

Sonatrach's Strategy at the Heart of Algeria's Energy Transition: A System Dynamics Approach

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Abstract

Sonatrach, Africa's leading oil company, is at the heart of Algeria's energy model. This article highlights the challenges facing the company, a longstanding pillar of the hydrocarbon sector. By comparing Sonatrach's low-carbon strategy with the national roadmap, the analysis reveals discrepancies between the Algerian government's climate ambitions and Sonatrach's strategic choices, which are focused on fossil fuels. Faced with persistent obstacles (excessive subsidies for fossil fuels, institutional monopoly, limited openness to private actors, and an unincitive legal and regulatory framework), Algeria must respond to climate challenges while preserving its economic model. How can this ambivalence be addressed? What role should Sonatrach play in the Algerian government's national roadmap? To answer these questions, we will return to the need for greater consistency between public policies and industrial strategies. This is where the bulk of the country's energy transition is at stake.

Keywords

Carbon Neutrality, Energy Roadmap, Fossil Fuel Subsidies, Scenarios, System Dynamics

1. Introduction

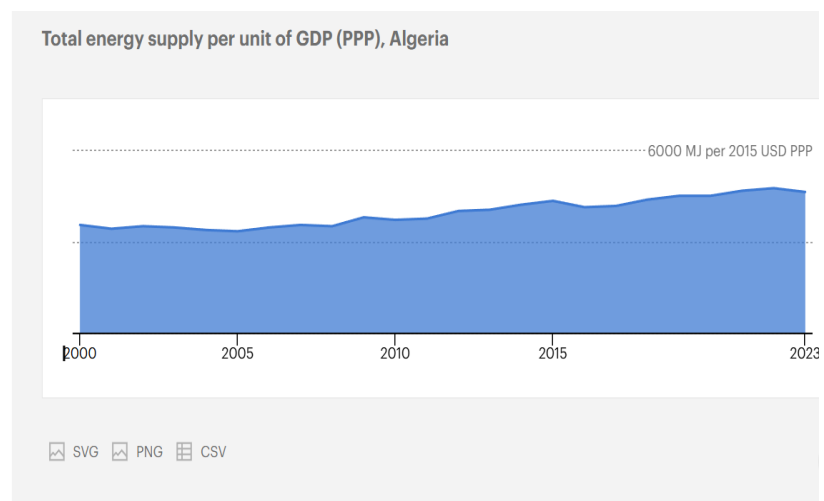
Sonatrach, Africa's leading company and the eleventh largest international oil group¹, is an economic giant whose creation dates back to 1963² (IEA, 2025,

¹"PIW'S TOP'50", Petroleum Intelligence Weekly, 2025.

²Décret No. 43-491 of December 31, 1963, approving the national hydrocarbon transport and marketing company.

2023). However, it was in 1966 that the company was given the legal means and instruments to carry out the functions and activities of an oil group³. This was made possible by the 1965 Franco-Algerian agreement, under which Algeria resumed an active role in the management of its hydrocarbons (Boubekour, 2008). The company was renamed Sonatrach and, in addition to transportation and marketing, was entrusted with hydrocarbon exploration and production activities. A new decisive step was taken in 1971 when Algeria decided to nationalize the shares held by foreign companies, mainly French, to the tune of 51%, a rule that remains in force to this day, except for a brief period in 2005⁴, which was quickly reversed (Aissaoui, 2021).

Since then, Sonatrach has been the guarantor of an energy policy in which hydrocarbon resources are essentially considered an inalienable national asset that must be “*shared with the population in the form of funding for social services, such as free healthcare and education*”⁵. It is the foundation of the economy, accounting for 26% of GDP and more than 50% of tax revenues. It also accounts for more than 95% of export revenues. In 2024, these revenues amounted to \$45.2 billion, down from \$50.4 billion in 2023 and \$60 billion in 2022. Added to this decline is the increase in domestic consumption, which is increasingly competing with exports (Banque d’Algérie, 2024).



Source: IEA (2025).

Figure 1. Total energy supply per unit of GDP (PPP) in Algeria.

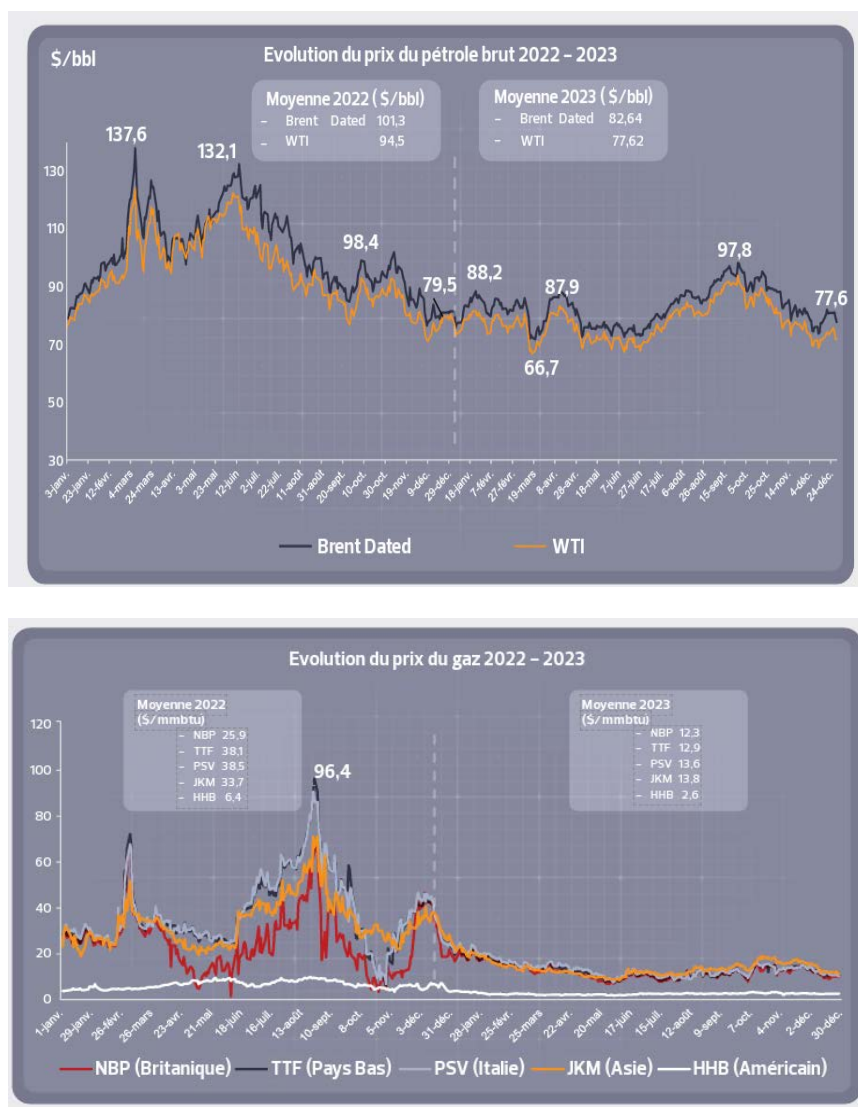
The energy structure of the economy, which tracks changes in total energy supply per unit of economic output (adjusted for purchasing power), allows us to estimate the energy intensity of the Algerian economy from 2000 to 2023 (Figure 1). The curve illustrates a stable but weak growth trend in this energy intensity

³Décret No. 66-296 of September 22, 1966, amending the articles of association of the national hydrocarbon transport and marketing company.

⁴In 2005, a law was enacted that abolished the principle of Sonatrach’s mandatory majority stake. Under intense pressure, an amendment to the law reinstated this principle.

⁵1986 National Charter.

relative to GDP, characteristic of an economy heavily dominated by the extractive industry (Algérie Presse Service, 2024). This downward trend undermines economic policy, given that the annual budget is calculated on the basis of a reference price per barrel of oil. As a result, the Algerian economy is heavily dependent on oil prices, and when these fall, they cause serious disruption to the government's projections and often lead to untimely revisions of finance laws. In 2023 alone, the oil and gas markets saw the price of Brent crude fall by 18% and gas prices fall by more than 50%.



Source: Sonatrach (2023).

Figure 2. Evolution of Brent crude oil and gas prices.

There is certainly talk of energy diversification, but in reality, hydrocarbons are the main source of energy for the economy, which is subject to multiple constraints and struggling to develop (Figure 2). This situation inevitably means that exploration efforts must continue in order to maintain production at a level that

allows the socio-economic model to be preserved. As a result, the development of renewable energies, which is one of the Algerian government's ambitions, remains subject to the same constraints as other sectors of the economy and is therefore struggling to develop. Thus, due to a combination of social and political constraints, most efforts are focused on maintaining hydrocarbon production, or even expanding it.

This paper aims to analyze: 1) Sonatrach's strategic choices and scenarios in order to determine whether they are compatible with the Algerian government's carbon neutrality roadmaps. 2) We draw on systems dynamics to model oil price trends and propose a forecasting tool for Sonatrach. 3) This tool shows that investments in fossil fuels remain very significant and could jeopardize the 2050 carbon neutrality scenario. The use of system dynamics enables an oil company to better understand the complex interactions between supply, demand, prices, and long-term climate policies. It helps simulate different scenarios through 2050 by incorporating variables such as the energy transition, technological advancements, and regulations. This tool highlights feedback effects and time lags—often invisible in traditional analyses—that can significantly influence outcomes. It also helps anticipate risks, such as a rapid decline in demand or stranded assets. By virtually testing different strategies (diversification, investments, emissions reduction), the company can make more robust decisions. Finally, this fosters a systemic and long-term perspective, which is essential in a rapidly transforming sector.

