Sustainable Aviation Fuels for Air Transportation Decarbonization

TotalEnergies

Executive Summary

Energy is an essential resource, everywhere indispensable for living. With the global population expected to grow by almost 2 billion by 2050, there is an urgent need to accelerate the development of a decarbonized energy system while maintaining the current energy system to meet global demand and ensure a just, orderly and equitable transition.

The aviation industry faces a considerable challenge to decarbonize itself, due to its growth and the current maturity and cost of low-carbon technologies. Sustainable Aviation Fuels (SAF) are anticipated to be the primary method for reducing air transportation emissions by 2050, provided that effective policies and regulations are put in place.

TotalEnergies aims to become a major player in SAF production. The Company is involved in various projects and partnerships to produce SAF from waste and residues, one of them in China.

1. More Energy, Less Emissions

Energy is an essential resource, everywhere indispensable for living: for food, lighting, heating and cooling, transport, healthcare, construction and trade.

Historically, energy demand has grown in line with demographic growth and rising living standards (see Chart 1).

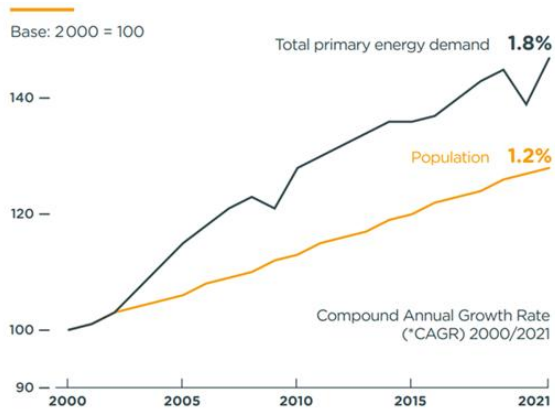

CHART 1: EVOLUTION OF TOTAL PRIMARY ENERGY DEMAND (TPED) AND WORLD POPULATION GROWTH

The world's population is set to grow by almost 2 billion additional inhabitants by 2050. This prospect will have significant implications for achieving the UN's Sustainable Development Goals (SDGs) to improve prosperity and social well-being while protecting the environment and biodiversity.

In the countries of the Global South, where access to energy is already one of the limiting factors in human development (see Chart 2), populations aspire to improve their quality of life.

In OECD countries, energy has enabled socio-economic development that no country is prepared to forego.

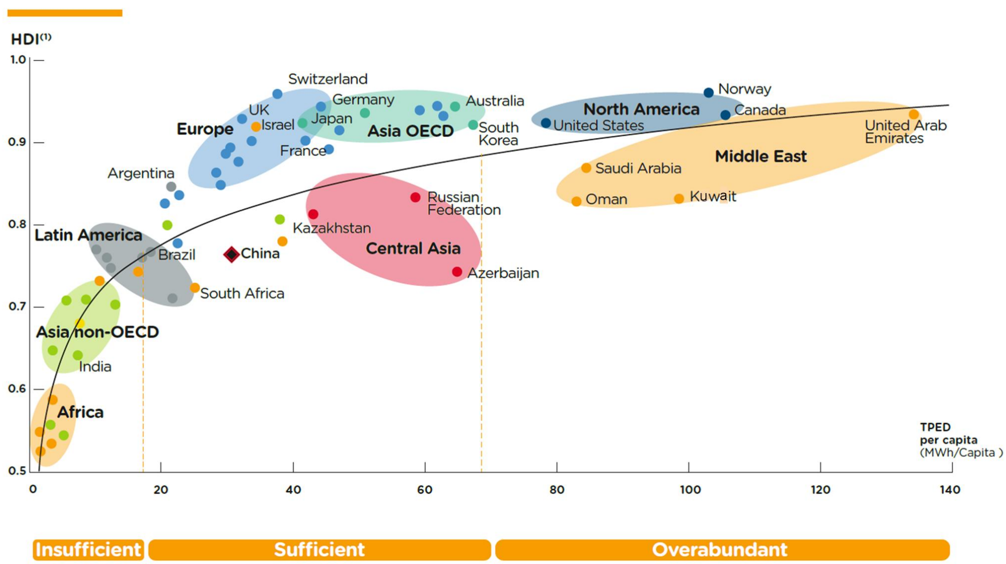

CHART 2: TOTAL PRIMARY ENERGY DEMAND (TPED) PER CAPITA VS THE HUMAN DEVELOPMENT INDEX (HDI)

