More comprehensive analysis of the economic effects of the energy transition includes as much as possible the indirect and induced effects. To quantify the net effect of these counterbalancing tendencies, macroeconomic simulation models are used. This approach enables a closed framework for the analysis, in which no feedback effects and feedback loops are lost. A model-based analysis of net economic effects consists of the following steps.

Data on various possible courses of the future is collected in so-called scenarios. One scenario contains a future with no additional measures and investment and serves as a reference development against which all others compare. Bottom-up technology models, cost benefit analyses, feasibility calculations, and profitability analyses as well as future market analyses lead to the definition of scenarios for individual investment causes. The resulting information comprises monetary effects (e.g. energy prices) and/or energy related effects (e.g. energy savings) and serves as an input to the macroeconomic simulation model described in Chapter 33 on macro-econometric models in this handbook. The macroeconomic model calculates the future development of economic quantities such as GDP, employment, sector specific output, or value added, taking into account feedback effects. A comparison of these quantities under different scenario assumptions with a reference scenario provides information on overall (net) economic effects of the developments defined in the scenarios. The differences between the results are then attributed to the effect of different scenario specific measures since all other parameters in the model are kept constant in all model runs (so-called ceteris paribus method).

In Figure 6.1, a scenario with high investment in energy transition goods is compared to a reference scenario without such investment. The scenarios are translated into model variables such as total additional investment, total energy saved, energy saved by energy carrier, and so forth. These inputs are quantified in partial analyzes of different markets and fields of action.

Figure 6.1 summarizes the economic and environmental effects elaborated above. Firstly, investments directly increase final demand and if the demanded goods are produced domestically increase production. More production also requires additional staff and employment is higher. In a rather tight labor market such as currently the German market, wages will increase. In particular, wages can increase in sectors with no or low international competition. In sectors active on international markets, wage increases are somewhat capped by prices attainable on international markets. Profits, production, and the amount of additional employment will adjust accordingly. The additional employment yields more income, which in turn is spent. This increased consumption of goods leads to further production and income effects.

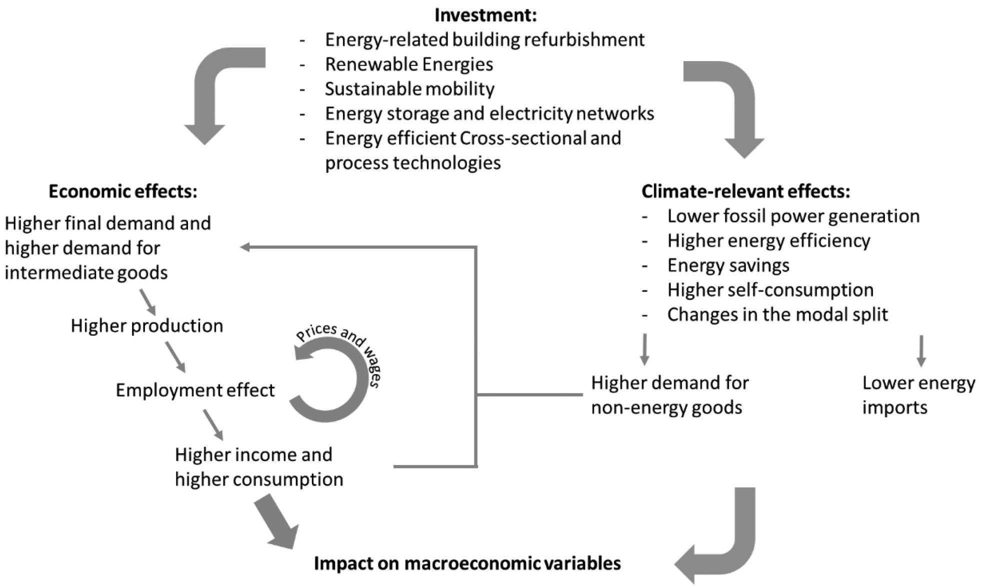

Figure 6.1 Economic and environmental effects of investment in energy transition

Source: GWS.

In addition to more labor, more intermediate goods are necessary for production, either domestic or imported. The production of intermediate goods itself increases the demand for these goods, and so on. These effects are taken into account in input-output tables using Leontief's approach, which link the production structure to the final demand. This makes it possible to determine the output of an industry as a whole. The input-output tables are at the center of some of the more complex macroeconomic models applied in Section 3.