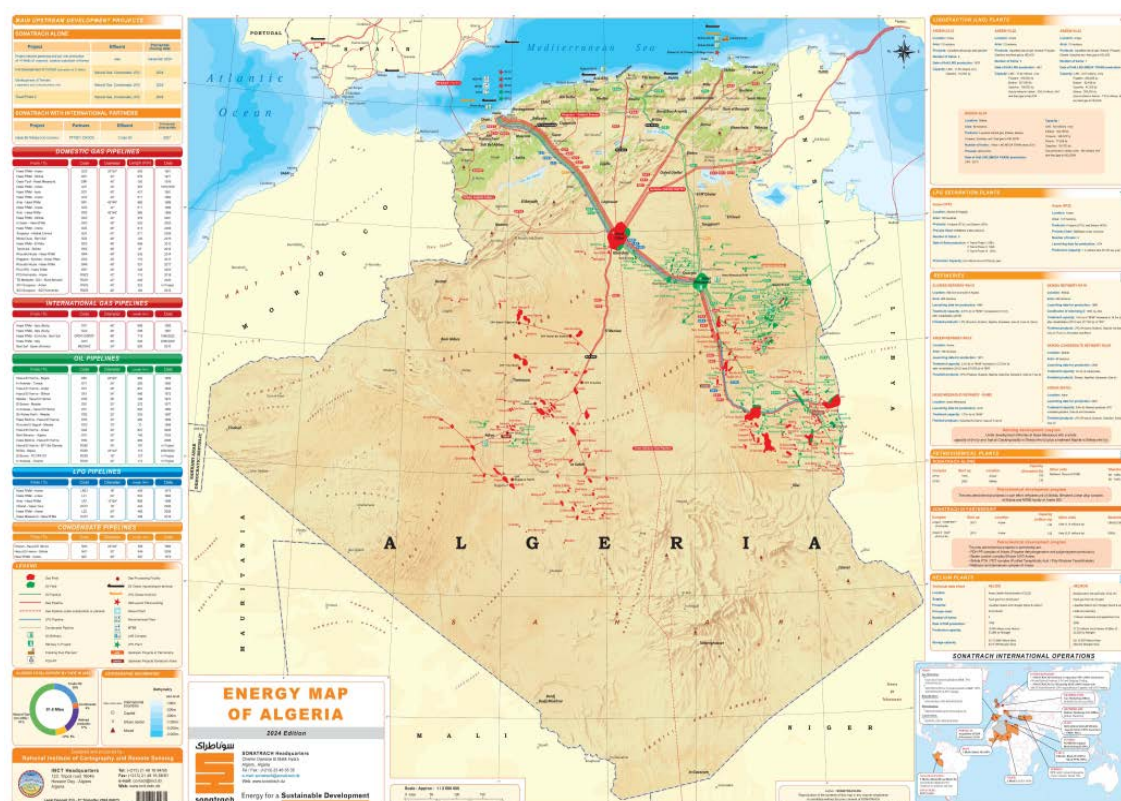
2. Strategic Choices and Scenarios for Sonatrach

As Africa's leading oil company, Sonatrach has a vast portfolio of fields, perimeters, and international holdings. The main basins and production areas are located in the southeast of the country: the Hassi Messaoud basin has a production capacity of approximately 6.4 billion barrels. It produces some 350,000 barrels per day, representing approximately more than 60% of the country's proven oil reserves. In the same geographical location is the Berkine sedimentary basin, which has estimated reserves of more than 1 billion barrels of recoverable oil and a daily production of 50,000 barrels. In addition to these two basins, there are many others, the most important of which are: Hassi R'Mel, Timimoun, Reggane, Ghardaïa, etc.

These numerous basins contain oil reserves estimated at between 10 and 12 billion barrels and more than 2.4 trillion cubic meters of natural gas⁶.

With its extensive network of pipelines, Sonatrach ranks among Europe's leading gas suppliers. It is the largest supplier of natural gas to Italy and the second largest to Spain, Türkiye, and Greece. This trade is supported by two gas pipelines, Transmed (to Italy) and Medgaz (to Spain). These two infrastructures are complemented by LNG facilities in Arzew and Skikda. All of these infrastructures ensure a continuous supply to its European customers and make it a strategic operator for gas exports to Europe and other markets (**Figure 3**).

⁶Annual Report Sonatrach, 2023.



Source: Sonatrach.com.

Figure 3. Energy map of Algeria.

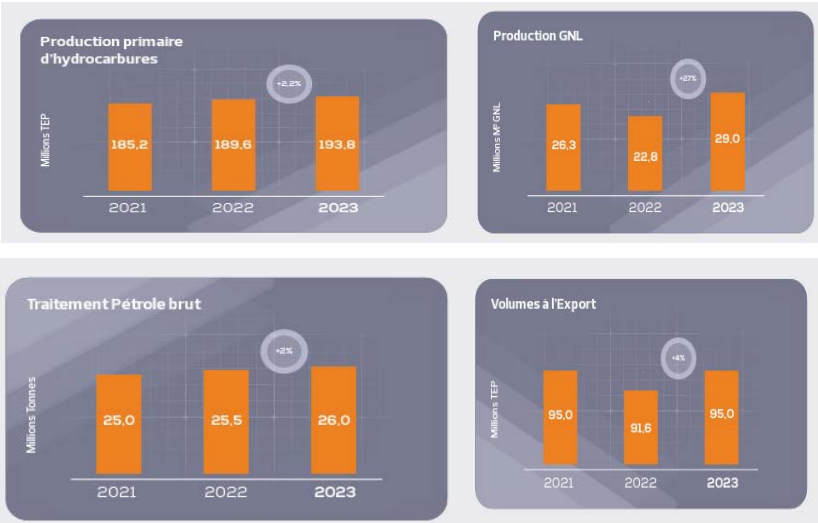
Les opérations internationales de SONATRACH



Source: Sonatrach.com.

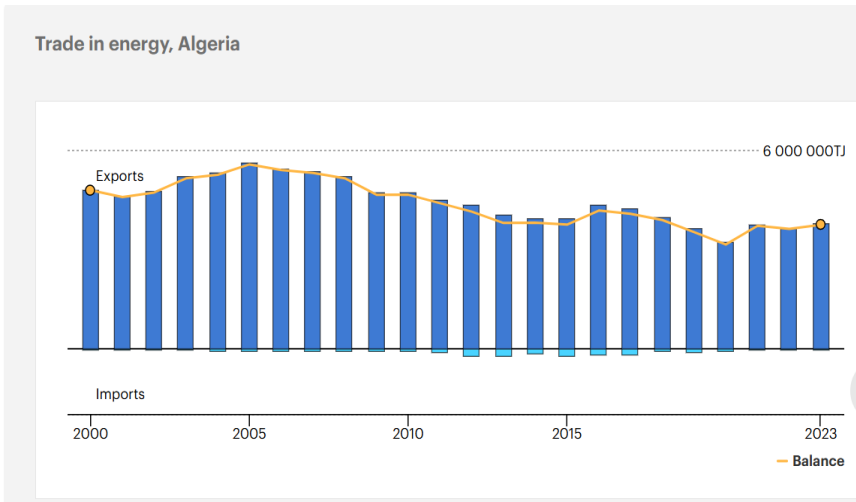
Figure 4. Sonatrach international operations.

Despite the impact of falling oil prices on the 2023 financial year, Sonatrach achieved its development and exploration objectives (Figure 4). Primary production peaked at 194 million TOE, up 2.2% compared to 2022. LNG production grew by 27% to reach 29 million cubic meters of LNG. Refined hydrocarbon production also maintained its momentum in 2023, as domestic market needs were met through imports.



Source: Sonatrach Report, 2023.

Figure 5. Sonatrach achievements in 2023.



Source: Sonatrach (2023).

Figure 6. Trade in Energy, Algeria.

The ranking of energy exporters highlights Africa’s role as a region that exports primary energy resources. According to 2023 data from the International Energy Agency (IEA), 18775812 TJ of primary energy production was exported by the African continent (Figure 5, Figure 6). Algeria is one of the main exporters alongside Libya, Angola, Nigeria, and South Africa. This situation highlights the geo-

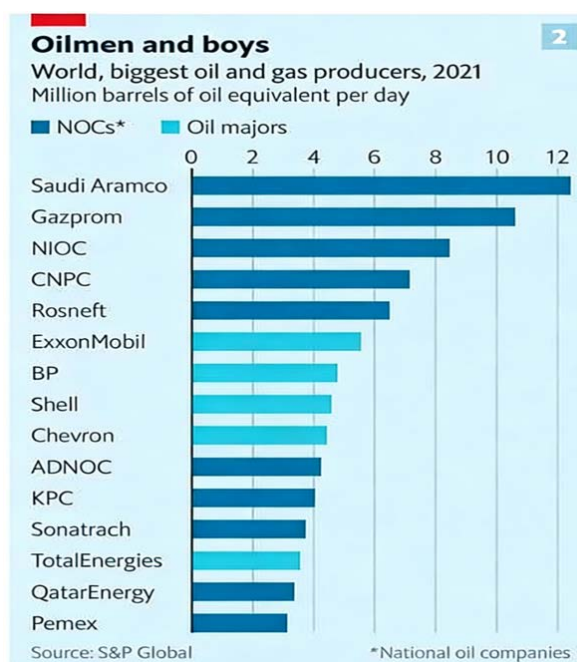
strategic and geoeconomic dynamics and their interdependencies that shape national and regional energy trajectories (**Table 1**).

Table 1. Ranking of energy exporters in the African region in 2023.

Ranking	Country	TJ
	Africa	18775812
1	Algeria	3799224
2	Nigeria	3290813
3	Angola	2457387
4	Libya	2457046
5	South Africa	2204553

Source: World Energy Balances.

Despite a potential decline in production, Sonatrach ranks among the world's largest national oil companies, alongside companies such as Saudi Aramco and Gazprom. The British magazine *The Economist* ranked the Algerian hydrocarbon company Sonatrach among the 15 largest oil producers in the world, ahead of major groups such as Qatar Energy and Total Energy in terms of oil and gas production.



Source: *The Economist* (2021).

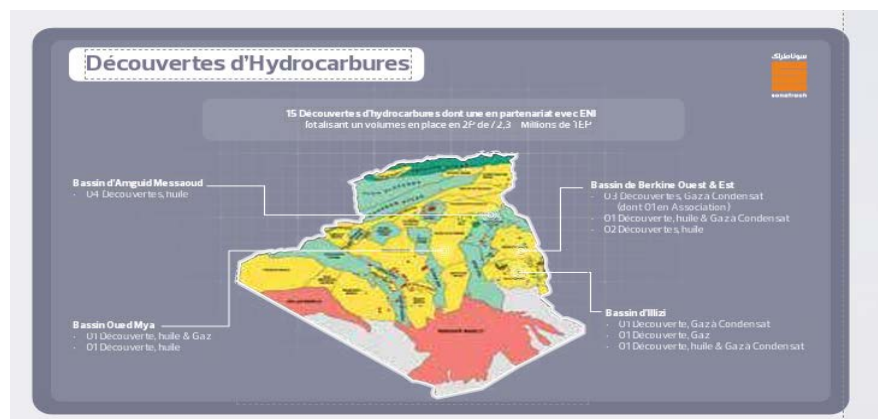
Figure 7. Ranking of the largest oil and gas companies.

