

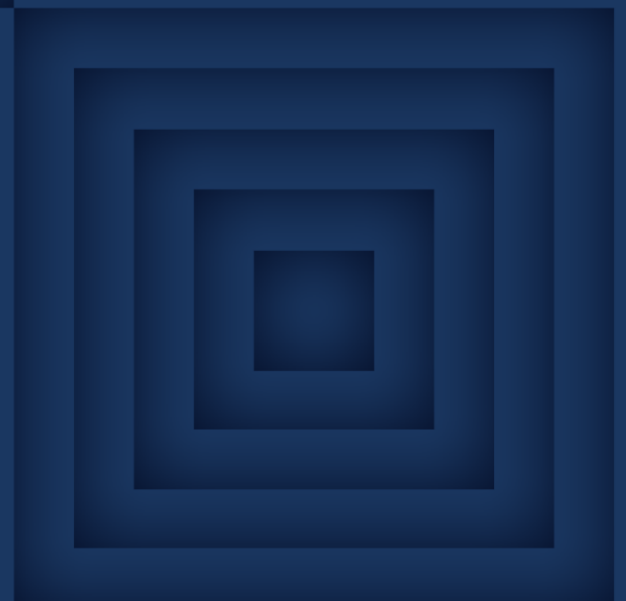
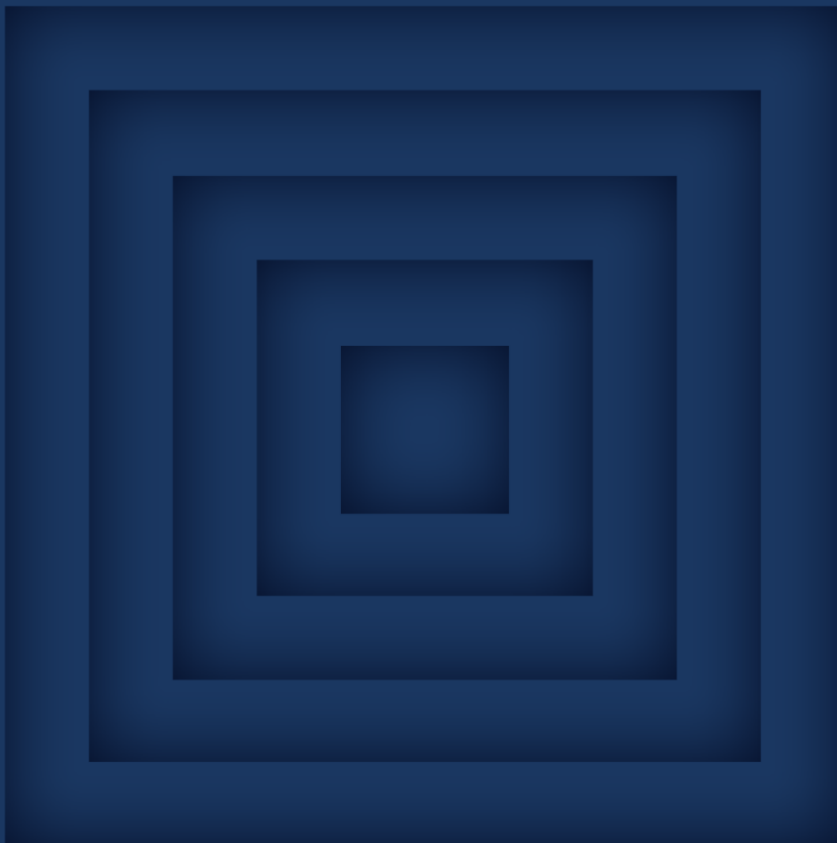


The Hague Centre  
for Strategic Studies

# **From the war in Ukraine to the energy transition**

## Searching for a new balance in the oil market

**Irina Patrahau, Lucia van Geuns and Jilles van den Beukel**  
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Authors: Irina Patrahau, Lucia van Geuns and Jilles van den Beukel

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The Hague Centre for Strategic Studies  
info@hcss.nl  
Lange Voorhout 1  
2514 EA The Hague  
The Netherlands

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# 1. Introduction

The global oil market is changing. The increasingly noticeable consequences of the energy transition are compounded by a series of economic and geopolitical events: the Covid-19 pandemic, followed by a rapid economic rebound, the war in Ukraine and, by now, an expected global economic recession. The world is struggling to find a new balance. Geopolitics is back to the fore.

Many of the issues that became evident in the 2022 energy crisis, including a tight oil market, lack of investments and geopolitical developments, are rooted in longer term trends. This paper aims to shed light on some of the structural issues that contributed to the current crisis, as well as look ahead into some important trends in the oil market up to 2050.

In the next 2-3 years, the sixth sanctions package of the European Union (EU) toward Russia, with the notable maritime oil boycott, is consolidating the pre-existing volatility in the global oil market.<sup>1</sup> As Russia is looking for new energy markets and the EU for alternative producers of fossil fuels, the world oil map is being redrawn. Trade routes will shift as oil traditionally sold to Asian or African consumers will now have to be re-routed to Europe. Russian oil that was traditionally exported to Europe has to find new markets, shifting toward China and India. Will the new energy world split apart into two zones, one dominated by the United States (US) and one dominated by the Organisation of the Oil Exporting Countries (including Russia) (OPEC+)? Can OPEC+ maintain its dominance in the global oil market and stabilize prices? Is the US emerging as the main energy superpower?

Decarbonization policies are having a major impact on the oil industry and oil markets. The peak global oil consumption may well come in the late 2020s, but it is uncertain how fast it will decrease afterwards.<sup>2</sup> European countries are struggling to find a balance between climate goals and energy security, especially as the war in Ukraine is forcing governments to move back to coal for the time being. Decisive and accelerated action is needed for an orderly energy transition, but current energy developments point to isolationism, nationalism and therefore a more chaotic exit of fossil fuels from our energy system. The increasing dependence on Middle Eastern and Chinese national oil companies in the next 10-20 years is making the energy transition more challenging. Up to 2050-2070, countries around the world have pledged to reach carbon neutrality. Depending on the scenario at hand, oil products will still be used in 2050 albeit to a much lower extent than today. The most important oil suppliers in this case will be those who can produce oil at a low cost with minimal greenhouse gas (GHG) emissions, for instance through carbon capture and storage.<sup>3</sup>

<sup>1</sup> "EU Adopts 6th Package of Sanctions against Russia," European Commission, June 2022, [https://ec.europa.eu/commission/presscorner/detail/en/IP\\_22\\_2802](https://ec.europa.eu/commission/presscorner/detail/en/IP_22_2802).

<sup>2</sup> "Global Energy Perspective 2022," McKinsey & Company, April 2022, <https://www.mckinsey.com/industries/oil-and-gas/our-insights/global-energy-perspective-2022?cid=other-eml-nws-mei-mei-oth-2205&sid=a0a30752-2201-4e5a-a5b3-f3b807b2030b>.

<sup>3</sup> Amy Chronis et al., "Positioning for Green: Oil and Gas Business in a Low-Carbon World" (Deloitte, 2021), <https://www2.deloitte.com/us/en/insights/industry/oil-and-gas/low-carbon-energy-transition.html>.

## 2. Setting the scene: structural issues in the oil market

The Covid-19 pandemic and the war in Ukraine have rapidly exacerbated a series of structural issues that the oil market has dealt with since 2014. The increasing tightness of the oil market in recent years is one of the most important ones.

The oil price plunge between 2014 and 2016 was to a large extent driven by the US shale oil boom, which added a significant amount of oil to the market. The supply glut rapidly led to a significant decrease in global prices. Subsequently, financial issues and market uncertainty led producers to almost half the capital expenditure in exploration and production projects (E&P Capex) between 2014 and 2016, from \$920 to \$503 billion (see Figure 1). Even though oil prices recovered in 2017, E&P Capex did not grow equally rapidly, to a large extent because of pressure from non-governmental organisations (NGOs), governments and investors to reduce oil consumption and move toward low-carbon energy sources. The low investments, however, had the unintended consequence of limiting the ability of oil producers to rapidly increase output if needed. The US is a notable exception.