Depending on the type of investment, environmental effects differ. Energy savings, increased self-consumption of energy and reduced fossil-fuel-based power generation are possible climate-relevant effects, which in turn lead to reduced energy imports. With the funds released, additional non-energy goods can be purchased, which leads to further economic reactions. Overall, investment affects the different macroeconomic variables such as gross domestic product and employment.

While most of the effects in Table 6.1 can be calculated directly, some of the discussed feedback and dynamic effects depend on assumptions about different circumstances such as business cycles or behavior of economic agents, which are to date not fully understood and difficult to model. These uncertainties include crowding out, the economic feasibility of investment partly due to uncertainties about future energy price developments, future technology cost development, the quantification of barriers and the cost of action, and behavioral changes such as rebound effects due to lower energy consumption. Rebound effects describe behavioral changes, which limit the energy savings of more energy-efficient technologies.

Crowding out refers to the possibility that the investments needed for the energy transition compete with and displace investments elsewhere in the economy. The likelihood of crowding out increases with the degree of capacity utilization. In an economy without unemployment and with fully functioning markets, crowding out will be (close to) 100%. After the economic and financial crisis starting in 2008, capacity utilization has been low in many countries and monetary policy extremely accommodative. Crowding out has been probably very low there.

Economic feasibility of investment is related to divergence of planned and realized investment. As future energy prices are uncertain, economic investment in energy transition can turn to not pay off for the investor. Different barriers such as the landlord-tenant problem can prevent investment. It is difficult to model them correctly. Technology cost development, especially for young technologies, is very difficult to project and model correctly. The modeling studies that are discussed next have to cope with all these effects.

3 Modeling studies

When comparing results of macroeconomic modeling studies of climate mitigation and energy transition, there is a striking difference between negative macroeconomic impacts reported by the IPCC (Clarke et al. 2014) and recently published positive results produced by or on behalf of international institutions (OECD 2017; Pollitt et al. 2017; IMF 2016). The fifth IPCC report shows cost for the idealized implementation scenarios of global consumption loss estimates for reaching levels of 430–480 ppm CO_2eq by 2100 ranging between 1% and 4% in 2030, 2% to 6% in 2050, and 3% to 11% in 2100 relative to consumption in the baseline (Clarke et al. 2014, p. 449). Similar deviations are reported for GDP. A comparison of different levels of ambition gives the robust result across studies "that aggregate global costs of mitigation tend to increase over time and with stringency of the concentration goal". The estimates are based on the assumption of a stylized implementation approach with a single global price for all GHG emissions. Carbon prices for reaching levels of 430–480 ppm CO_2eq by 2100 range from around 100 to almost 1000 USD2010/t CO_2eq in 2050 and between 100 and a few 1000 USD2010 in 2100. Carbon prices are estimated to be substantially smaller for lower ambition levels. The modeling studies make use of global integrated assessment models (IAMs) with low regional and sectoral resolution. Low-carbon or no-carbon technologies are specified on a high level. Assumptions about availability of mitigation technologies explain part of the variations of model results. Regional mitigation costs differ according to income levels. A unique carbon price is relatively higher in low-income countries. Therefore, impacts are about half of the average in OECD and highest in least developed countries.

A big caveat of these estimates is the assumption of idealized policy implementation with a single price instrument in perfectly functioning markets without any distortions, market failures, or institutional constraints. The authors of the IPCC conclude that "the reality that assumptions of idealized implementation will not be met in practice means that real-world aggregate mitigation costs could be very different from those reported here" (Clarke et al. 2014, p. 455). This does not devaluate these estimates, but they have to be interpreted accordingly.

The IEA has developed a scenario, which will reach the 2°C target with a probability of 66% and compares it to its new policies scenario as a reference (OECD et al. 2017). Carbon prices per t of CO_2eq will have to reach 190 USD in OECD countries in 2050, 170 USD for major emerging economies including China and 80 USD for other regions. The authors emphasize that carbon prices alone will not be sufficient to drive the energy transition. They assume the phase out of fossil fuel subsidies, additional fuel taxation, and the coordinated enforcement of command and control policies such as standards as well as energy market reforms, research, development, and deployment.