In its report (**Figure 7**), the magazine cited Sonatrach's production volume for 2021, which exceeded 185 million tons of oil equivalent, strengthening Sonatrach's position in the global energy market and placing it among the top international

companies.

3. Exploration and Discoveries

Sonatrach continues to announce numerous discoveries and new exploration and development contracts, particularly with international groups. Both exploration and the development of existing deposits are survival objectives for Sonatrach and the state owner. This is because, even in a world that aspires to move away from fossil fuels, the renewal of reserves is a strategic objective for Sonatrach as long as it remains the backbone and guarantor of the Algerian economy (**Décret exécutif n° 17-98 du 26 février 2017, 2017**). The year 2023 ended with a total of 15 hydrocarbon discoveries in its own name and one discovery in partnership with ENI. These discoveries totaled a production of 72.3 million TEP (**Figure 8**).



Basin	Number of discoveries	Type of resource	Details
Anguedi Messaoud	4	Oil	
Oued Mya	2	Oil & Gas	
Berkine Ouest & Est	6	Condensate Gas, Oil & Condensate Gas	Agreement with ENI
Illizi	3	Condensate Gas, Gas, Oil & Condensate Gas	

Figure 8. Discovery of new hydrocarbon deposits.

4. Sonatrach’s Energy Transition Strategy

In southern countries, whose economies are heavily dependent on fossil fuels, the energy transition has not yet been fully realized due to the structural and socio-economic challenges they face. Algeria is no exception. Given the difficulty of maintaining reserve levels and the volatility of the hydrocarbon market, it is likely that the energy transition is not one of Sonatrach’s strategic priorities. It is indeed difficult, if not complex, to reconcile the imperative of transition with that of maintaining reserve levels and export revenues. Even though Sonatrach occupies

a dominant position in the energy market, it also has to contend with structural obstacles such as aging infrastructure, volatile international oil prices, heavy budgetary dependence, and rapidly growing domestic energy demand.

These are all challenges facing Sonatrach, compromising its long-term viability and strategic choices. The first of these challenges is the instability of oil revenues, which could paradoxically resolve the contradiction between the goal of maintaining reserves and that of energy transition. The development of renewable energies could prove to be a crucial element in portfolio diversification, thereby offsetting the proven decline in revenues from hydrocarbons. Other challenges include upgrading its aging production infrastructure, adopting environmentally friendly and innovative technologies, and strengthening its expertise and the knowledge of its human capital. Sonatrach operates in a highly competitive environment and therefore also needs to create an environment conducive to attracting strategic partnerships and sharing the risks associated with energy reserve development and exploration projects. It must also focus on communication and transparency with its stakeholders, including society, in order to support its projects and ensure the sustainability of its reserves.

Sonatrach is fully committed to the energy transition by developing gas and solar power to diversify its energy mix, in line with the national policy for the development of renewable energies. The company aims to cover 80% of the energy needs of its oil sites with solar power plants by 2030, thereby reducing hydrocarbon consumption and greenhouse gas emissions in a responsible and sustainable manner. Solar energy production capacity could eventually reach 1.3 gigawatts (GGFRP, 2023; GMI, 2023).

Thanks to its contribution to the national renewable energy development program, Sonatrach could enable Algeria to save nearly 1.6 billion cubic meters of gas intended for sale by 2040.

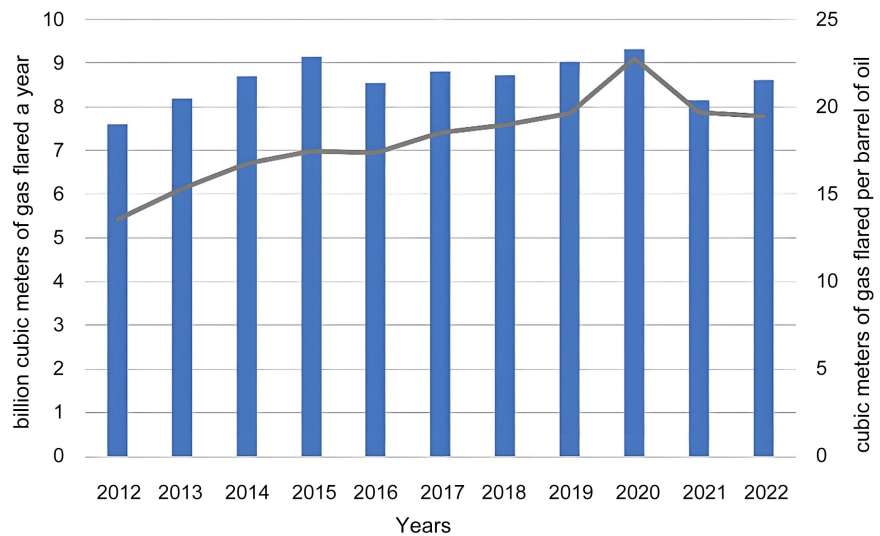
Given its central role in the national economy, Sonatrach aspires to be a leader in the energy transition at both the national and regional levels. Sonatrach intends to play a leading role in ensuring the success of this transition. On July 21, 2024, Sonatrach presented its carbon neutrality strategy, designed to respond to climate challenges (Sonatrach, 2024). This strategy is based on a set of measures and actions focused on five strategic areas, including reducing greenhouse gas emissions, increasing the integration of renewable energies, and developing natural and technological carbon sequestration solutions.

4.1. First Focus: Balance between Emissions and Absorption

Sonatrach has launched a structural initiative in partnership with the Directorate General of Forests to strengthen national carbon capture capacities. With a budget of \$1 billion, the company plans to plant 10 million shrubs in the first phase. This operation is part of a plan to eventually plant more than 420 million trees across an area of 560000 hectares. The goal is to help achieve a balance between greenhouse gas emissions and absorption by carbon sinks by the second half of the century.

4.2. Second Focus: Reducing Emissions Linked to Flaring

Algeria is one of the countries most affected by gas flaring, accounting for a significant share of global volumes. Sonatrach (2023) has made reducing flaring a priority in its decarbonization strategy. In 2023, the company reaffirmed its commitment to addressing this environmental issue in line with its goal of off-setting its GHG emissions with available absorption capacities. This approach reflects a desire to reduce the climate impact of oil activities while maintaining economic balance.



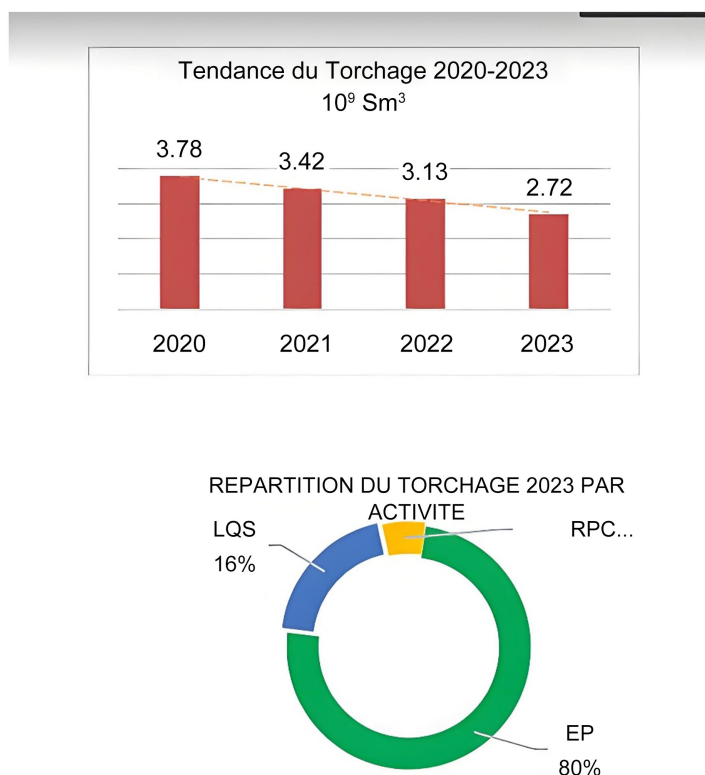
Source: IEA.

Figure 9. Volume of flared gas, Algeria 2012-2022.

During 2023, the total volume of gas flared by Sonatrach's operational activities was estimated at 2.72 billion Sm³*, with Exploration and Production (Upstream) alone accounting for 80% of the total volume flared, or 2.18 billion Sm³. It should be noted that there has been a downward trend in flared gas volumes, with a 13% reduction compared to 2022 and a 28% reduction over the last four years (2020-2024), representing 1.06 billion Sm³ of avoided flared gas (Figure 9).

This decline is mainly due to the commissioning of several associated gas recovery projects in several regions of the Production Division, primarily the Hassi Messaoud Region, with a significant decrease of 377 million Sm³. Algeria is involved, through its oil company Sonatrach, in the Global Flare and Methane Reduction Partnership (GFMR), which aims to end routine flaring and reduce methane emissions from the oil and gas sector to near zero by 2030. In this context, Sonatrach has been making significant efforts to reduce its flared gas, particularly in several upstream oil fields, for the past 30 years. The construction of flared gas recovery units has reduced the rate of gas burned from 5.43% in 2020 to 3.19% in 2024. For fugitive methane emissions, Sonatrach has signed a framework agreement with the Algerian Space Agency (ASAL) to identify methane leaks by satel-

lite and measure the quantities of CO₂ emitted (**Figure 10**).



Source: Sonatrach.

Figure 10. Trend in the reduction of flared gas from Sonatrach Group activities.

4.3. Third Focus: CO₂ Capture and Sequestration

Sonatrach is developing carbon capture and sequestration projects, identifying suitable sites for storing CO₂ in depleted reservoirs. In fact, the world's first carbon sequestration experiment was carried out by Sonatrach in 2004 at its Krechba site, where 3.8 million tons of CO₂ were captured.

4.4. Fourth Focus: Renewable Energy

Sonatrach is integrating more renewable energy into its energy mix while developing low-carbon fuels and green hydrogen, with the goal of covering 80% of the energy needs of its oil sites with solar power plants by 2030. In 2011, the company set up a 150 MW hybrid solar-gas power plant in Hassi R'Mel, marking the beginning of its commitment to renewable energies.