Sources. Population: Oxford Economics, TPED–Enerdata. Graph: adapted from Smil, Vaclav. Energy and Civilization: A History. The MIT Press, 2018; data from World Bank, Energy Institute, EIA databases. Human Development Index (HDI) combines life expectancy at birth, adult literacy, combined educational enrollment, and per capita GDP.

The Global South, which generally refers to the countries with a lower level of economic development covering a population of almost 4 billion, has an average energy demand per capita of only 50GJ/capita. India as well is only averaging 30GJ/capita for its 1.4 billion population. The NZ50 countries (mainly OECD countries) present an average of 166GJ/cap.

The IPCC reiterated in 2021[1] that global warming is the consequence of GHG emissions linked to human activities and warned of the environmental and socio-economic impacts of this already tangible climate change.

Since the Paris Agreement in 2015, States have jointly pledged *"to strengthen the global response to the threat of climate change, in the context of sustainable development and the fight to eradicate poverty, in particular by holding the increase in global average temperature to well below 2°C above pre-industrial levels and pursuing efforts to limit the temperature increase to 1.5 °C above pre-industrial levels"*.

The energy system must therefore be transformed, because energy is at the heart of this global climate challenge: green-house gas (GHG) emissions linked to the production or use of energy account for over 60% of global emissions in 2021 (ref. IPCC & IEA), as the global energy system is still 80% relying on fossil fuels.

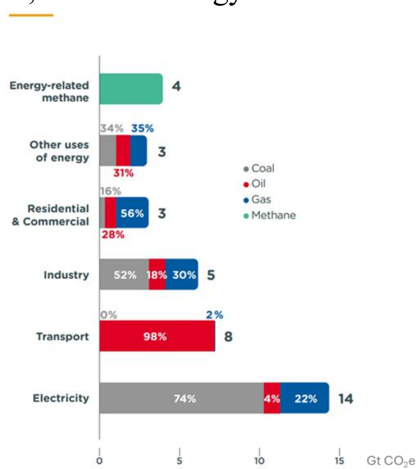

CHART 3: GLOBAL GHG EMISSIONS FROM FOSSIL FUEL COMBUSTION IN 2021 - 37 Gt CO_2e

Sources : CO2 Emissions in 2022, IEA, rapport et database : https://www.iea.org/reports/CO2-emissions-in-2022 – Emissions in 2022 – Analysis - IEA. Greenhouse Gas Emissions from Energy Data Explorer (update 2023) : https://www.iea.org/data-and-statistics/data-tools/greenhouse-gas-emissions-from-energy-data-explorer – Greenhouse Gas Emissions from Energy Data Explorer – Data Tools - IEA.

There is an urgent need to accelerate the development of a decarbonized energy system while maintaining the current energy system at a level sufficient to meet global demand and organize a just, orderly and equitable transition of energy systems. Rather than one unique "energy transition", each country will have its own development path for a sustainable energy future.

That being said, reducing energy-related emissions (see Chart 3), can be done by

1 Climate Change 2021: The Physical Science Basis and other assessment reports.
The Intergovernmental Panel on Climate Change (IPCC) is the United Nations body for assessing the science related to climate change

leveraging some common global levers

• minimizing the share of coal in the electricity mix, starting from OECD countries

• decarbonizing the transport sector (currently 90% powered by petroleum products), including the aviation sector

• aiming for the elimination of methane emissions from fossil fuel production processes

To achieve this, massive investments are needed, not only in renewable energy, but also in electricity networks and systems enabling the availability and stability of the new electricity system.