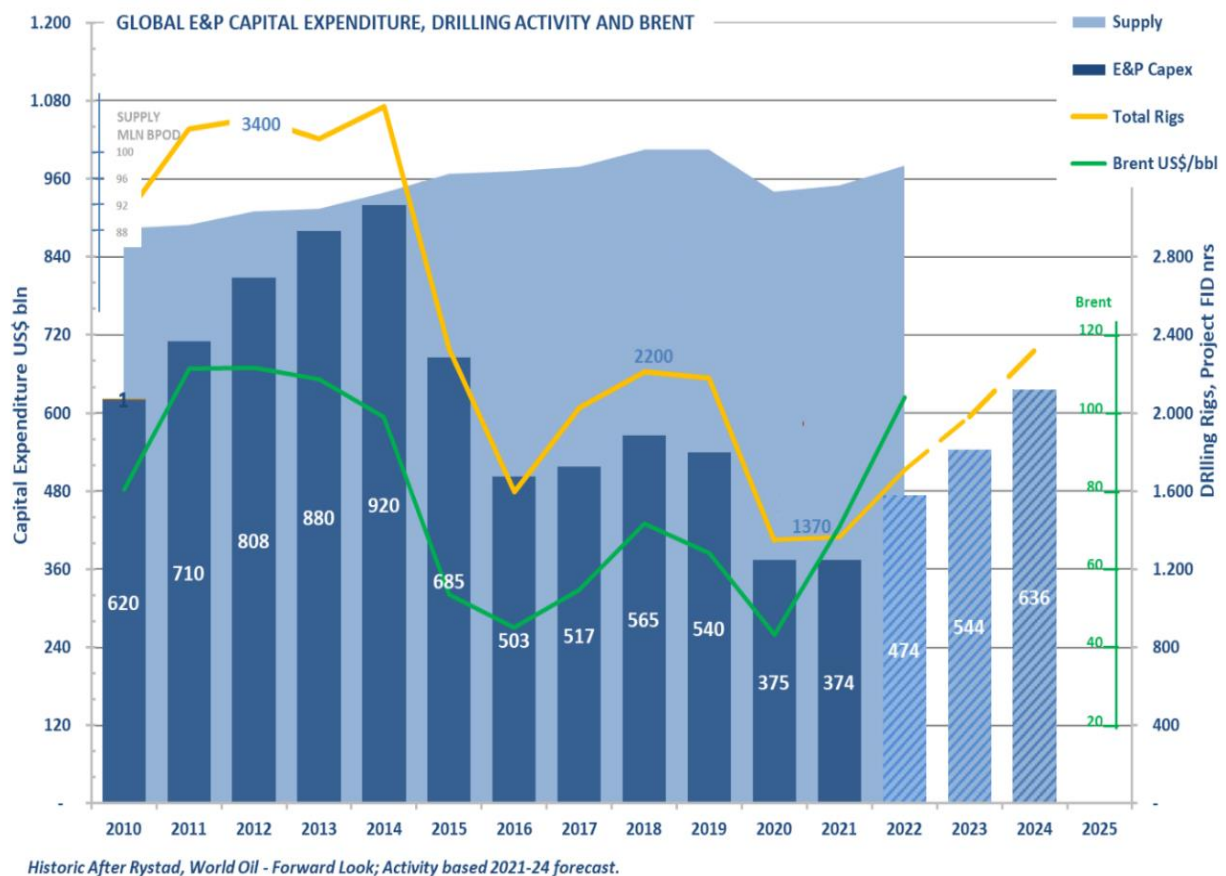


Figure 1. Global exploration and production capital expenditure (E&P Capex), drilling activity and Brent oil price.

Because of the short cycle time of shale oil, the US can adjust to oil price movements more rapidly than OPEC countries. The US became a balancer in the oil market, even though the shale industry was struggling with financial issues of its own (see next section).

The oil industry was put under significant pressure in 2020. The Covid-19 pandemic resulted in one of the sharpest declines in global oil consumption in history, as oil demand declined from 99 million barrels a day (mb/d) in 2019 to 90 mb/d in 2020.<sup>4</sup> This was caused by working from home mandates and the significant reduction in air transport, paired with the slow-down in industrial activity and manufacturing, and re-shoring of supply chains.<sup>5</sup> The tumultuous period at the beginning of the Covid-19 lockdown measures led to global prices plummeting to unprecedented levels in April 2020. Oil producers were struggling to find sufficient storage capacity for the surplus of oil that could not be sold due to the decrease in demand, with oil stocks reaching all-time high levels in June 2020.<sup>6</sup>

The spot price for Brent Crude, the global benchmark for oil prices, fell from \$63.65 per barrel (bbl) in January 2020 to \$18.38/bbl in April.<sup>7</sup> The May 2020 contract for US crude oil (Cushing, Oklahoma), reached \$-37.63/bbl just before contract expiry.<sup>8</sup> This negative value was partly caused by limitations in existing infrastructure in the physical market, as Cushing is a landlocked hub dependent on pipeline capacity to deliver the oil. Contrastingly, Brent is a waterborne crude with the hub in the ARA (Amsterdam-Rotterdam-Antwerp) ports, which could be sent away with more ease. This situation was also affected by the supply war between Russia and Saudi Arabia, who instead of immediately cutting production to stabilize the market, continued production and flooded the market. Eventually, in an attempt to reduce surplus and stabilize prices, OPEC+ decided to decrease production in May 2020.<sup>9</sup>

In 2021, pandemic measures were gradually eased, resulting in a recovery of global oil demand. Demand averaged 96 mb/d in 2021.<sup>10</sup> In 2022, global oil demand returned to 2019 levels. The rapid post-pandemic recovery, characterized by a sharp increase in road transport, aviation, and shipping, was not met by an equally fast increase in oil production. Production outages caused by weather events like Hurricane Ida in the US, combined with fires at facilities in Mexico and Russia, as well as operational issues in Nigeria, Libya and Kazakhstan, led to continued issues for suppliers to meet demand.<sup>11</sup> Other OPEC+ members have been struggling to reach their production targets due to political instability, corruption and/or lack of investments (see next section). The largest oil producers in OPEC, particularly Saudi Arabia and the United Arab Emirates, could raise their production but made a choice not to do so.

The record levels of oil inventories in 2020 were followed by a sharp decline in stocks that lasted almost two years, as shown in Figure 2. High oil prices, tight supply and geopolitical instability led to a number of coordinated releases of strategic reserves from OECD countries.<sup>12</sup> When inventories and spare capacities are low, the ability of market players to stabilize oil prices becomes very weak. The oil price therefore becomes highly susceptible to external factors and volatility dominates the market.

The Russian invasion of Ukraine in February 2022 placed additional pressure on the global energy system, after two years of already volatile markets. In the first weeks after the war erupted, governments started sanctioning Russian companies. Self-sanctioning by companies also became common, for instance by temporarily or permanently

<sup>4</sup> IEA, "Oil Market Report," December 2021, [https://iea.blob.core.windows.net/assets/0921d7d0-7a36-4f15-b920-efcbbff2038b/-14DEC2021\\_OilMarketReport.pdf](https://iea.blob.core.windows.net/assets/0921d7d0-7a36-4f15-b920-efcbbff2038b/-14DEC2021_OilMarketReport.pdf).

<sup>5</sup> Dan Klein and Mark Mozur, "Moving Mountains: COVID-19 and Peak Oil Demand," 2020, <https://www.spglobal.com/en/research-insights/featured/moving-mountains-covid-19-and-peak-oil-demand>.

<sup>6</sup> IEA, "Oil Market Report," August 2020, <https://www.iea.org/reports/oil-market-report-august-2020>.

<sup>7</sup> "Europe Brent Spot Price FOB (Dollars per Barrel)," U.S. Energy Information Administration, June 15, 2022, <https://www.eia.gov/dnav/pet/hist/LeafHandler.ashx?n=PET&s=RBRT&f=M>.

<sup>8</sup> "Cushing, OK Crude Oil Future Contract 1 (Dollars per Barrel)," U.S. Energy Information Administration, June 15, 2022, <https://www.eia.gov/dnav/pet/hist/RCLC1D.htm>.