Since then, isolated projects have been launched by the Algerian oil group, notably the construction—in partnership with the Italian association ENI—of a first 10 MW solar power plant in Bir Rebaa Nord, which will avoid emissions of 10000 tons of CO₂ equivalent per year. In the medium term, Sonatrach plans to deploy solar power plants at its industrial sites in Tin Fouye Tabenkort, Rhourde Nouss, Ohanet, and El Borma.

4.5. Fifth Focus: Energy Efficiency

Sonatrach has launched an energy efficiency action plan to improve the energy performance of its operations and ensure energy savings. This began with a lengthy energy audit program, 50% of whose recommendations have been implemented.

5. Sonatrach's Low-Carbon Strategy and Algeria's Roadmap: Alignment or Divergence?

Algeria's exceptional solar potential—with an estimated average annual sunshine of 3000 hours, average irradiation of 6.57 kWh/m²/day, and the unique geography of its vast Saharan desert territory (86% of the total area)—should enable the development of megaprojects, particularly in solar thermal and photovoltaic energy. These are all assets that should enable Algeria to contribute to the global effort to develop renewable energy sources, and should enable the development of megaprojects, particularly in solar thermal and photovoltaic energy. These are all assets that should enable Algeria to present an ambitious energy transition roadmap as part of the global effort to combat global warming. This roadmap is based on a national program for the development of renewable energies and energy efficiency (PNDER) launched in 2011 (Loi n° 12-03 du 12 janvier 2012, 2012).

6. Algeria's Roadmap for Energy Transition

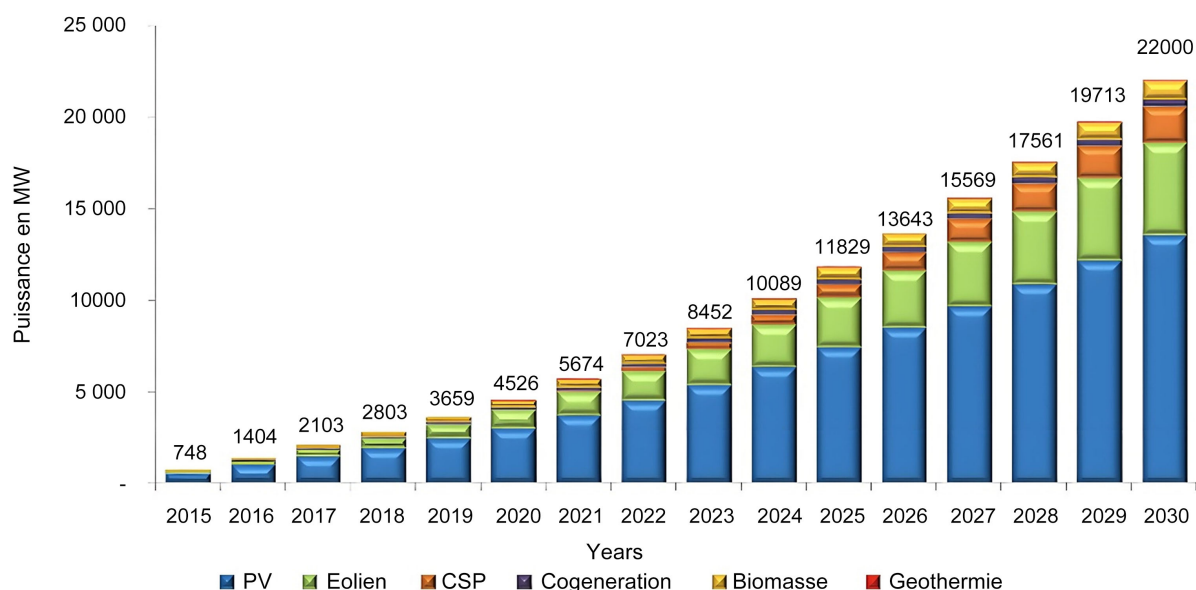
Algeria is a country rich in fossil fuel resources. It has begun to implement an energy transition to diversify its energy mix, reduce its dependence on hydrocarbons, and respond to the challenges of climate change while meeting growing energy needs. Two official documents define these objectives and commitments (Bessalem, Diemer, & Karbout, 2025).

- *The National Program for the Development of Renewable Energy and Energy Efficiency*⁷ (PNEREE, 2011-2030). This program aimed to bring 22000 MW of renewable energy online by 2030, including 12000 MW for the domestic market and 10000 MW for export. For reasons of economic realism and technological capacity, this program was revised in 2020 to adopt gradual targets, aiming for 15000 MW of installed capacity by 2035 (Figure 11).

- *The National Strategy for Hydrogen Development*⁸ (SNDH) (2023), which is the ministerial document setting out the country's ambitions for hydrogen production and the various phases of infrastructure deployment. For the Algerian authorities, "The establishment of a renewable and clean hydrogen sector will contribute, in the medium and long term, to accelerating the energy transition, strengthening the country's energy security, and enabling Algeria to participate in the global effort to combat climate change" (Ministère de l'Énergie et des Mines, 2025) (Figure 12).

⁷<https://www.energy.gov.dz/?article=programme-de-developpement-des-energies-renouvelables>

⁸[https://www.energy.gov.dz/Media/galerie/doc_strategie_nationale_hydrogene_v.fr_\(sept.2023\)_65b65e6f0b8eb.pdf](https://www.energy.gov.dz/Media/galerie/doc_strategie_nationale_hydrogene_v.fr_(sept.2023)_65b65e6f0b8eb.pdf)



Source: <https://www.energy.gov.dz/en>.

Figure 11. Algeria's renewable energy deployment program through 2030.

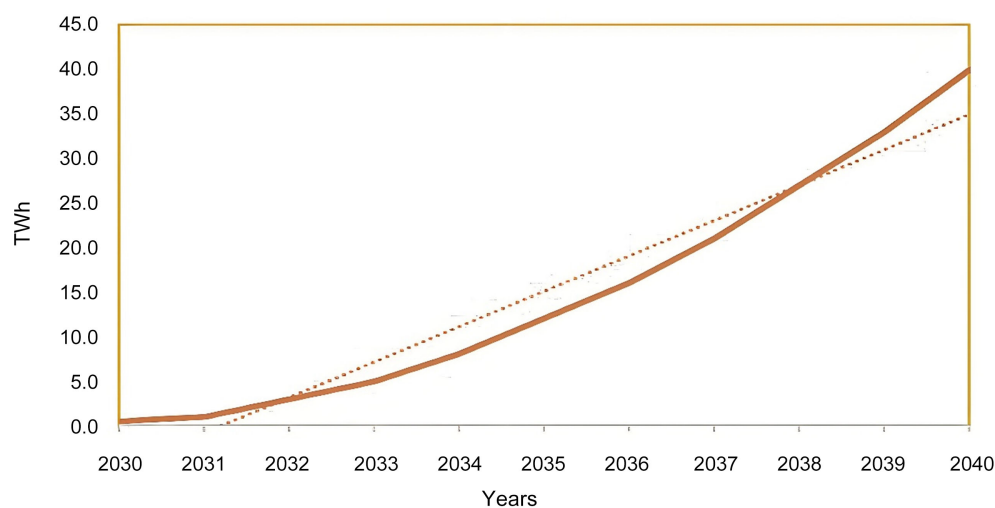


Figure 12. Evolution of Algerian hydrogen production by 2040.

However, these programs face many obstacles to their implementation and actual realization. Among these obstacles, we can cite (Hasni et al., 2021):

- *The policy of increased subsidies for fossil fuels.* It appears that the state subsidy for fossil fuels was estimated by the 2012 finance law at nearly \$15 billion. This estimate is based on a comparison of export prices and domestic market prices. These prices were respectively \$8/MMBTU for gas for export, with the domestic market price being \$0.27/MMBTU, and for electricity, the cost price of electricity produced was estimated at 8 DA/kWh. This assessment was corroborated by IMF figures (nearly 10% of GDP). These subsidies would not allow renewable energy projects to achieve the expected profitability (Table 2).

Table 2. Energy subsidies (US\$ billion).

	2012	2020	2030	Observations
Electricity	0.197	4.352	7.232	
Carburants	0.46	15.51	20	2013: 3 Milliards de US\$ Importation
Gaz	11	20.5	37	
Total	11.6	40.3	64.2	

- *The second obstacle*, and not the least significant, concerns Algeria's legislative and regulatory framework, which, in its current form, has slowed down the implementation of the National Renewable Energy Program (PNER). In fact, the Ministry of Energy, through an executive decree, granted the national operator Sonelgaz a monopoly on the exclusive implementation of renewable energy projects, thereby canceling the advantages initially granted to renewable energy producers by the 2012 law on public gas distribution (for access to the feed-in law market). This lack of political will has blocked the opening of the market and slowed down the development of renewable energy in the country. Furthermore, despite the fact that the country has no shortage of financial resources, private investors face difficulties in accessing the capital and credit needed to finance large fossil fuel projects (while external financing was ruled out on the grounds that it could indebt the state).

- *The third obstacle* is that decision-makers have long considered Algeria's energy security to be limited solely to electricity use, even though this actually accounts for only 12.33% of the country's total energy consumption (**Table 3**).

It is in this context that **Hasni, Malek & Zouioueche (2021)** proposed prospective scenarios for 2030-2050, taking into account socio-economic, technological, environmental, and cultural dimensions (**Figure 13**).