Another challenge is to reduce fossil fuel consumption at the right pace. In the Global South, fossil fuels remain an affordable solution for providing growing populations with access to energy, and therefore greater prosperity.

The transition will not take place without social acceptability (both between North and South and within OECD countries) and without genuine efforts in terms of climate justice. Accelerating the pace of investment in low-carbon energies requires strong cooperation between the private and public sectors.

China Energy Landscape

China is the world's 2nd largest economy, with the leading growth rate among the world's major economies with an average annual growth rate of ~5% in the past 3 years. It is the world's largest energy consumer, with high ambitions to achieve its energy transition.

In September 2020, China announced its pledge to reach peak carbon emissions by 2030 and carbon neutrality by 2060. Along with this announcement, the Government of China has set some key targets by 2030:

- Coal consumption to peak during the 15th Five-Year Plan period (2026-2030)
- Over 1,200 GW of total installed capacity for wind & solar power, which was reached in 2024
- Add ~100 GW battery storage capacity
- Reach 120 GW pumped storage hydropower installed capacity
- Electric Vehicles to reach 40% of new car sales, which was already exceeded in 2024
- Reach 25% coverage of national forests (2010: 21.4%, 2021: 23.6%)
- Lower CO_2 emissions per unit of GDP by >65% from the 2005 level
- Non-fossil energy's share in primary energy use to reach ~25%

- National unified power market with 100% renewables transacted

The country also shows ambitions in the decarbonization of transportation, notably with the promotion of electrification and LNG-fueled heavy-duty trucks for road transportation, the development of high-speed rail network for long distance travels, and the participation in the Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA) in order to address the CO2 emissions generated by international aviation. It is worth mentioning that in the context of the 14th Five-Year Plan, a non-mandatory target for Chinese airlines to reach 50 kt of accumulated consumption of SAF by 2025 was set.

2. The Decarbonization of Aviation Industry through Sustainable Aviation Fuels (SAF)

According to the International Energy Agency, the aviation industry emissions reached almost 950 Mt CO_2 in 2023, accounting for 2.5% of global energy-related CO2 emissions in 2023 and having grown faster between 2000 and 2019 than road, rail or shipping.

The worldwide aviation traffic is expected to recover its pre-COVID level by 2024/2025 and should double by 2050 to reach more than 20 000 billion passenger kilometers (bn p.km.) annually. Over the same period, aviation energy demand is expected to increase by ~60% only thanks to significant energy efficiency improvements, notably engines, aerodynamics, air traffic management.

Aviation poses a difficult challenge to the global effort to decarbonize transportation. Air travel is popular, and emissions from the sector are growing rapidly. But the low-carbon technologies required to decarbonize aviation are still maturing and expensive. For this reason, aviation (along with shipping and energy-intensive industrial sectors such as steelmaking) is often described as “hard to abate.”

Decarbonizing aviation will not be easy and SAF is expected to be the main source of reduction by 2050.

3. Aviation Fuel and SAF Demand

The global aviation industry is projected to continue its growth trend particularly with the rising population and the growing middle class boosting more demand for aspirational travel.

Overall, Aviation Fuel (Jet) demand is expected to reach about 500 Mt by 2050 in most forecasts, versus approximately 260 Mt in 2023, and 320 Mt in 2019 pre COVID.

Growth in the Asian region will be particularly strong: in the TotalEnergies Energy Outlook 2024 Trends scenario[2], energy demand for aviation in the region is expected to grow at 2.9% per year until 2050, reaching more than 40% of global demand by 2050 vs. about 30% today. By 2050, China is expected to reach almost 20% of the global demand vs. 15% today, thus becoming the second-largest market in the world after the US[3].