<sup>9</sup> IEA, "Oil Market Report," April 2020.

<sup>10</sup> IEA, "Oil Market Report," June 2022, <https://www.iea.org/reports/oil-market-report-june-2022>.

<sup>11</sup> IEA, "Oil Market Report," September 2021, [https://iea.blob.core.windows.net/assets/0921d7d0-7a36-4f15-b920-efcbbff2038b/-14DEC2021\\_OilMarketReport.pdf](https://iea.blob.core.windows.net/assets/0921d7d0-7a36-4f15-b920-efcbbff2038b/-14DEC2021_OilMarketReport.pdf).

<sup>12</sup> IEA, "Oil Market Report," June 2022, 50.

exiting the Russian market, by refusing to receive and handle tankers with Russian oil in their ports, or by withdrawing from joint ventures with Russian companies (e.g., Maersk, Equinor, BP).<sup>13</sup>

The United States and Canada quickly imposed bans on imports of Russian oil.<sup>14</sup> As their dependency on Russian oil was minimal, these measures were politically motivated and had little direct economic impact. For the EU, the largest market for Russian oil, imposing such a ban was a more problematic decision due to its large economic impact. The EU's dependency on Russian gas further complicated matters, as interruptions in the delivery of oil and gas could not be seen in isolation from each other. Between February 24 and June 3, the Russian revenues derived from European imports of Russian fossil fuels amounted to €57 billion.<sup>15</sup>

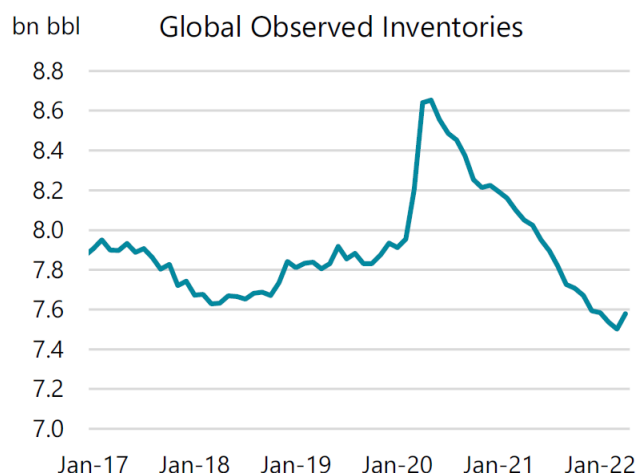


Figure 2. Global observed oil inventories 2017-2022 (Figure from IEA, "Oil Market Report," 2022, 44).

In fact, Russian supplies of oil and gas flowed toward Europe without interruption between the beginning of the war in February and June 2022. During the first 100 days of the war in Ukraine, China, the Netherlands, Italy and Germany were the largest importers of Russian oil (Figure 3).<sup>16</sup> Ports of Rotterdam, Trieste and Maasvlakte received the largest shipments of Russian oil. Despite sanctions, Russia was the OPEC+ member that saw the largest increase in oil production in May 2022.<sup>17</sup> In other words, the oil market had been under significant pressure due to geopolitical tensions and uncertainty although the physical amount of Russian oil had not (yet) decreased.

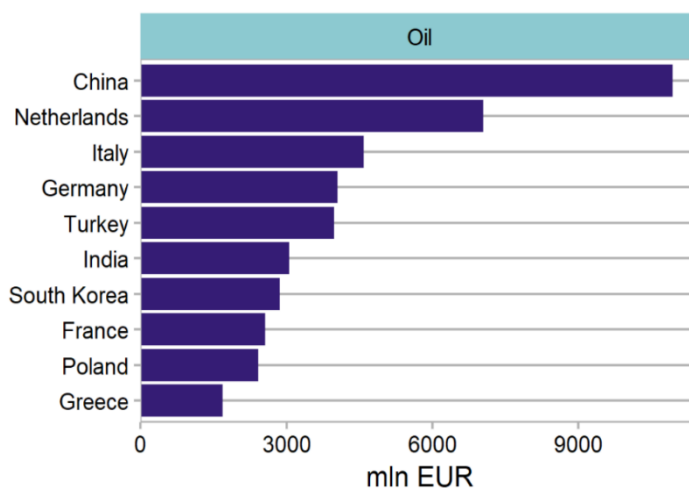


Figure 3. Largest importers of oil from Russia in the first 100 days of the invasion (Figure from CREA, "Financing Putin's War: Fossil Fuel Imports from Russia in the First 100 Days of the Invasion," 2022, 7).

<sup>13</sup> "Tracking Sanctions against Russia," *Reuters*, May 31, 2022, <https://graphics.reuters.com/UKRAINE-CRISIS/SANCTIONS/byvrvjenzmve/>.

<sup>14</sup> "Tracking Sanctions against Russia."

<sup>15</sup> CREA, "Financing Putin's War: Fossil Fuel Imports from Russia in the First 100 Days of the Invasion," June 13, 2022, 2, [https://energyandcleanair.org/wp/wp-content/uploads/2022/06/Financing-Putins-war-100-days\\_20220613.pdf](https://energyandcleanair.org/wp/wp-content/uploads/2022/06/Financing-Putins-war-100-days_20220613.pdf).

<sup>16</sup> CREA, 7.

<sup>17</sup> IEA, "Oil Market Report," June 2022, 18.

# 3. Short term: volatility and a new energy system

The search for a new equilibrium in global politics is unmistakably mirrored by energy markets. Geopolitics is once again the driving force in the global energy system, in a world that has not yet rearranged after the pandemic. The EU and its allies are decoupling from Russia, struggling to secure affordable energy supplies and continue the fight against climate change. A more fragmented (energy) world is emerging, with different views of whether Russia is an acceptable partner and energy provider. Geopolitics and geology are turning the US into the world's energy superpower.

The next 2-3 years may see an increasing amount of volatility and uncertainty as a new energy map is emerging. The high oil prices will eventually decrease as a result of demand destruction. But how long will it take for the system to settle down? Until a new energy system is established, and a new balance is found, prices will remain susceptible to the constant market shocks and geopolitical events. The following sections outline some of the main developments affecting oil market players: energy crisis in the EU, significant losses for Russia, production issues for OPEC, and unexpected gains for the US.

## 3.1. Energy crisis and economic recession

EU member states reached an unprecedented degree of integration in their energy policy by agreeing to an embargo on Russian seaborne oil imports (see Box 1).

Even though the EU oil boycott will not be enforced until the end of 2022, its anticipated arrival has already led to significant consequences for both the global and the European energy markets. The most significant impact relates to energy prices, inflation and the possibility of an economic recession. A perfect storm of geopolitical instability, tight supplies and a decrease in investments in oil exploration and production, has led to the high oil prices. The war in Ukraine is placing significant pressure on oil and gas markets, but also on global food supplies. Diesel is the most widely used oil product in the EU as taxation schemes in the last decades have incentivized the switch from gasoline in road transportation. Although the EU is producing a large part of its diesel, the Union is still very dependent on Russian supplies. Many refineries, especially in Central Europe, function based on Russian crude oil.<sup>18</sup> Diesel imports are also required to fulfill domestic demand. In 2019, 80% of Europe's diesel imports came from Russia, while around 20% came from the US.<sup>19</sup> The Russian oil boycott is bringing upward pressure on prices due to expected diesel shortages in Europe.

The crisis is amplified by Putin's weaponization of energy. In the first two months of the war, natural gas and oil from Russia to Europe flowed under a business-as-usual scenario. Europe had decided to reduce dependency on Russia, but such a shift, especially from Russian natural gas, could not be done in the short term. Europe would need to find new suppliers and establish the needed infrastructure.

<sup>18</sup> Benedict George, "Europe Would Struggle to Replace Lost Russian Products," Argus Media, January 24, 2022, <https://www.argusmedia.com/en/news/2294752-europe-would-struggle-to-replace-lost-russian-products>.

<sup>19</sup> FuelsEurope, "Statistical Report 2021," 2021, 31.