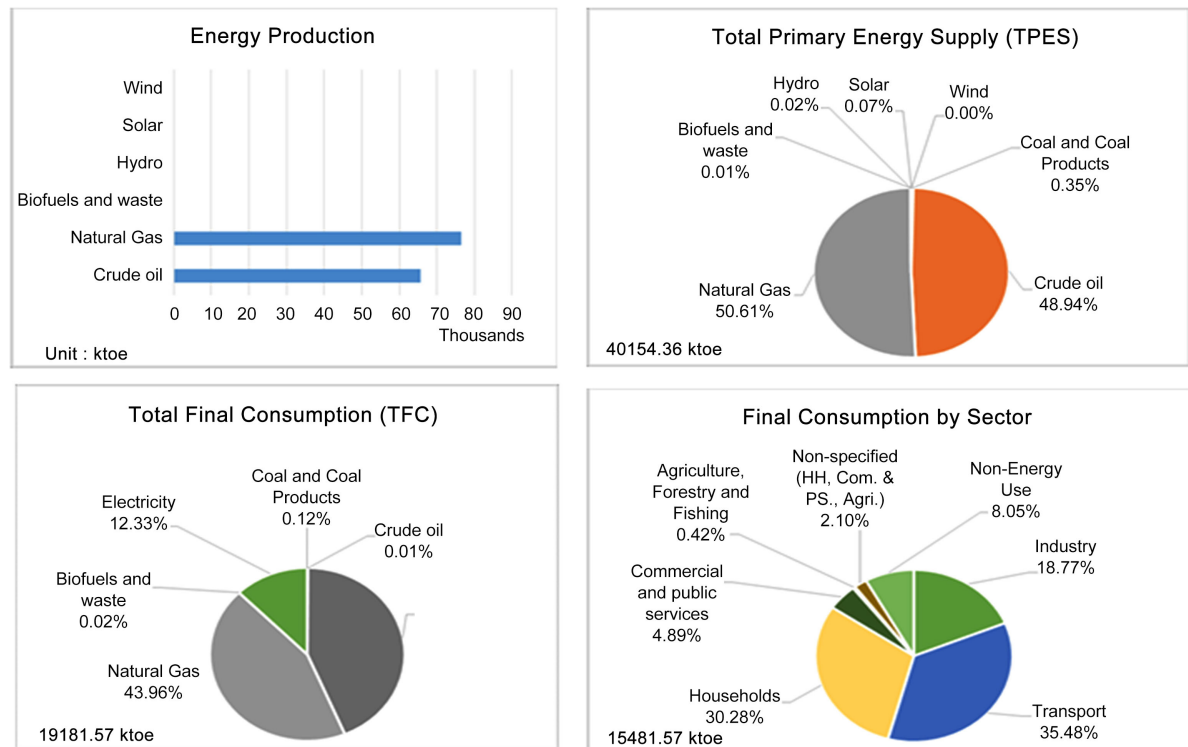
Table 3. Energy balances and indicators for Algeria.

Thousand Tonnes of Oil Equivalent (ktoe)	Coal and Coal Products	Crude oil	Oil products	Natural Gas	Biofuels and waste	Hydro	Solar	Wind	Electricity	Total of all energy sources
Production	-	65716.6	-	76539.7	10.3	13	58	0.8	-	142338.5
Imports (+)	269.6	164.6	2394.3	-	-	-	-	-	45.7	2874.2
Exports (-)	-	-27027.3	-21178.9	-36385.3	-	-	-	-	-57.9	-84649.4
International Marine Bunkers (-)	-	-	-10	-	-	-	-	-	-	-10
International Aviation Bunkers (-)	-	-	-	-	-	-	-	-	-	-
Stock Changes (+ draw, - build)	8.1	-23.9	7&8	-	-	-	-	-	-	63

Continued

TOTAL PRIMARY ENERGY SCPPY	277.7	38830.1	-18715.7	40154.4	10.3	13	58	0.8	-12.2	60616.4
Transfers: Origin (-) and Destination (+)	-	-8218.3	9015.2	-	-	-	-	-	-	796.9
Statistical Difference	-1.5	42.2	699.5	338.5	0	-	-	-	-24.9	1053.7
TRANSFORMATION										
Inputs (•) and Outputs (+)	982.6	-29564.2	29502.3	-17078.9	-	-13	-58	-0.8	7008.5	-9221.6
Electricity plants	-	-	-221.4	-17078.9	-	-13	-58	-0.8	7008.5	-10363.6
CHP Plants	-	-	-	-	-	-	-	-	-	-
Heat Plants	-	-	-	-	-	-	-	-	-	-
Coke ovens	-213.2	-	-	-	-	-	-	-	-	-213.2
blast furnaces	1207.0	-	-	-	-	-	-	-	-	1207.0
Oil Refineries	-	-29564.2	29074.8	-	-	-	-	-	-	-489.4
Coal-to-liquids plants	-	-	-	-	-	-	-	-	-	-
Gas-to-liquids plants	-	-	-	-	-	-	-	-	-	-
Charcoal production plants	-11.3	-	-	-	-	-	-	-	-	-11.3
Transformation not elsewhere specified	-	-	648.9	-	-	-	-	-	-	648.9
Energy Sector Own use	256.2	390	7.8	3201.3	-	-	-	-	789.2	4644.4
Losses	951.8	611	89.5	354.2	-	-	-	-	851	2857.5
FINAL CONSUMPTION	53.8	4.4	19004.9	19181.6	10.3	-	-	-	5381.0	43636.1
Industry	53.8	-	1360.2	4884.1	7	-	-	-	1886.6	8191.8
Transport	-	4.4	14801.1	535.7	-	-	-	-	140.4	15481.6
Households	-	-	1594.2	9333.6	3.3	-	-	-	2281.5	13212.6
Commercial and public services	-	-	132.4	1041.5	-	-	-	-	961.3	2135.2
Agriculture, Forestry and Fishing	-	-	37.8	34.4	-	-	-	-	111.2	183.5
Non-specified (HH, Com. & PS., Agri.)	-	-	917.5	-	-	-	-	-	-	917.5
Non-Energy Use	-	-	161.8	3352.2	-	-	-	-	-	3514.0

Source: African Energy Commission (AFREC, 2021).



Source: African Energy Commission (AFREC, 2021).

Figure 13. Energy balances for Algeria.

7. Energy Scenarios for 2030-2050

The model proposed by NEAL (New Energy Algeria) is based on limiting Sonelgaz's electricity production to 60 TWh with an installed capacity of 20 GW in 2021. Solar energy, in both its CSP and photovoltaic forms, would cover the remaining 93 TWh. This model incorporates the increase in thermal needs linked to the development of the industrial and agricultural sectors by 2030 (Table 4).

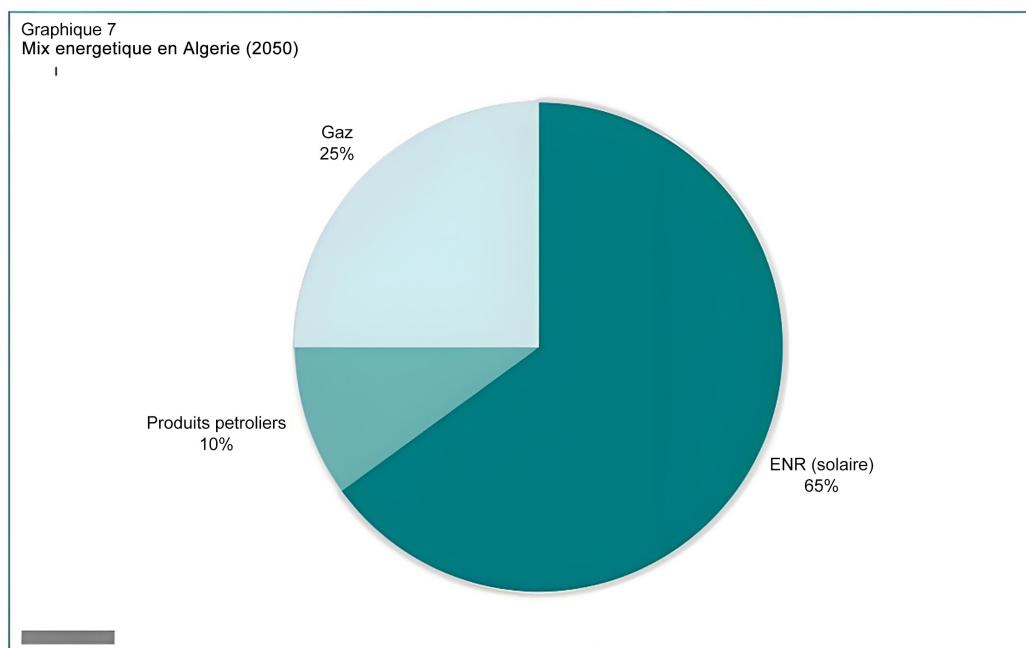
Table 4. Electricity consumption forecasts.

	2015	2020	2024	2030 1
Consommation globale électrique	61%	88%	112%	150%
Photovoltaïque 13000 MW (2030)	0.18%	16.60%	17.60%	23%
Eolien	0%	0.31%	0.60%	0.90%
Solaire thermique hybride-gaz torches 14000 MW (2030)	0.10%	12%	50%	70%
Cycle combine gaz 14000 MW (2020)	61%	59%	60%	60%

Source: Hasni, Malek, & Zouioueche (2021).

Figure 14 shows how Algeria's energy mix could evolve by 2050. It clearly shows that solar energy will play a central role, accounting for 65% of production, reflecting a strong commitment to renewable energies. Gas will continue to account for 25% of the mix, mainly to ensure system stability. Petroleum products,

meanwhile, account for only 10%, reflecting a shift towards reducing GHG emissions. This scenario is based on a gradual transition, taking into account the country's available resources and climate commitments.



Source: Hasni, Malek, & Zouiouèche (2021).

Figure 14. Energy mix in Algeria in 2050.

Although Algeria's energy transition roadmap, based on two national programs—the PNDEREE renewable energy development program (PV and wind power) and the SNDH hydrogen development program—sets ambitious targets for integrating renewable energy into the energy mix by 20250, the actions selected by SONATRACH in its industrial climate strategy (focusing on reducing emissions from flared gas and methane, as well as self-consumption at its sites using photovoltaic energy) remain modest. Like many international oil companies (Bessalem, Diemer, & Karbout, 2025), this key player in the country's energy transition still seems to be banking on fossil fuels for the next 30 years. The budget allocated to the development of alternative energies (i.e., \$13 billion over the period from 2015 to 2025) is significantly lower than that allocated to the development of hydrocarbon deposits over the same period (i.e., \$30 billion).

As highlighted in the study by Hasni et al. (2021), the success of the energy transition depends on a paradigm shift based on diversifying the energy mix (by integrating CSP solar thermal alongside photovoltaic and wind power), the gradual reduction of fossil fuel subsidies, an update of the legal framework to ensure a favorable environment for investment in renewable energies, and the restructuring of the industrial fabric around renewable energy sectors, particularly solar thermal. This low-carbon transition cannot be effective without a comprehensive, integrated approach. In the following, we propose to mobilize systems dynamics

(Forrester, 1961, 1968, 1969; Sterman, 2000; Diemer, 2004, 2012, 2018) in order to identify all the challenges of the energy transition in a context where fossil fuels play a predominant role in the country's economy.