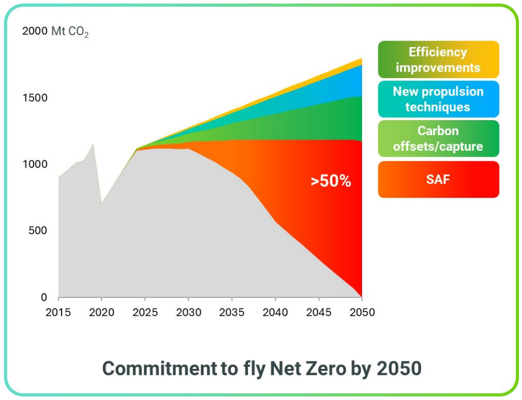

CHART 4: GLOBAL AVIATION DECARBONIZATION ROADMAP (IATA)

With the further growth projections in Jet Demand, reducing associated GHG emissions is a priority.

As shown in the International Air Transportation Association (IATA) roadmap to the decarbonization of global aviation (see Chart 4), four ways are privileged to achieve the commitment taken by the industry to "Fly Net Zero" by 2050.

- Optimization of flight operations (flight paths and taxiways);
- Technical improvements to engines and fleet renewal;
- Carbon offsets / capture;
- Sustainable Aviation Fuels (mainly in the form of Biofuels but also E-fuels), a solution that is available immediately.

Among these four levers, SAF is the most immediate and most efficient[4] solution for reducing CO_2 emissions from air transport and allowing customers to achieve their own targets for CO_2 emissions reductions.

By 2050, according to the IATA Roadmap, SAF will deliver more than 50% of the carbon reduction of the global aviation industry (up to 65% depending on the publication; 65% representing about 400 Mt of SAF by 2050).

However, as SAF is more costly than traditional jet fuel and as so far very few countries/regions have enacted SAF regulation with mandates (Europe, UK, Brazil representing 18% of 2023 total demand), different scenarios for SAF

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2 TTE has published in its TotalEnergies Energy Outlook 2024 three main scenarios 'TRENDS', 'MOMENTUM', and 'RUPTURE'- (TRENDS reflects the current trajectory of the various countries and anticipates technological developments and public policies / MOMENTUM scenario assumes NZ50 countries reach their objectives/ RUPTURE scenario is a back-casting approach meeting Paris Agreement)
3 TTE Demand growth consistent with most other forecasts, for example the International Energy Agency. IATA is an outlier, which expects more than 600 Mt by 2050.
4 According to a lifecycle analysis methodology done by European Union (RED II EU Directive), SAF demonstrated a reduction of at least 50% in greenhouse gas emissions compared to the fossil equivalent

penetration are presented in TotalEnergies Outlook 2024 (Chart 5).

The most ambitious one, RUPTURE, is close to the IATA projection with ~70% penetration of SAF by 2050 (~300 Mt) whereas the TRENDS scenario is more cautious with ~14% penetration of SAF by 2050 (70 Mt). Similar uncertainty can be seen amongst peer scenarios, as shown in Table 1.

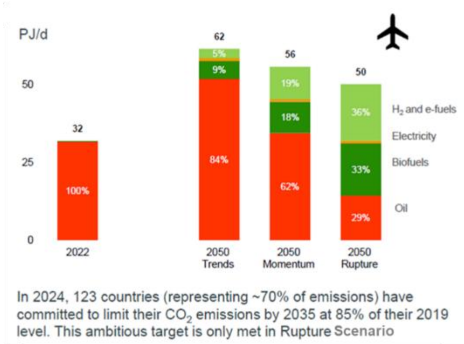

CHART 5: AVIATION 2050 FINAL CONSUMPTION SCENARIOS (SOURCE: TOTALENERGIES ENERGY OUTLOOK 2024)

TAI ERALL AVIATION FUEL DEMAND AND SAF DEMAND SCENARIOS FOR 2050

Scenario	**TRENDS24**	**RUPTURE24**	**IEA STEPS24**	**IEA APS24**	**DNV ETO24**	**IATA NZ24**
2050 SAF	~70Mt (14%)	~300Mt (70%)	~65 Mt (12%)	~200Mt (40%)	~210Mt (40%)	~400Mt (65%)
2050 Jet (Fossil+SAF)	~500Mt	~420Mt	~530 Mt	~500 Mt	~530Mt	~600Mt

4. SAF Production pathways

There are various pathways of producing SAF according to the feedstock and technology used to produce the molecules. They differ in feasibility and maturity of process and implementation, and they differ in terms of cost (see Chart 6).