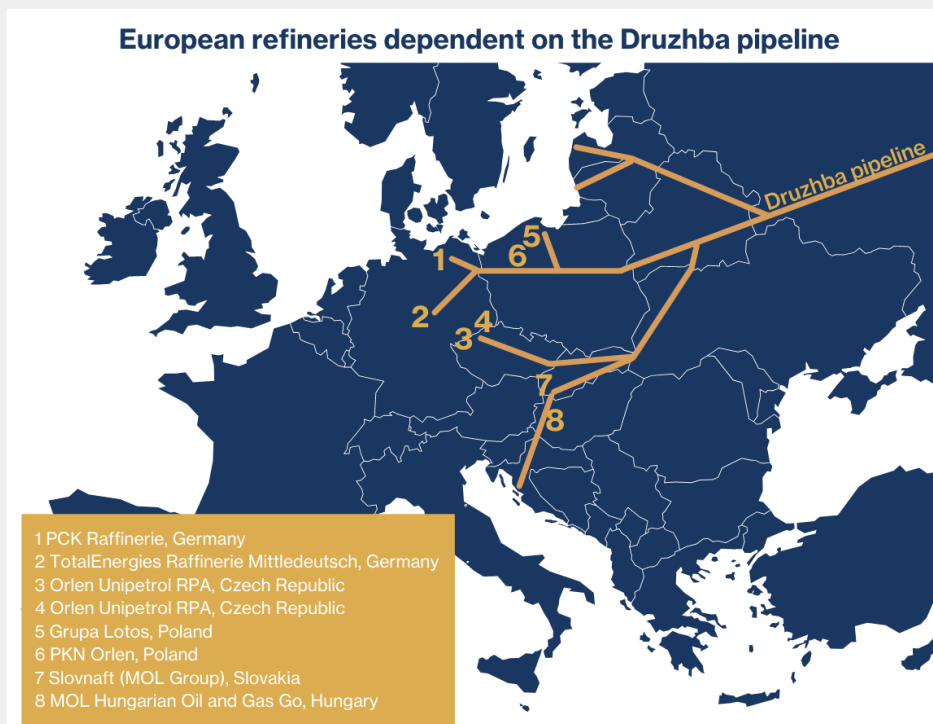
A further reduction of gas exports is Putin's retaliation to the oil boycott. The first disruptions in gas supplies were announced at the end of April 2022, when countries like Poland, Bulgaria and the Netherlands refused to pay state-owned Gazprom in rubles for the imported gas.<sup>20</sup> Once the European Commission announced the oil boycott, more serious interruptions targeted the largest European consumers of Russian gas, Germany and Italy. The interruptions were rationalized based on arguments such as missing technical pieces or were simply not explained at all.<sup>21</sup> There is little doubt that these arguments were pretexts and that the moves were geopolitically motivated.

The Russian government still has some leverage until the boycott is enforced. If Moscow decides to stop oil through the Druzhba pipeline before December, Europe in general and countries in central and eastern Europe in particular would suffer significantly.

The geopolitical instability and energy crisis are directly affecting consumers, who have to pay increasingly higher bills for gasoline and diesel, electricity and heat, but also food. The soaring inflation in the Eurozone and in the US is the highest it has been in years, leading the European Central Bank and US Federal Reserve to increase interest

### Box 1 | What does the 2022 EU oil boycott cover?

For crude oil, the boycott will apply from November 2022 onwards; for petroleum products from January 2023 onwards. Some exceptions apply for Bulgaria until the end of 2024, who will be able to keep importing Russian oil, as well as Croatia until 2023, who can proceed with the imports of vacuum gas oil (VGO). Moreover, the EU boycott excludes oil coming through the Soviet-time Druzhba pipeline to Poland, Hungary, Slovakia, the Czech Republic and Germany. Oil refineries in Central Europe are highly dependent on Russian Urals blend coming through this pipeline, as illustrated in the map below. Especially landlocked countries like Hungary and the Czech Republic will encounter issues in replacing this oil as they cannot directly import non-Russian oil. Excluding pipeline imports to several Central and Eastern European countries is meant to partly mitigate the negative economic impact.



Box 1. The EU oil boycott.

<sup>20</sup> Daniel Boffey, "Russia Begins 'Gas Blackmail' of Poland and Bulgaria Ahead of UK Call to Boost Ukraine Military Aid," *The Guardian*, April 26, 2022, <https://www.theguardian.com/world/2022/apr/26/russia-to-halt-gas-supply-to-poland-government-told>.

<sup>21</sup> Stanley Reed, "Russian Gas Flows to Germany Get Snarled in Canada," *The New York Times*, June 14, 2022, <https://www.nytimes.com/2022/06/14/business/russian-gas-germany-canada.html>.

rates.<sup>22</sup> A boycott of Russian oil will further tighten the oil and food markets and could lead to economic recession.<sup>23</sup> Eventually, the high oil prices will shrink because of demand destruction – consumers would use less oil because they cannot afford it, decreasing demand and thus stabilizing the market. But price instability and volatility will remain the leitmotif until the new energy system is settled.

## 3.2. Russia: how to cope with the oil boycott?

In 2021, oil and natural gas revenues accounted for 45% of Russia's federal budget.<sup>24</sup> This is a higher proportion than the 35-36% reported in previous years and it can be explained by the high energy prices.<sup>25</sup> For this same reason, the Russian economy was not immediately significantly affected by the announcement of the EU oil boycott. The boycott further tightened the oil market, increasing Russia's revenues in the short term. The expected insurance ban by the EU and the UK, which would prevent the largest providers of maritime insurance in the world from insuring Russian shipments, will make it more difficult for Russia in the short term to keep exporting oil.<sup>26</sup> However, as of July 2022, the UK has yet to follow suit with implementing such a ban. As London is the centre of the marine insurance industry, the UK's participation is vital.<sup>27</sup>

In the short term, Russian oil is finding its way to alternative consumers. A large part of Russia's oil exports could be redirected away from Europe, and losses will be balanced by increasing consumption in India, China or African countries.<sup>28</sup> Indian imports of Russian oil have been sharply growing since the war in Ukraine, despite the country barely having purchased any Russian oil in the first two months of 2022.<sup>29</sup> Indian refiners have been taking advantage of discounted Russian crude oil. A large part of the refined oil products are believed to be sent on to Europe, making India the de facto refining hub for banned Russian oil.<sup>30</sup>

### Box 2 | What type of oil does Russia produce and how is it different from others?

Russia is the third largest producer of oil, after the US and Saudi Arabia. Russian exports include (mainly) crude oil as well as refined products, specifically naphtha (used mainly in the petrochemical industry), diesel, fuel oil (shipping fuel) and vacuum gas oil (VGO), used to produce the very low Sulphur fuel oil required by the International Maritime Organization since 2020.

The most widely exported type of Russian oil is the Urals blend, a medium sour crude with a relatively high Sulphur content. Oil with similar characteristics (high density/heavy and high in Sulphur/sour) is mainly produced by Iran and Venezuela. Contrastingly, the United States crude, Brent oil from the North Sea and Libyan oil tend to be light (low in density) sweet (low in Sulphur) types of crude oil. Refineries in Central and Eastern Europe, dependent on the relatively heavy and sour Russian oil, cannot replace it with light sweet oil without making technical changes to their facilities.

#### Box 2. Russian oil production.

<sup>22</sup> Nick Edser, "Eurozone Interest Rates Set to Rise for First Time in 11 Years," *BBC News*, June 9, 2022, <https://www.bbc.com/news/business-61749090>; "US Makes Biggest Interest Rate Rise in Almost 30 Years," *BBC News*, June 15, 2022, sec. Business, <https://www.bbc.com/news/business-61804877>.

<sup>23</sup> Maartje Wijffelaars, Elwin De Groot, and Erik-Jan Van Harn, "Boycott of Russian Oil Will Tip the Eurozone into a Mild Recession," RaboResearch - Economic Research, June 2, 2022, <https://economics.rabobank.com/publications/2022/june/boycott-of-russian-oil-will-tip-the-eurozone-into-a-mild-recession/>.

<sup>24</sup> IEA, "Energy Fact Sheet: Why Does Russian Oil and Gas Matter?," IEA, March 2022, <https://www.iea.org/articles/energy-fact-sheet-why-does-russian-oil-and-gas-matter>.