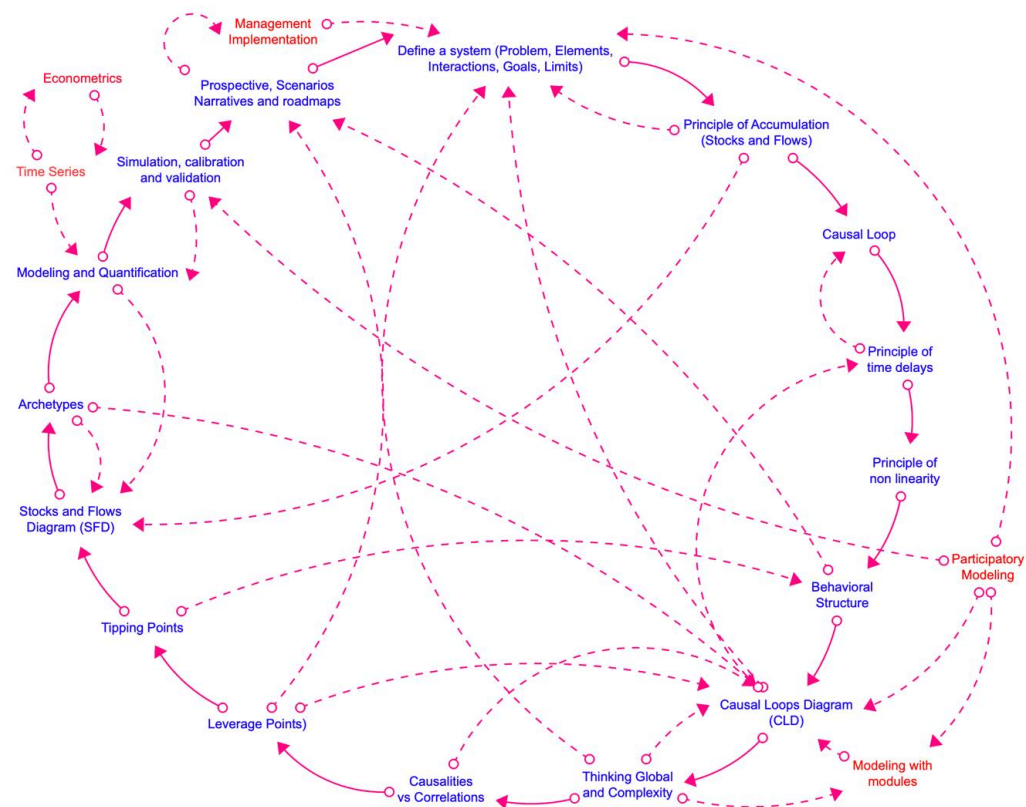
8. System Dynamic Modeling for Energy Price

System dynamics provides an analytical framework particularly well-suited for modeling oil price formation and guiding the strategic decisions of a company such as Sonatrach. Introduced by Forrester (1961, 1968, 1969, 1991, 1995, 2007), this approach is based on representing complex systems through feedback loops, stocks, and flows. It is particularly relevant to the oil market, which is characterized by nonlinear dynamics, investment lags, and price cycles (Randers, 1976). The work of Sterman (2000) shows that system dynamics provides a better understanding of emergent behaviors in systems where interactions are numerous and interdependent. In the case of oil, investment decisions influence future supply with significant time lags, generating cycles of expansion and contraction. These mechanisms are also analyzed in models inspired by the work of Meadows et al. (2004), which emphasize the physical and environmental limits of economic systems.

The energy literature also highlights the value of these approaches for simulating long-term scenarios. Reports from the International Energy Agency, IEA (2025) and OPEC (2025) provide key assumptions regarding demand, technologies, and climate policies. By integrating this data into dynamic models, it becomes possible to test contrasting oil price trajectories through 2050. Furthermore, authors such as Senge (1990) have shown that systems thinking improves strategic decision-making in complex organizations. For a company like Sonatrach, this allows for the evaluation of different strategies: maintaining investments in hydrocarbons, diversifying into gas or renewable energy, or adapting to decarbonization policies. These choices can be tested virtually to assess their long-term impacts.

Other studies applied to the energy sector, such as those by Hall & Klitgaard (2012) and Ayres & Warr (2009), highlight the importance of energy constraints and diminishing returns in price trends. These factors can be incorporated into system dynamics models to enhance the analysis. Finally, this approach enables the anticipation of major risks, such as price volatility, geopolitical shocks, or the emergence of stranded assets (Smil, 2017; Yergin, 2008). It thus provides a coherent framework for linking economic, technical, and environmental dimensions. By combining analytical rigor with scenario exploration, system dynamics serves as an essential strategic tool for an oil company facing the uncertainties of the energy transition by 2050.

In this part, we use materials coming from Diemer (2022, 2024, 2026), which present the 16 stages of system dynamics modeling, and more specifically from the stock-flow diagram (SFD) used to present a quantitative model with simulations for 2050.



Source: Diemer (2026, 2022).

This system dynamics analysis is based on Stella software to catch oil price dynamics. This modeling exercise is a starting point for all models addressing the issue of energy, and more specifically hydrocarbons. Our system dynamics model is based on a stock-flow model that simulates oil price dynamics based on the interaction between supply (production capacity and oil production) and demand (oil consumption) (**Figure 15**).

The central mechanism is a balancing loop (B1) in which oil stocks act as a buffer that regulates prices. If stocks are high, prices fall, which stimulates consumption and reduces stocks. If stocks are low, prices rise, which slows consumption and allows stocks to rebuild. A second balancing loop (B2) introduces the supply response lag. High oil prices encourage investment, which increases production capacity stocks over time. Increased capacity leads to higher oil production, which ultimately increases oil stocks and lowers prices. This structure reflects the typical boom-bust cycles observed in commodity markets, often described by the “overshoot and collapse” archetype where delays in capacity adjustment cause oscillations around the equilibrium price.

8.1. First Step of the Model

The first step in the model is based on causal links between several variables that affect oil price dynamics. The variables are production capacity stock, oil production, production utilization, oil inventory, inventory ratio, reference inventory,

price impact from inventory, base price, oil price, price elasticity multiplier, base demand, oil consumption, investment fraction, investment rate, capacity depreciation, capacity lifetime.

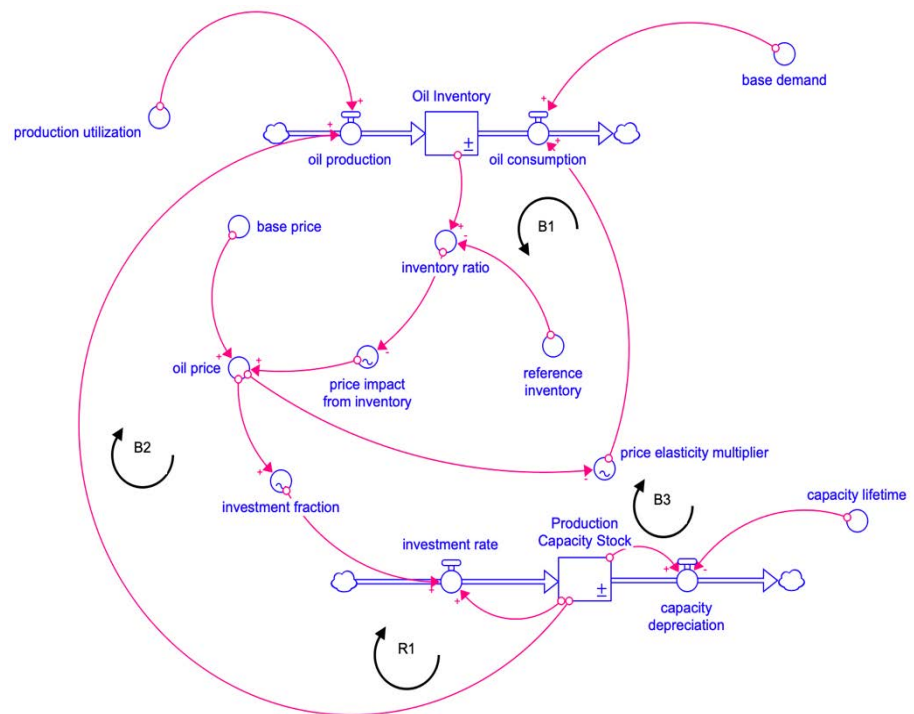


Figure 15. Dynamics of oil price.

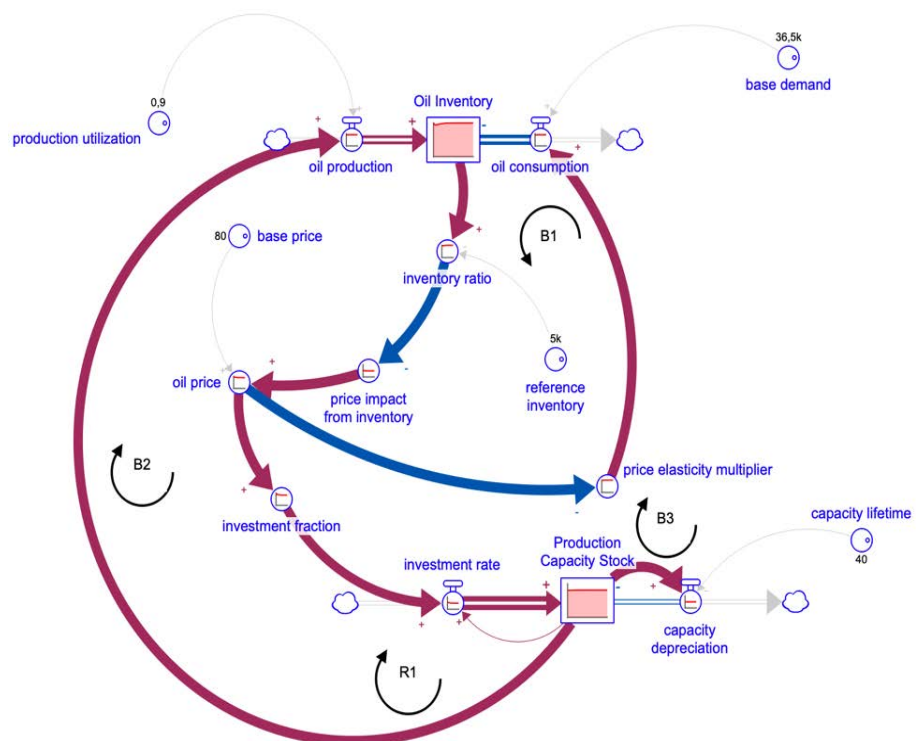
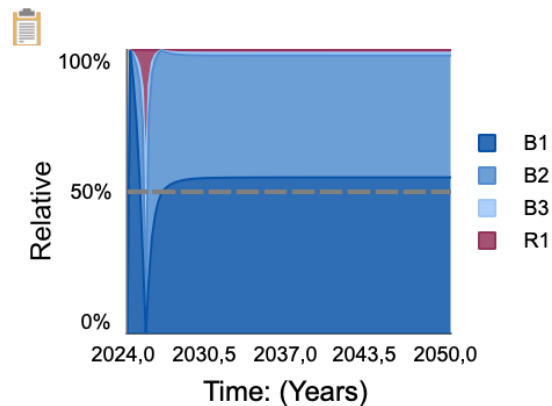