- SAF from HEFA pathway (including Coprocessing): such SAF biofuels are derived from biomass through Hydrotreated Esters and Fatty Acids (HEFA). This pathway can use vegetable oils or waste and residues from the circular economy.

Currently, there is a growing preference to produce SAF from waste and residues generated by the local economy:

- o Used Cooking Oil (UCO): UCO has a global potential of around 15 Mt/y (12 Mt/y in 2024, growing to 17 Mt/y by 2030). Collection circuits are gradually being set up to recover these used materials from food processing plants and restaurants.

- Animal Fat (AF): recycled animal fat comes from suppliers at rendering plants and abattoirs. They are subject to strict health controls. The global resource is around 10 Mt/y.

Advanced feedstocks such as food waste, brown greases and intercrops will allow to access additional volumes of feedstocks to complement UCO and AF resources.

- SAF from Alcohol to Jet (AtJ) pathway: Such SAF biofuels are produced in a process where sugary, starchy biomass such as sugarcane and corn grain are converted via fermentation into ethanol or other alcohols which can then be shipped or piped before being converted to fuel. This pathway is less mature today, and more costly.
- Gasification + Fischer-Tropsch (FT): The Gasification process involves converting the feedstock, for instance Municipal Solid Waste (MSW), into syngas, a mixture of carbon monoxide (CO) and hydrogen (H_2). This syngas can then be used in various applications, including the production of Fischer-Tropsch liquids, via a catalytic chemical reaction. This pathway remains more costly than the HEFA route.
- e-SAF: a synthetic fuel derived from renewable energy. It is also known as Power-to-X, synthetic fuel, renewable fuel of non-biological origin (RFNBO), or e-fuel, and is manufactured from captured CO_2 combined with renewable hydrogen or low-carbon hydrogen. Based on maturity of this pathway, scaling of e-SAF is a post-2030 story.

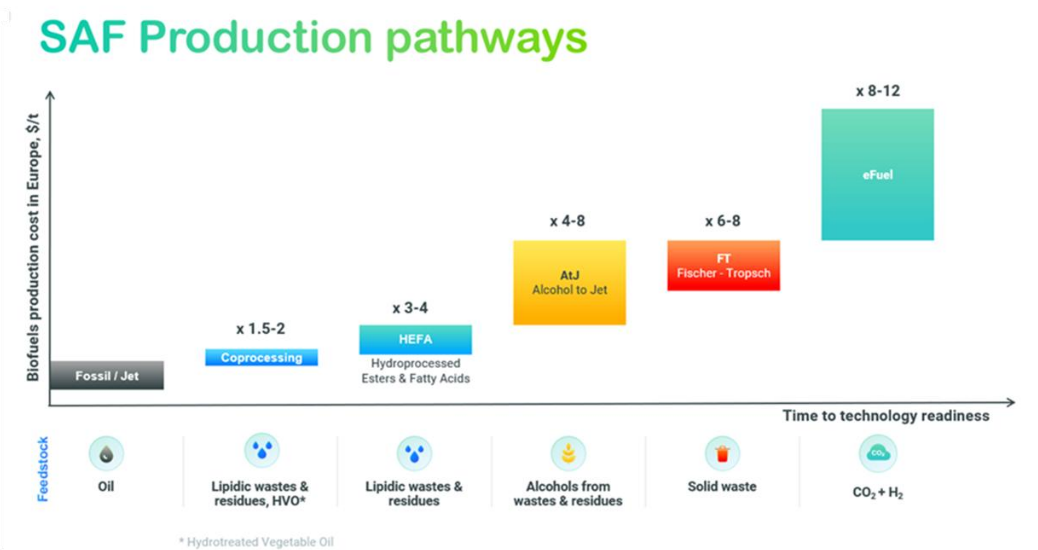

CHART 6: SAF PRODUCTION COSTS, CURRENT VISION (SOURCE: TOTALENERGIES)

The energy transition will require the combination of these different pathways and different feedstocks to ensure a sustainable journey with available and accessible solutions. Research and Development (R & D) efforts focused on innovating on newer technologies will be key to help accelerate the development of competitive SAF.