<sup>25</sup> "Russian Federation," OECD Inventory of Support Measures for Fossil Fuels: Country Notes, 2022, <https://www.oecd-ilibrary.org/sites/23fe599b-en/index.html?itemId=/content/component/23fe599b-en#:text=Oil%20and%20gas%20revenues%20contributed,federal%20budget%20decreased%20to%2028%25>.

<sup>26</sup> Andy Bounds, Jim Pickard, and Ian Smith, "UK and EU Hit Russian Oil Cargoes with Insurance Ban," *Financial Times*, May 31, 2022.

<sup>27</sup> Harry Dempsey, Tom Wilson, and Oliver Ralph, "West eases efforts to restrict Russian oil trading as inflation and energy risks mount" *Financial Times*, July 31, 2022. <https://www.ft.com/content/333f7447-aed8-40d2-87e9-f8d289162707>

<sup>28</sup> Anait Miridzhanian, "South Africa Should Consider Russian Crude Imports, Minister Says," *Reuters*, June 15, 2022, <https://www.reuters.com/article/safrica-energy-russia-idINL8N2Y24TF>; Shruti Menon, "Ukraine Crisis: Why Is India Buying Russian Oil?," *BBC News*, June 10, 2022, <https://www.bbc.com/news/world-asia-india-60783874>.

<sup>29</sup> Menon, "Ukraine Crisis."

<sup>30</sup> William Watts, "Why India Is the Big Winner as EU's Russia Oil Ban Redraws Energy Trade Map," *MarketWatch*, May 31, 2022, <https://www.marketwatch.com/story/why-india-is-set-to-win-big-as-eu-bans-russian-oil-imports-11654021874>.

The energy relations between China and Russia could further tighten, as China has been reticent to publicly denounce and impose sanctions on Russia following the war. Still, support for Russia has been limited as the Chinese government has been careful to not violate existing sanctions either.<sup>31</sup> In June 2022 Russia became China's largest supplier of crude oil, replacing Saudi Arabia.<sup>32</sup> Riyadh still dominates financially, as Russian oil is sold at a discounted price due to sanctions.

But whether and how much Russian oil these new markets can absorb, as well as the time required for such a shift remains uncertain. While Russian deliveries of oil to Europe were made over short distances and took between two and three weeks to reach destination, tankers will now have to travel for much longer to China and India.<sup>33</sup> Bottlenecks in infrastructure, including storage and transport of oil, will force Russian producers to decrease output and therefore export less. This will hurt the already bleeding Russian economy.

In the medium to long term, the EU oil boycott will make Russian oil production and exports substantially decrease. Estimations made after the invasion of Ukraine show a decrease of 2 million barrels per day (mb/d) by 2030, compared to 2021.<sup>34</sup>

Even before the war in Ukraine, it was becoming increasingly difficult for Russia's oil industry to maintain production levels.<sup>35</sup> Post-2014 sanctions packages have significantly hurt the Russian energy sector, as companies have been unable to procure Western technology and finance.<sup>36</sup> The sanctions packages introduced in 2022 will certainly continue to hurt the Russian oil and natural gas sectors. From a geological perspective, most of Russia's oil comes from brownfields that have been in operation for decades.<sup>37</sup> Increasingly high costs as well as depletion rates of these fields make it challenging to maintain production levels. Although unconventional (offshore) reserves have been discovered for instance in the Arctic, technological limitations are making it difficult for Russia to develop these fields. Other conventional reserves exist as well, though they are small fields scattered around the country, which require large investments in infrastructure to connect them with existing facilities.<sup>38</sup>

Sanctions have made the development of new oil and gas fields equally challenging, especially when it comes to the Arctic LNG-2 (technological challenges) and the Vostok oil (financial challenges) project.

### 3.3. OPEC+ response: unwilling or unable?

For decades, OPEC played a central role in stabilizing the oil market through concerted decisions to scale up production when demand is high and the other way around. In 2016, OPEC expanded into a broader alliance that includes (among others) Russia and Kazakhstan, usually referred to as OPEC+. Saudi Arabia has the largest spare production capacity out of the group, and over time it has used it strategically to maintain the status quo in the oil market. While this ability has been challenged by the US in the last decade, Saudi Arabia remains an important balancer in the market.

<sup>31</sup> Austin Ramzy, "Russia Becomes China's Biggest Crude-Oil Supplier as Europe Cuts Imports," *The New York Times*, June 20, 2022, sec. World, <https://www.nytimes.com/2022/06/20/world/russia-becomes-chinas-biggest-crude-oil-supplier-as-europe-cuts-imports.html>.

<sup>32</sup> Ramzy.

<sup>33</sup> Tsvetana Paraskova, "The Biggest Reshuffle Of Oil Flows Since The 1970s," OilPrice.com, June 7, 2022, <https://oilprice.com/Energy/Energy-General/The-Biggest-Reshuffle-Of-Oil-Flows-Since-The-1970s.html>.

<sup>34</sup> Daria Melnik and Victor Ponsford, "Lifting the Curtain on Russia's Oil and Gas Sectors That Will Bring in an Estimated \$240 Billion in 2022," Rystad Energy, May 2, 2022, <https://www.rystadenergy.com/newsevents/news/press-releases/lifting-the-curtain-on-russia-oil-and-gas-sectors-that-will-bring-in-an-estimated-240-billion-in-2022/>.

<sup>35</sup> Jilles van den Beukel and Lucia van Geuns, "Russia's Unsustainable Business Model: Going All In on Oil and Gas" (The Hague Center for Strategic Studies, January 2021), <https://hccss.nl/sites/default/files/files/reports/Russias%20Unsustainable%20Business%20Model.pdf>.

<sup>36</sup> Tatiana Mitrova, Ekaterina Grushevenko, and Artyom Malov, "The Future Of Oil Production In Russia: Life Under Sanctions" (Skolkovo, March 2018).

<sup>37</sup> van den Beukel and van Geuns, "Russia's Unsustainable Business Model: Going All In on Oil and Gas."

<sup>38</sup> Mitrova, Grushevenko, and Malov, "The Future Of Oil Production In Russia: Life Under Sanctions," 30.

The OPEC+ response to the war in Ukraine has been controversial, mainly because Russia is one of the largest members of OPEC+. Despite the spike in prices following the war, OPEC+ was not willing to increase production, blaming the price crises on geopolitical tensions rather than fundamentals and issues with the physical supply of oil.<sup>39</sup> Instead, a lot of countries, led by the US, released strategic reserves in order to decrease global prices. In the few months of maintaining alignment with Russia, the alliance came under significant pressure from the international community. US President Biden in particular has been publicly requesting Saudi Arabia and others to increase output and mitigate some of the market pressure.<sup>40</sup>

Shortly after the announcement of the EU oil ban and partly motivated by a decrease in Russian oil output, OPEC+ announced an increase in production target from July 2022. While the decision has been welcomed by the US and EU, oil prices still registered a slight increase after the OPEC meeting as the target is considered relatively modest.<sup>41</sup> However, OPEC+ has been facing issues with achieving their production targets for years already.

After the pandemic, several large oil suppliers faced difficulties to ramp up their production. The largest decrease in oil production came from Venezuela, Libya, Nigeria and Angola. In Libya, anti-government protests and domestic conflict have led to blockades over oilfields and terminals.<sup>42</sup> In Nigeria and Angola, where domestic corruption and lack of investments led to technical and operational problems at oil facilities.<sup>43</sup> In the last decade, Angola's oil output has steadily decreased due to the lack of investment in the upstream oil sector.<sup>44</sup> Nigeria is similarly facing investment issues. Moreover, domestic insurgencies, pipeline vandalism and violent disputes also contribute to the irregularities in oil exports.<sup>45</sup> Moreover, Iraq's internal security situation and instability, as well as water shortages, inhibit the country's ability to increase its oil production capacity.<sup>46</sup>

Venezuelan and Iranian crude oil blends are particularly important in the current crisis because they resemble Russian Urals most closely. In other words, they can replace Russian oil with minimal issues. Yet both of these countries are under embargo for oil exports due to various sanctions packages applied by the EU and US over time. As the world is struggling to find alternatives to Russian oil, revived discussions with Venezuela and renegotiations of a potential nuclear deal with Iran are taking place. The visit of a US governmental delegation in March 2022 in Venezuela points to the potential of relieving sanctions. Even so, continued domestic issues would prevent sharp increase in production.<sup>47</sup> Moreover, while expectations that Iranian oil production would increase due to negotiations of a new nuclear deal, it appears that an agreement is far from being reached. The US placed additional sanctions on Iran in 2022, showing the decreased likelihood of a new nuclear deal.<sup>48</sup> Even if sanctions remain in Venezuela and Iran, it is telling that the EU and US are willing to re-negotiate deals despite virtually no improvement in the domestic conditions that initially led to sanctions in these countries. It shows that the urgency of replacing Russian oil is greater than previous European and American foreign policy goals.