If this ambitious 66% scenario is combined with economic reforms in G20 countries, GDP on average across the G20 could be by 2.5% higher in 2050 compared to the reference (OECD 2017). Macroeconomic impacts will also be positive in the short term. According to the report,

> the modelled growth effect is driven by a combination of investment in low-emission, climate-resilient infrastructure; an additional fiscal initiative to fund climate-consistent

> non-energy infrastructure; pro-growth reform policies to improve resource allocation; technology deployment; and green innovation. The benefits of combined growth and climate policies more than offset the impact of higher energy prices, tighter regulatory settings, and high-carbon assets that may become economically stranded before the end of their economic life.

Carbon tax revenues are used to lower public debt in most countries. Revenue recycling will also have economic impacts.

The OECD (2017) uses its Yoda model, which is a macroeconomic model with structural features such as hysteresis, which means that unemployment is possible. Parameters have been estimated econometrically using a panel of annual time series data as much as possible, especially for the growth and the Philipps curve functions. Other parameters are calibrated. Each country model comprises about 20 equations. The Yoda model is highly aggregated and does not differentiate any industry or technology detail.

Recent studies with the E3ME model show positive macroeconomic impacts of additional energy efficiency measures in the EU (Pollitt et al. 2017) and of an increased deployment of renewable energy at a global level (IRENA 2016). An increase in energy efficiency ambition in the EU to 40% in 2030 (against 27% in the reference) could boost GDP by 4% without crowding out. If partial crowding out is assumed, the positive GDP effect will reach 2.2% in 2030. For renewables, the ambitious deployment scenario REmap is compared to the new policies scenario of the IEA (2014b), which includes existing and expected policy measures from that date. REmap assumes a doubling of the renewable energy share in global energy consumption between 2010 and 2030 according to the IRENA roadmap. As a net effect, global GDP will be 0.6% higher compared to the reference in 2030. However, for some countries and industries impacts will be negative. Net employment effects are also positive in both studies. E3ME is a global, macro-econometric model designed to address major economic and economy-environment policy challenges (Cambridge Econometrics 2017). Behavioral parameters are estimated econometrically. A high level of disaggregation enables detailed analysis of sectoral and country-level effects from a wide range of scenarios. It is based on post-Keynesian principles with a focus on the demand side (IRENA 2016), while many other models as documented in Clarke et al. (2014) follow neo-classical economic thinking, which pronounces the supply side of the economy. In general, economic impacts of energy transition are reported to be negative in these models, if compared to an optimal state of the economy.

Therefore, the philosophy of the economic models is important for the sign of the effects, but Château et al. (2014) have calculated positive macroeconomic effects with a computable general equilibrium model as well, which is also based on neo-classical theory. They compare the efficient world scenario of the IEA (2012) with a new policies scenario. The efficient policy scenario includes energy efficiency investment, which pays off, but is prevented by various barriers. Simplified, it is assumed that the economic potential of energy efficiency is exhausted. Global GDP is 1.1% higher in the energy efficiency scenario in 2035. Some countries and industries, which are characterized by high shares of fossil fuels, will lose, however.

To model the economic impacts of the energy transition comprehensively, it is important to keep in mind that mitigating climate change is not the only target of the energy transition and there are wider socioeconomic benefits, which are often not correctly or not at all depicted in the national accounts. Accounting for the internalization of these external effects will reduce the economic costs of climate change. The energy transition can aim at increasing energy security as well as improving the health and well-being of the population and reducing local air pollution.

IEA (2014a) describes the multiple benefits of energy efficiency improvement. In many cases these additional benefits and other targets are the major drivers of energy transition policies.

China for example has announced its e-mobility quota for new passenger cars of 10% for 2019, not in the first place to mitigate climate chance, but to reduce local air pollution in large cities, thus improving health and well-being of the population. Some industrial policy ideas to foster domestic car production and strengthen the domestic car industry may have supported this regulation. Globally, deployment of electric cars is largely driven by the respective policies. Announcements of governments and cities around the world to prohibit fossil-fuel-driven vehicles from a certain year onwards will spur this development. This comes with other developments such as autonomous and connected driving and mobility as a service. All these trends have the potential to revolutionize the global car industry. Car manufacturers around the world plan massive investment in the new technologies to keep market shares and profits.