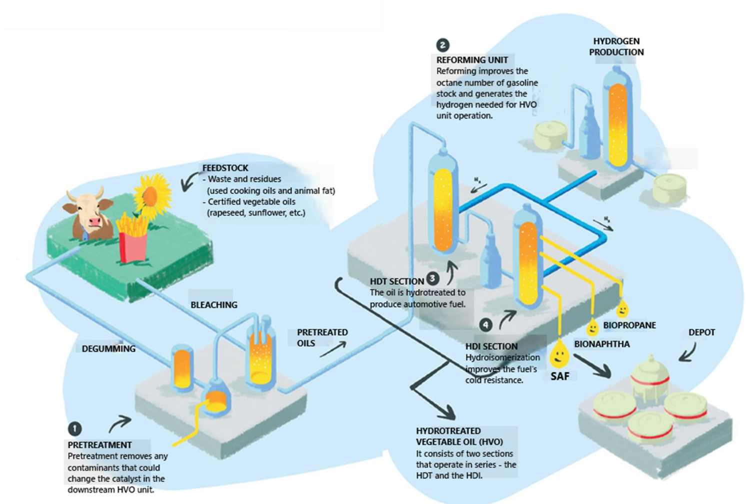

FIGURE 1: SAF PRODUCTION SCHEME IN A BIOREFINERY
(SOURCE: TOTALENERGIES)

In addition to production through new biorefineries (see Figure 1) or e-SAF units, SAF could also be produced in a standard refinery using the existing facilities through co-processing; with the incorporation of biomass feedstock alongside the standard fossil feedstock. After being produced, approved SAF products can then be a drop-in fuel that is blended into fossil jet to reduce greenhouse gas emissions by comparison with a standard aviation fuel.

5. SAF regulation

The history of SAF incorporation shows the vital role that policies and regulations play in the development of the market.

Due to the higher cost of production of SAF compared to the conventional fossil jet fuel, efficient policies and regulations are needed to provide a conducive environment to support investments in production capacities of SAF and to create the conditions for the SAF market to develop.

To give confidence in the SAF value chain, those policies and regulations should be stable in time and give enough visibility on the evolution of the size of the market over the mid/ long term, as it is the case in Europe which has put in place a blending mandate starting with 2% in 2025 and increasing progressively to reach 70% in 2050.

With Asia's rapidly growing Aviation fuel demand and the ambition to develop SAF to accompany the decarbonization of the industry in the region, authorities are currently considering implementing dedicated SAF policies to unlock SAF development and consumption in their countries.

Some common and efficient principles in discussion in several parts of the world and implemented in the EU are considered to do so:

- SAF definition: A clear definition of what qualifies as SAF is necessary. Key elements include the GHG savings threshold and the list of eligible feedstocks for SAF production (preferably local feedstocks, with attempts to harmonize the definition with other regions and/or regulations where possible).
- SAF Feedstock Traceability: A traceability policy involves identifying and tracing the origin, distribution, location, and application of products and materials through the various supply chains. A certification scheme based on a set of sustainability criteria should be established for SAF to provide confidence to the market and ensure the real benefits of using SAF.
- SAF blending mandates: Mandates are a set of measures aimed at reducing the carbon footprint of the aviation sector by requiring the airlines to gradually increase the use of sustainable aviation fuels (SAF) in their operations. Establishing a clear schedule of SAF percentage incorporated with fossil Jet fuel over the next 10 to 20 years, as done by the EU and UK, allows for the continuous evolution of the demand and accelerates the investment decisions for new capacities. Penalties mechanisms can be put in place to accompany the non-compliance of these mandates, supporting price signals for the development of SAF.
- Incentives mechanisms, such as tax credits or subsidies, can help and support the actors in making their investments in SAF infrastructure and or production units. It can also be used to help reduce the price gap between conventional Jet fuel and SAF for the consumers (Airlines).
- "Cap and Trade" principle sets a limit on the total amount of certain greenhouse gases that can be emitted within an Industry sector. This requires stakeholders (e.g., airlines) to monitor, report, and verify their CO_2 emissions. Under such regulation, Airlines are allocated a certain number of emission allowances (quotas) each year based on their historical emissions. The cap on emissions is gradually reduced over time to ensure the continuous progress in reducing carbon emissions.
- Flexibility: Establishment of a national mass balance system that allows a fuel supplier to deliver SAF to any airport in the country as long as it