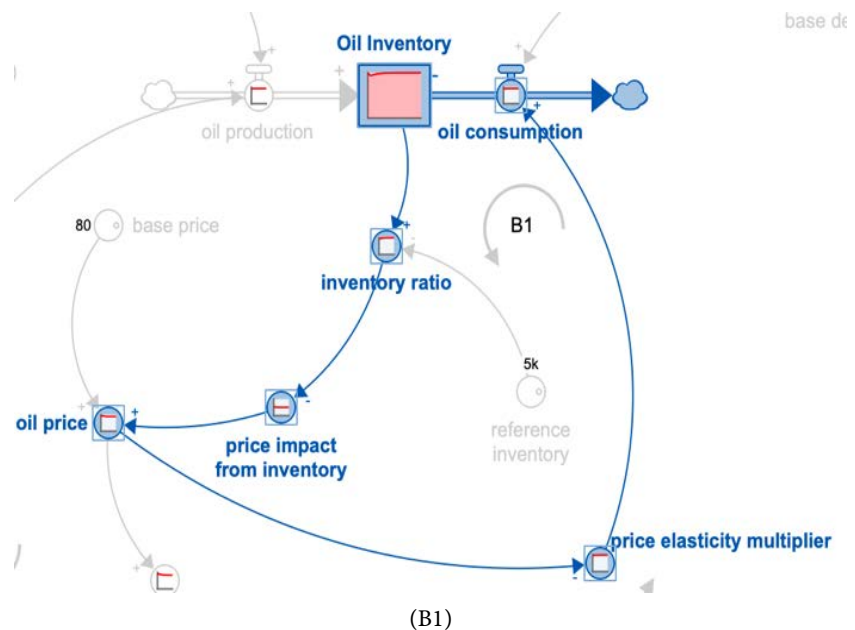
Figure 16. Simulation oil price dynamics.

These causal links enabled us to develop an initial structural model and therefore to test a few simulations to see how our model would behave. The base price of oil is based on an average value of \$80 (with possible variations between \$60 and \$100). In a context of oil storage and increased production capacity (high investment rate), oil price dynamics are based solely on oil production and sales. High capacity would therefore tend to drive oil prices down (Figure 16).

Four loops (three Balancing loops B1, B2, B3, and one Reinforcing loop R1) generate the dynamics of the oil price.

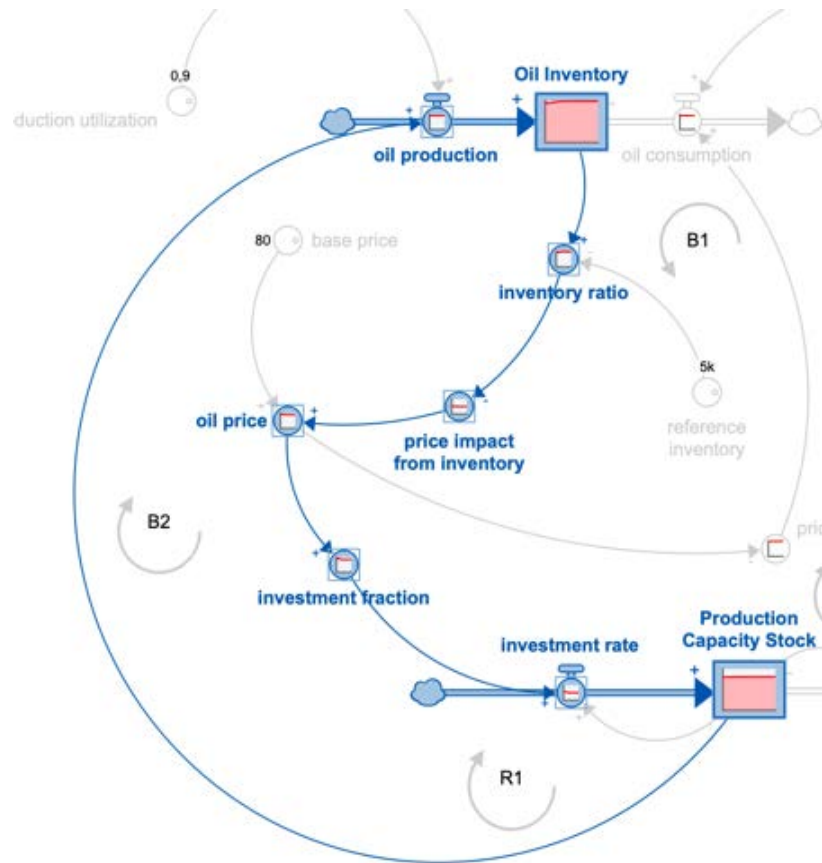


Loop B1 starts with oil stocks, which induce a storage ratio (+), which defines the impact of stocks on the price of oil (-), which introduces an increase in the price of oil (+), which reduces the price elasticity multiplier (-), increases demand for oil (+), which reduces oil stocks (-).



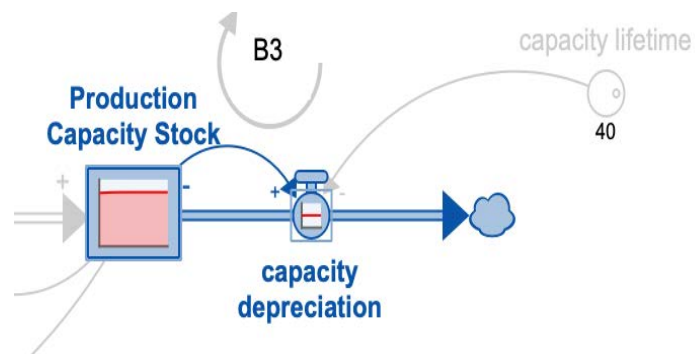
The B2 loop starts with an increase in oil production, which in turn increases oil stocks. The stock rate rises, reducing the price impact of oil stocks, and the

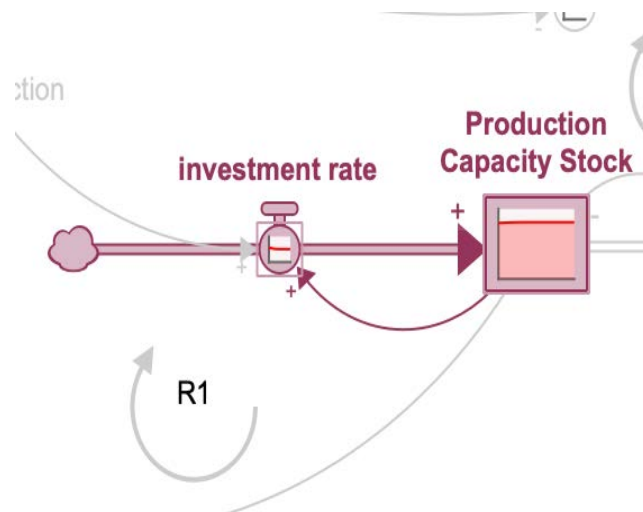
price of oil increases, stimulating investment in production capacity. The investment rate increases, causing an increase in production capacity, which in turn generates an increase in oil production.



(B2)

Loop B3 specifies that the use of production capacity (production tools) results in capital depreciation (+), which will ultimately reduce production capacity (-) without additional investment. Loop R1 emphasizes that an increase in the investment rate (+) causes an increase in production capacity (+), which in turn generates a further increase in investment (+). This reflects the principle of accumulation described by Samuelson (1947).





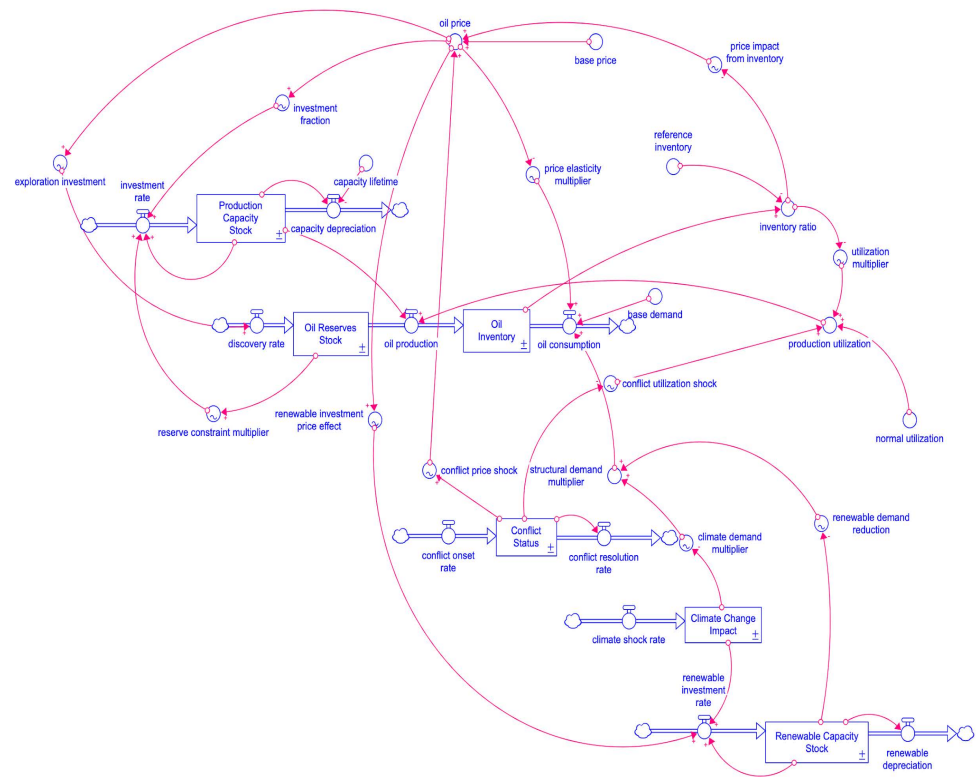
8.2. The Second Step of the Model

The second step of the model introduces shock variables into the system. Based on the literature and current events, we have selected four variables that are likely to impact oil price dynamics: investment in oil fields, the possibility of a climate shock affecting oil, investment in renewable energies, and the possibility of a major conflict between Europe and Russia. The model was expanded to include four major external factors, closing several new feedback loops.