For the German government, the phase-out of nuclear energy in the light of the Fukushima accident has been the major trigger for starting the energy transition and is one of the key targets of the national energy transition concept, as the majority of the population is against nuclear power. In the United States, the shift from coal to gas in power generation is not mainly the result of climate mitigation policies but has been driven by technological progress and cost reduction in unconventional gas production. The resulting price decrease for domestic gas in the United States has been quite a game changer.

These examples show that understanding the economic dimension and effects of the energy transition in the short and medium term needs realistic models and a multi-target and multi-instrument perspective. Future models have to even better include the complexity of the different sectors and their interlinkage. Potential technical breakthroughs in battery technology for e-mobility will for example also open new options for power storage.

The simple assumption of a global carbon price, which has to induce all the changes to decarbonize the economies, cannot map this complexity. It is, however, a suitable proxy in long-term modeling, which has to abstract from concrete policies, technologies, and country specifics. Recognizing these different uses calls for a more elaborated portfolio of models to evaluate the various dimensions of the energy transition. No model is able to map all the effects on different regional and temporal levels. Therefore, authors have to clearly describe the scope and limits of their modeling exercises.

4 Conclusions and outlook

There are large differences in the results of macroeconomic modeling studies. While the last IPCC report shows negative effects of mitigating climate change during this century, recent studies of and on behalf of international organizations exhibit positive macroeconomic impacts of the energy transition at least until 2050. The devil lies in the details. IPCC reports the results of long-term global integrated assessment models with a global carbon price as major policy variable. While this is academically accepted, it has to be related to the benefits of mitigating climate change and it reflects reality only to a very limited extent. International institutions such as OECD, IRENA and the EU make use of models with more country and sector detail and focus on the next decades. In some cases, results of technology-based bottom-up models are used for scenario development in macroeconomic models. Compared to IPCC, the latter focus on energy transition rather than climate change mitigation. Though the two issues overlap, energy transition includes economic and fiscal aspects not necessarily covered by climate change mitigation studies. For instance, the IMF explicitly combines energy transition and macroeconomic reforms in its policy proposals.

But even the wider approach to energy transition falls short in covering some aspects. A first shortcoming of the models used is that effects such as learning are often not adequately included in the models. Here, the combination of bottom-up micro modeling and macro modeling needs to be improved. Other effects, such as crowding out, are very difficult to model, because they are not observable in the past and data are not available. Thus, modeling crowding out almost fully depends on assumptions.

Other differences in model results in the literature can be explained by the time horizon of the respective analysis, ambition levels to mitigate climate change and the industry or sector and spatial resolution of the models. In a long-term perspective until the end of the century, scenarios will be on a more aggregate spatial resolution and abstract from specific technologies, sectors and policies. The respective results inform about the cost side of a long-term transition, about key variables and the effects of acting immediately or later in the future. They should not, however, be misinterpreted as short-term policy advice.

Economic theory is struggling with the explanation of technological change. As Nobel Prize Laureate William Nordhaus wrote in 1969, "at the present time there is no compelling empirical evidence pointing toward technological change rather than associating increases in productivity with economies of scale, learning by doing, errors of measurement, or even sunspots". The empirical evidence has improved, but the difficulty of inclusion of endogenous technical change in many of the models remains. It calls for sensitivity analyses to better understand the implicit uncertainties. Economic theory and modeling fall short of explaining and guiding the whole energy transition. Diffusion of electric vehicles, societal acceptance of nuclear, windmills or grid extension, digitization, and storage all have behavioral and social aspects that have to be considered. Interdisciplinary approaches are needed in modeling energy transition.

The same holds for different economic uncertainties such as the probability and magnitude of crowding out of investment in the energy transition. More realistic scenarios have to be developed to take multi-targets and multiple policy measures into account. The macroeconomic benefits of mitigating climate change and of the transition to a more sustainable energy mix are highly relevant. In the future, more complex and realistic views will help to understand the macroeconomic impacts of the energy transition and relate them to wider socioeconomic effects to complete sustainable development. This is particularly important as mitigating climate change often needs additional talking points for governments and economic agents.

The recent perception of the globalization creating winners and losers also calls for more focus on the distributional effects of the energy transition. Costs and benefits for countries, industries, and groups of households have to be addressed to draw a more realistic picture of the energy transition and show possibilities and difficulties for policy making.

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