fulfills its obligation in average with the total volumes of SAF delivered that year. Such flexibility is essential for integrating SAF into existing fuel supply chains and can help in balancing supply and demand more effectively.

- Production pathways: The market should be allowed to choose the most feasible and economical pathways to produce SAF (i.e. be tech neutral). Only when necessary, policies can incentivize the development of less mature pathways by putting sub-mandates in place.

TotalEnergies in China

TotalEnergies is a global integrated energy company that produces and markets energies: oil and biofuels, natural gas and green gases, renewables and electricity. Our more than 100,000 employees are committed to provide as many people as possible with energy that is more reliable, more affordable and more sustainable. Active in about 120 countries, TotalEnergies places sustainability at the heart of its strategy, its projects and its operations. TotalEnergies reaffirms the relevance of its balanced integrated multi-energy strategy considering the developments in the oil, gas and electricity markets. Anchored on two pillars, Oil & Gas, notably LNG, and electricity, the energy at the heart of the energy transition.

Present in China since 1979, TotalEnergies is active across the entire value chain of China's energy industry, with a team of ~ 4,000 employees. TotalEnergies' ambition and strategy fit China's energy transition goals to achieve carbon peak by 2030 and carbon neutrality by 2060.

The main activities and projects in China are: (1) in Natural Gas, the production of tight gas in South Sulige (Inner Mongolia) together with CNPC started in 2012. 4 bcm/y were produced in 2023; (2) in LNG, TotalEnergies is a key supplier to China with both long-term contracts and spot deals; (3) in Onshore and Offshore Renewables, TotalEnergies, a large player in wind and utility-scale solar worldwide, is screening attractive opportunities to develop renewable projects in China together with strategic partners; (4) in Energy Storage, with a battery plant and a manufacturing hub for energy storage solutions (ESS) in Zhuhai, TotalEnergies' battery company Saft serves market sectors ranging from civil electronics to rail transportation; (5) in Distributed Solar Generation (DG), through JVs with Envision and Cathay Capital, TotalEnergies has been active since 2019 in solar DG for industrial and commercial customers (~500 MW capacity in operation); (6) in EV Charging, there are ~4,600 EV charging points currently operated through a JV with China Three Gorges (CTG) in Hubei, Sichuan, Hunan and Shaanxi provinces; (7) in Retail, TotalEnergies currently operates ~440 service stations, in Wuhan through its wholly-owned company and in North & East China regions through a JV with Sinochem; (8) in Sustainable

Aviation Fuels (SAF), TotalEnergies intends to become a major player in the production of SAF, with a target of 1.5 Mt/y by 2030, thanks to SAF production in its platforms or through partnerships. In Asia, TotalEnergies and SINOPEC signed a Heads of Agreement (HoA) in 2024 to jointly develop a SAF production unit at a SINOPEC's refinery in China. The planned unit, jointly owned by SINOPEC and TotalEnergies, will have the capacity to produce 230 kt/y of SAF, and will process local waste or residues from the circular economy; (9) in Lubricants, TotalEnergies owns 3 local blending plants and offers a comprehensive range of high-quality lubricant products for the automotive (incl. EV fluids), industrial sectors and the marine fleet; (10) in Chemicals, TotalEnergies is active as trader and distributor of petrochemicals & polymers and has polypropylene compounding operations in Zhenjiang. Its specialty chemicals affiliate Hutchinson, present in China since 1998, which has continuously expanded its operations to multiple production sites.