<sup>39</sup> Sameer Hashmi, "Oil-Producing Nations Stick to Their Plan despite Ukraine," *BBC News*, March 3, 2022, sec. Business, <https://www.bbc.com/news/business-60591107>.

<sup>40</sup> Derek Brower and David Sheppard, "Opec Agrees to Accelerate Oil Production Following US Pressure," *Financial Times*, June 2, 2022.

<sup>41</sup> Brower and Sheppard.

<sup>42</sup> Charles Kennedy, "Libya Declares Force Majeure On Biggest Oilfield," *OilPrice.com*, 2022, <https://oilprice.com/Latest-Energy-News/World-News/Libya-Declares-Force-Majeure-On-Biggest-Oilfield.html>.

<sup>43</sup> IEA, "Oil Market Report," June 2022.

<sup>44</sup> "Angola," U.S. Energy Information Administration, January 2021, <https://www.eia.gov/international/analysis/country/LBY>.

<sup>45</sup> Ankit Ajmera, "Nigerian Oil Output Growth Threatened by Technical and Security Hurdles," *S&P Global*, November 22, 2021, <https://www.spglobal.com/commodityinsights/en/market-insights/latest-news/oil/112221-nigerian-oil-output-growth-threatened-by-technical-and-security-hurdles>.

<sup>46</sup> Meghan Gordon and Dania Saadi, "Iraq Not Likely to Increase Oil Exports, Backs OPEC Cuts as a Success: Finance Minister," *S&P Global*, April 20, 2022, <https://www.spglobal.com/commodityinsights/en/market-insights/latest-news/oil/042022-iraq-not-likely-to-increase-oil-exports-backs-opec-cuts-as-a-success-finance-minister>.

<sup>47</sup> Luisa Palacios and Francisco Monaldi, "Venezuela Oil Sanctions: Not an Easy Fix" (Columbia University Center on Global Energy Policy, March 2022).

<sup>48</sup> Charles Kennedy, "With No Nuclear Deal In Sight, U.S. Slaps Extra Sanctions On Iran," *Oil Price*, June 16, 2022, <https://oilprice.com/Latest-Energy-News/World-News/With-No-Nuclear-Deal-In-Sight-US-Slaps-Extra-Sanctions-On-Iran.html>.

### 3.4. US: the energy superpower?

Over time, the booming shale industry has brought great benefits to the US government, both economic and geopolitical. The country has become virtually energy independent and also the largest gas exporter in the world. The current energy crisis is allowing the US to lead the way into a newly emerging energy system, as Russia is no longer a thrustworthy oil and gas producer for the western world and OPEC+ countries are facing troubles to maintain their production levels. The US is promising to deliver liquefied natural gas (LNG) to Europe, replacing a part of Russian gas and establishing itself as a major European supplier. Despite some issues discussed below, it seems like the US could leave this crisis in a much better geopolitical situation than a few years ago.

The production of shale oil in the US has not yet reached pre-pandemic levels, partly because of insufficient financing and partly because of issues in global supply chains preventing producers from getting the right equipment.<sup>49</sup> The shale industry registered a negative cash flow of \$300 billion since 2010 and saw almost 200 bankruptcies.<sup>50</sup> Most of the generated revenue was reinvested in new production. Despite the enormous boom, investors have for a long time been disillusioned with US shale oil and the Covid-19 pandemic enhanced the financial issues of the shale industry. This has only recently changed and over the last two years cash flow has become positive. Reinvestment rates plummeted during the pandemic and instead generated free cash flows for investors.<sup>51</sup> Some time is needed to fix the industry's long time looming problems.

Now, shale oil companies are trying to ramp up production after almost two years of underinvestment. The global market pressure is likely driving an increase in output. While it is uncertain whether and how long it would take for the shale industry to recover, conditions seem to be favorable for the US to consolidate its position as the world's largest energy superpower.

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<sup>49</sup> David Messler, "The U.S. Shale Patch Is Facing A Plethora Of Problems," Oil Price, May 2, 2022, <https://oilprice.com/Energy/Energy-General/The-US-Shale-Patch-Is-Facing-A-Plethora-Of-Problems.html>.

<sup>50</sup> Deloitte, "The Great Compression: Implications of COVID-19 for the US Shale Industry," 2020, <https://www2.deloitte.com/us/en/pages/energy-and-resources/articles/covid-19-implications-for-us-shale-industry.html>.

<sup>51</sup> Rystad Energy, "Shale Getting Stingy? Reinvestment Rates in the US Hit Historic Lows in Q3 Shaping Record Free Cash Flow," November 22, 2021, <https://www.rystadenergy.com/newsevents/news/press-releases/shale-getting-stingy-reinvestment-rates-in-the-US-hit-historic-lows-in-Q3-shaping-record-free-cash-flow/>.



## 4. Mid-term: orderly or chaotic energy transition?

In the short term, the energy crisis and price volatility are taking away attention from climate goals. But up to 2030, the energy transition will bring about considerable changes. How will the transition unfold? Will it be orderly, characterized by international cooperation and a simultaneous decrease in fossil fuel consumption and production? Or will it be chaotic as countries remain competitive, focus on protectionist policies and economic gains, and climate action is left behind?

### 4.1. Europe: disruptive change or business-as-usual?

By 2030, Europe is aiming at a decrease in greenhouse gas emissions of 55%.<sup>52</sup> The demand for diesel and gasoline is expected to decrease across all OECD countries, as road transport rapidly moves toward electrification.<sup>53</sup> Chemical production, shipping and aviation will remain highly dependent on oil products up to 2030 – naphtha, fuel oil and jet/kerosene, respectively – given the lack of mature low carbon alternatives in these sectors.<sup>54</sup>

If 2030 goals are to be achieved, however, accelerated action will have to be taken in all economic sectors. This requires significant lifestyle changes from consumers all over the world – less air travel, less meat consumption, less plastics demanded. To what extent are Europeans ready to make such disruptive lifestyle changes? So far, the European consumption of fossil fuels has not decreased as fast as expected. Will real change be seen by 2030, or will business-as-usual continue?

Achieving an orderly transition requires incremental but decisive action to reduce energy demand, increase supply of renewables, and build infrastructure. It also requires cooperation between states, for knowledge and technological transfer, as well as for keeping the old, fossil fuels market stable. In this way, investments can be directed mainly to balancing the old and new energy systems until the latter takes over. However, progress made until now seems to point to a more chaotic transition.

The war in Ukraine brought forward energy security concerns for the EU, especially regarding the oil and gas dependency on Russia. To mitigate supply security issues, the EU decided to accelerate the energy transition and

<sup>52</sup> European Commission, “‘Fit for 55’: Delivering the EU’s 2030 Climate Target on the Way to Climate Neutrality,” July 14, 2021, <https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A52021DC0550>.

<sup>53</sup> IEA, “Oil 2021” (Paris: IEA, 2021), 31, <https://www.iea.org/reports/oil-2021>.

<sup>54</sup> European Commission, “Proposal for a Regulation on Ensuring a Level Playing Field for Sustainable Air Transport,” July 14, 2021, [https://ec.europa.eu/info/sites/default/files/refueu\\_aviation\\_-\\_sustainable\\_aviation\\_fuels.pdf](https://ec.europa.eu/info/sites/default/files/refueu_aviation_-_sustainable_aviation_fuels.pdf); European Commission, “Proposal for a Regulation on the Use of Renewable and Low-Carbon Fuels in Maritime Transport and Amending Directive 2009/16/EC” (Brussels, July 14, 2021), [https://ec.europa.eu/info/sites/default/files/fueu\\_maritime\\_-\\_green\\_europe\\_maritime\\_space.pdf](https://ec.europa.eu/info/sites/default/files/fueu_maritime_-_green_europe_maritime_space.pdf).

reduce consumption of fossil fuels altogether.<sup>55</sup> But the energy crisis is forcing European governments to move back to coal to ensure sufficient and affordable energy supplies.<sup>56</sup> The aim remains to phase out coal in the next 10 years, but it is unclear whether this pace of can be maintained.

## 4.2. Increased dependence on national oil companies

The strong decarbonization policies in OECD (The Organisation for Economic Co-operation and Development) countries are placing significant pressure on international oil companies (IOC) such as Shell or BP to make divestments from new exploration and production projects. On the global level, however, the expected increase in oil demand in Asia-Pacific and Africa is boosting investments in oil production capacity. In a scenario of 1.8°C temperature rise by 2100 compared to industrial levels, Rystad Energy expects 64 mb/d of new oil to be needed to satisfy demand, in addition to already producing wells.<sup>57</sup> Under the same scenario, global oil demand in 2030 will be approximately 105 mb/d.<sup>58</sup>

In response to the demand for new oil, national oil companies (NOC) from the Middle East are heavily investing in upstream activities. Middle Eastern NOCs are increasing their spending by more than 10% in 2022.<sup>59</sup> Saudi Aramco and Petrochina are leading the global investment in upstream activities, with 23 and 25 billion USD in 2021, respectively (see Figure 4). Compared to 2019, upstream spending decreased for European IOCs. ExxonMobil and

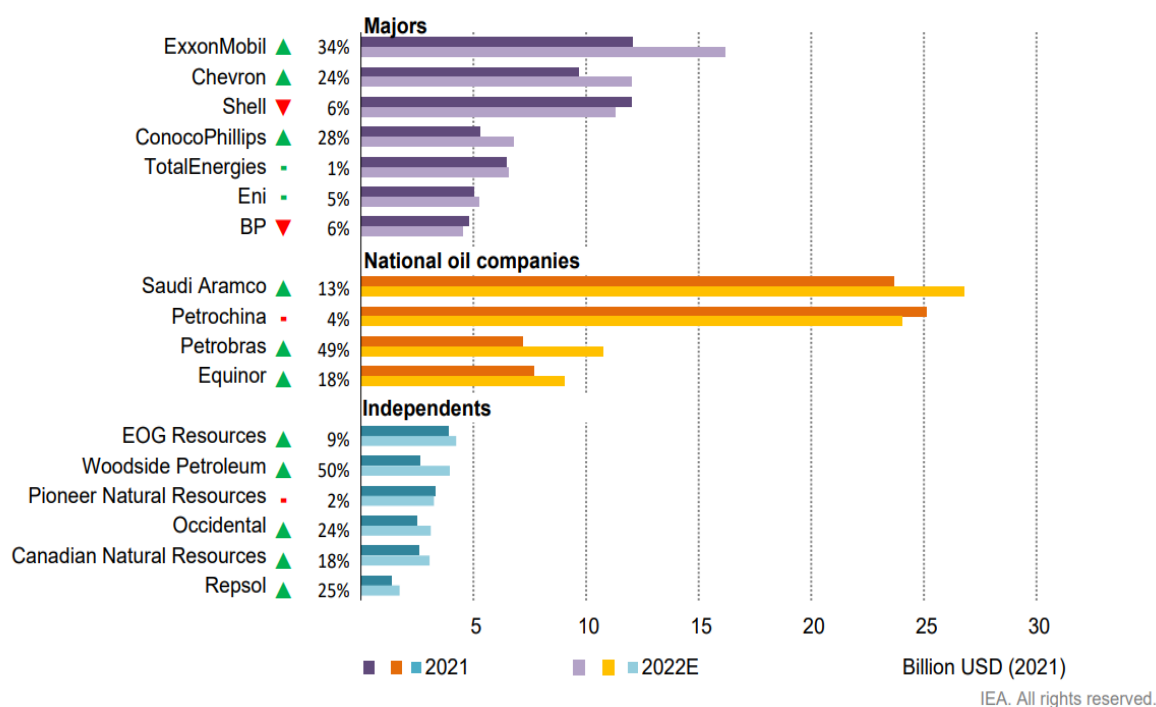


Figure 4. Upstream investment by selected oil and gas companies, 2021 and expected in 2022 (Figure from IEA, "World Energy Investment 2022," 2022, 67).

<sup>55</sup> "REPowerEU: Affordable, Secure and Sustainable Energy for Europe," European Commission, accessed June 24, 2022, [https://ec.europa.eu/info/strategy/priorities-2019-2024/european-green-deal/repowereu-affordable-secure-and-sustainable-energy-europe\\_en](https://ec.europa.eu/info/strategy/priorities-2019-2024/european-green-deal/repowereu-affordable-secure-and-sustainable-energy-europe_en).

<sup>56</sup> Insa Wrede, "Why Germany Is Reviving Dirty Coal to Counter Russian Gas Cut," DW, June 20, 2022, <https://www.dw.com/en/why-germany-is-reviving-dirty-coal-to-counter-russian-gas-cut/a-62195008>.

<sup>57</sup> Rystad Energy, "Oil Transition Report," May 2022.

<sup>58</sup> Rystad Energy.

<sup>59</sup> IEA, "World Energy Investment 2022," 2022, 67, <https://iea.blob.core.windows.net/assets/db74ebb7-272f-4613-bdbd-a2e0922449e7/WorldEnergyInvestment2022.pdf>.

Chevron are the largest IOC investors in upstream oil, with about 12 and 9 billion USD, respectively, mainly because of their recent discoveries in Guyana and Suriname (see next section).<sup>60</sup> Still, these investments are half of those of Saudi Aramco or Petrochina. This means that the share of oil export in the next decades will be increasingly concentrated in the hands of NOCs.

Saudi Arabia is trying to become the 'last man standing' in the global oil market. Seeing that oil consumption will not disappear even by 2050 and public pressure for decarbonization is limited in the case of Middle Eastern NOCs, they are expanding both their crude oil production and refining capacity.<sup>61</sup> Saudi Aramco is investing in carbon capture and storage (CCS) technology and other energy efficient technology, to reduce emissions associated with crude oil production. The company is in a particularly advantageous position because of their abundant reserves, low production costs and, importantly, low carbon intensity upstream. Saudi Arabia produces crude oil with some of the lowest carbon intensity levels in the world (around 5 g CO<sub>2</sub>eq./MJ). This is slightly lower than Norway and the UK, but much lower than Russia with about 9 g CO<sub>2</sub>eq./MJ, the US with about 12 g CO<sub>2</sub>eq./MJ or Algeria with more than 20 g CO<sub>2</sub>eq./MJ.<sup>62</sup> Aramco's low carbon intensity can be explained by low per-barrel gas flaring rates and low water production, resulting in less energy used in fluid handling and treatment.<sup>63</sup> This is a particularly advantageous position when looking at initiatives like carbon border tax mechanisms, preventing high-intensity carbon products from being consumed in Europe and elsewhere.

Although Saudi Aramco seems to be headed to a decarbonized oil production system, it is much more difficult to influence the actions of NOCs than IOCs. As international companies are moving away from fossil fuels, countries all around the world are becoming more dependent on oil produced by NOCs. As most of these are not publicly listed, information about their operations is limited and untransparent. It will be more difficult for governments in Europe and the US to scrutinize oil companies and request that their processes are as clean as possible.

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<sup>60</sup> IEA, 66.

<sup>61</sup> Laury Haytayan et al., "National Oil Companies and Energy Transition in the Middle East and North Africa" (Natural Resource Governance Institute, 2021), 2.

<sup>62</sup> Mohammad S. Masnadi et al., "Global Carbon Intensity of Crude Oil Production," *Science* 361 (August 31, 2018): 852, <https://doi.org/10.1126/science.aar6859>.

<sup>63</sup> Masnadi et al., 851.



## 5. Long term: the fight for low-carbon and low-cost oil

The energy transition brings about significant changes in the oil market. Oil consumption will be lower than current levels, although it will likely not disappear. The precise demand level depends on policy choices, investments and speed of the energy transition. In 2050, global oil demand could range between 20-70 mb/d in the net zero scenario (NZE) and announced pledges scenario (APS) of the IEA, respectively.<sup>64</sup>

Oil companies can follow several pathways in the energy transition.<sup>65</sup> Some companies try to move toward a new green energy portfolio, either in the initial stage or once technologies are mature enough. For African economies that are very dependent on exports of fossil fuels like Nigeria, Angola or Libya, this would be a very beneficial move. The oil sector in these countries requires significant investment in the next years to remain competitive and the upstream sector is intensive in terms of GHG emissions.<sup>66</sup> This is not only environmentally problematic, but also economically as the EU and other countries are moving toward carbon border tax and low-carbon energy sources. Redirecting the investments away from the oil industry and into renewable energy development would therefore contribute to climate goals and diversify their economies away from natural resource exports.<sup>67</sup>

Other companies can keep investing in oil production. A large part of oil companies chooses to follow this path.<sup>68</sup> On the one hand, by investing in low-cost production methods in places with minimal regulatory risk, companies would be trying to maximize their market share in the time that oil is still a main energy source. On the other hand, by investing in oil with a low-carbon footprint, companies can be more resilient in the next decades, given that global oil consumption will continue for the foreseeable decades.

The oil market in the energy transition will likely be dominated by the fight for low-carbon and low-cost oil. The key for producers will be to ensure minimal emissions along the supply chain, both upstream and downstream. By ensuring that the newly established production processes are as clean as possible, for instance by using CCUS technologies, maximizing energy efficiency and strictly limiting flaring, upstream emissions are reduced. Moreover, by producing light and sweet oil, refining processes will similarly be less carbon intensive.

Non-OPEC oil producers are becoming increasingly important in the market, due to new discoveries of oil as well as low-carbon approaches to oil production. As IOCs are moving away from exploration and production in Europe, they are finding new markets elsewhere, e.g. in the Guyana Basin and Africa. These areas' light sweet oil paired with

<sup>64</sup> IEA, "World Energy Outlook 2021" (Paris: IEA, 2021), 220, <https://www.iea.org/reports/world-energy-outlook-2021>.

<sup>65</sup> Chantal Beck et al., "How Oil and Gas Is Navigating the Energy Transition," McKinsey & Company, 2021, <https://www.mckinsey.com/industries/oil-and-gas/our-insights/the-big-choices-for-oil-and-gas-in-navigating-the-energy-transition>; Chronis et al., "Positioning for Green."

<sup>66</sup> Acha Leke, Peter Gaius-Obaseki, and Oliver Onyekweli, "The Future of African Oil and Gas: Positioning for the Energy Transition," McKinsey & Company, June 2022, <https://www.mckinsey.com/industries/oil-and-gas/our-insights/the-future-of-african-oil-and-gas-positioning-for-the-energy-transition>; Masnadi et al., "Global Carbon Intensity of Crude Oil Production."

<sup>67</sup> Leke, Gaius-Obaseki, and Onyekweli, "The Future of African Oil and Gas: Positioning for the Energy Transition."

<sup>68</sup> Chronis et al., "Positioning for Green," 8.

modern technologies can reduce emissions along the supply chain and make up a large part of the oil that will be needed in the next few decades globally.

Guyana started producing oil in 2019 after a consortium led by ExxonMobil first discovered oil five years before.<sup>69</sup> Exploration projects have been very successful, making 18 discoveries since 2015.<sup>70</sup> Guyana is expected to add about 0.7 mb/d to global oil supply by 2030.<sup>71</sup> The government of Guyana is pursuing the production of low-carbon oil through energy efficient technologies, no flaring, as well as using renewable energy and CCS.<sup>72</sup>

Similarly, TotalEnergies and Apache Corporation made significant oil and gas discoveries in Suriname.<sup>73</sup> The exploitation of oil reserves will support the economic development of Suriname, which has been struggling with high poverty levels. The oil is of a medium to light grade with a low sulphur content, which is becoming increasingly popular due to relatively lower emissions associated with its consumption, compared to the heavy oil. Suriname could derive major economic benefits from becoming an oil exporter by minimizing the environmental impact.

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<sup>69</sup> Nermina Kulovic, "Guyana Sells Its First Share of Crude Oil from Its Second Offshore Project to ExxonMobil," *Offshore Energy* (blog), April 25, 2022, <https://www.offshore-energy.biz/guyana-sells-its-first-share-of-crude-oil-from-its-second-offshore-project-to-exxonmobil/>.

<sup>70</sup> "Guyana," ExxonMobil, accessed June 24, 2022, <https://corporate.exxonmobil.com:443/Locations/Guyana>.

<sup>71</sup> IEA, "World Energy Outlook 2021," 219.

<sup>72</sup> "Guyana's Low Carbon Development Strategy 2030: Draft for Consultation" (Government of Guyana, 2021), 76–78, <https://lcds.gov.gy/wp-content/uploads/2021/10/LCDS-2030-Final-DRAFT-for-consultation-min.pdf>.

<sup>73</sup> "Suriname: TotalEnergies Announces Another Significant Discovery in Block 58," TotalEnergies, February 2022, <https://totalenergies.com/media/news/press-releases/suriname-totalenergies-announces-another-significant-discovery-block-58>.

## 6. Conclusion

The international oil market is undergoing significant changes. The consequences of the Covid-19 pandemic, war in Ukraine and subsequent energy crisis are revealing deep rooted trends that are permanently changing the structure of energy markets. Tight oil supplies, low investments in the oil market, geopolitics and the energy transition are influencing the shape of the newly emerging energy system.

The central theme for the oil market up to 2024-2025 will be volatility. As the world is struggling to find a new power balance, the fragmentation in different spheres of influence based on whether Russia is an acceptable partner or not is mirrored in the oil market. Europe, one of the largest consumers of oil, is looking for alternative suppliers. Oil flows will be redirected to fill the gap left by Russian oil. Renegotiations of pre-existing sanctions with Venezuela and Iran, who can produce the oil most similar in characteristics to Russian Urals, are showing the urgency in European and American policy to remove Russia from the global economy. Conversely, Russia is looking for new markets, but whether and how fast Asian and African countries can absorb this oil is unclear. Russia's oil output will likely decrease by at least 2 mb/d by 2030 and its federal budget will certainly be hurt by new sanctions.

Members of OPEC+ are facing difficulties in maintaining a dominant position in the oil market. Trends in the last few years show that many oil producers are facing domestic instability and insecurity. The low investments in E&P since the 2014 price plunge have led to a tight market, making it difficult to rapidly return to pre-pandemic production levels. The role of OPEC+ in balancing the market is increasingly questioned. Instead, the US is emerging as the main energy superpower. The United States is perfectly positioned to become the global energy leader, due to its promising shale oil industry, fall of Russia as an energy superpower and issues within OPEC+.

In the mid- to long-term, the energy transition is the driving force in the global oil market. The main question is whether the transition can take place in an orderly, cooperative way, or if it will be chaotic, characterized by isolationism and nationalist gains. Although Europe (and other OECD countries) are expected to change their energy system most dramatically by 2030, so far progress has been limited. While producers in the North Sea are at risk losing their license to operate, demand does not seem to be decreasing as fast as expected. Instead, Middle Eastern and Chinese NOCs are gaining market shares. They are expanding production capacity to reap the benefits of global divestments in oil and continued oil demand by 2050. From an environmental perspective, the increased dependence on NOCs is problematic as their often-opaque decision making and processes are making it difficult to scrutinize. The main investments of IOCs are concentrated in newly discovered oil reserves like Africa and the Guyana Basin, as the sweet light grade of crude oil paired with efficient technologies can decrease emissions along the oil supply chain. Low-carbon and low-cost oil is expected to be the most desirable to fulfill the limited global demand in 2050.