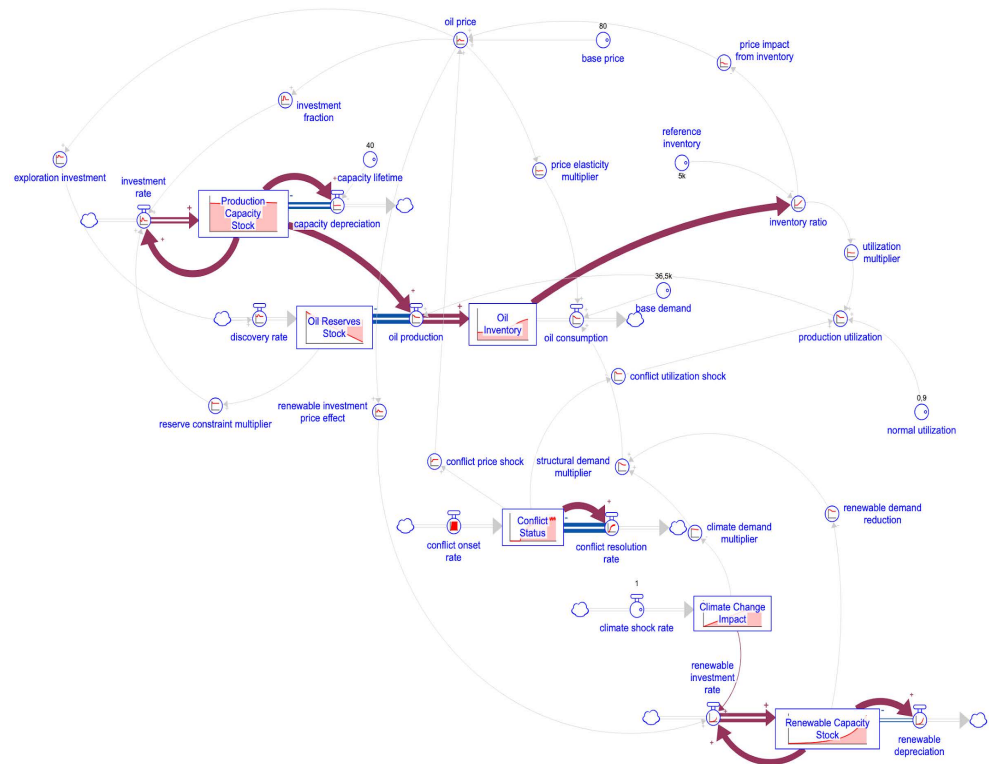
Oil Reserves and Discovery: A new stock, oil reserves stock, was introduced, depleted by oil production and replenished by discovery rate. The discovery rate is driven by exploration investment, which is positively linked to oil price. This creates a balancing loop: High Price $\rightarrow$ high investment $\rightarrow$ high discovery $\rightarrow$ high reserves $\rightarrow$ relaxed constraint $\rightarrow$ high capacity investment $\rightarrow$ high production $\rightarrow$ low price. Furthermore, the reserve constraint multiplier now limits the investment rate for capacity, linking the physical resource base to the economic capacity growth loop.

Climate Change and Renewables: Two new stocks were added: climate change impact (accumulating policy pressure) and renewable capacity stock. Climate impact drives renewable investment and directly reduces oil demand via the climate demand multiplier. Renewable capacity growth, driven by both climate impact and oil price competitiveness, reduces oil demand via the renewable demand reduction multiplier. These two multipliers are combined into the structural demand multiplier, which scales oil consumption. This establishes another balancing loop: high oil price $\rightarrow$ High Renewable Investment $\rightarrow$ High Renewable Capacity $\rightarrow$ Low Oil Demand $\rightarrow$ Low Oil Price.

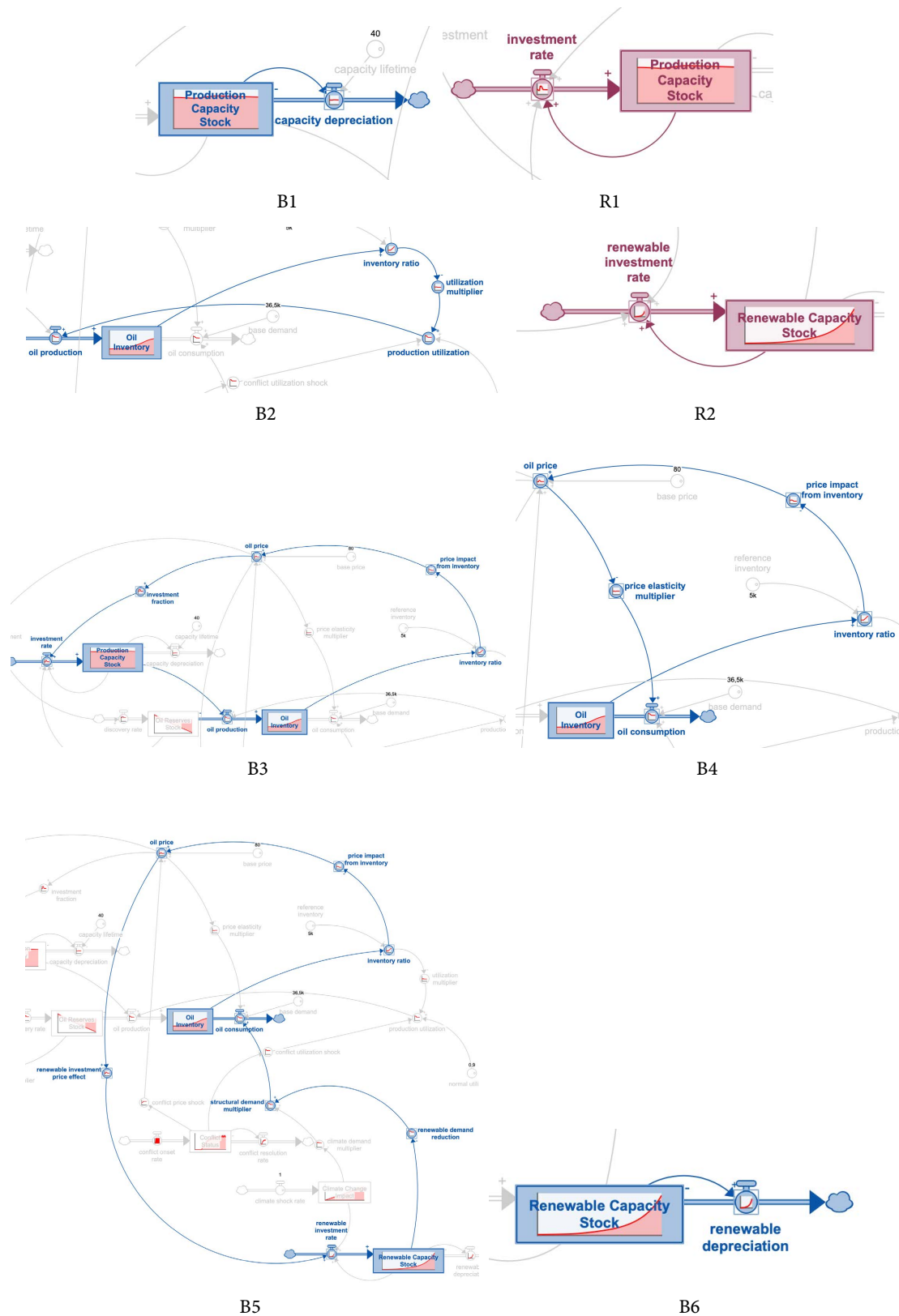
Geopolitical Conflict: The conflict status stock models a temporary shock (e.g., Russia/Europe conflict). This status simultaneously creates a positive conflict price shock (increasing oil price) and a negative conflict utilization shock (reducing production utilization), modeling the dual effect of supply disruption and market panic.

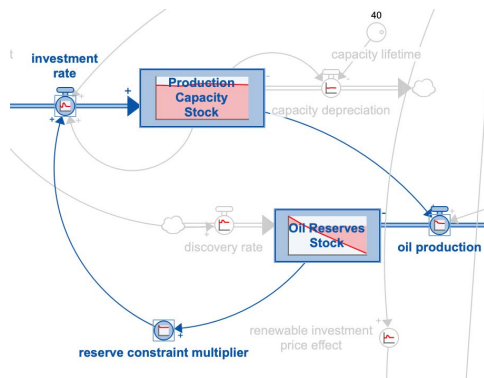


Investments in oil production capacity, investments in renewable energy (climate change impact) and political (and commercial) conflict are the three main drivers of the system.

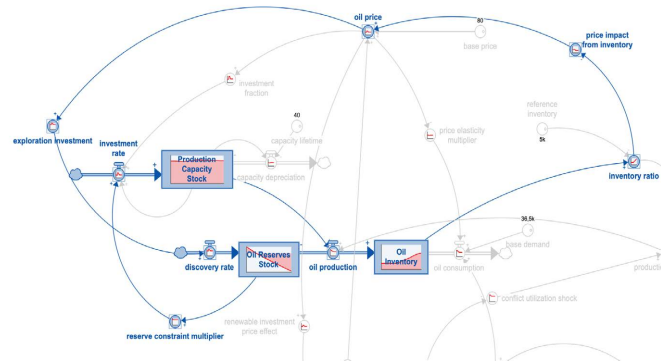


Simulation of the new model introduces 8 balancing loops (B1, B2, B3, B4, B5, B6, B7, B8) and 2 reinforcing loops (R1, R2).





B7



B8

9. Dynamic Systems Modeling Applied to Sonatrach's Strategy and Key Results

In this last part of the paper, we add the effect of the oil model on the strategy of Sonatrach. To incorporate the strategic influence of a major national oil company like Sonatrach, a new feedback loop was introduced linking global climate pressure back to global capacity investment via Sonatrach's strategic choices. This addresses how a major producer might shift its focus away from oil maximization in response to external pressures. The model introduces ten new variables:

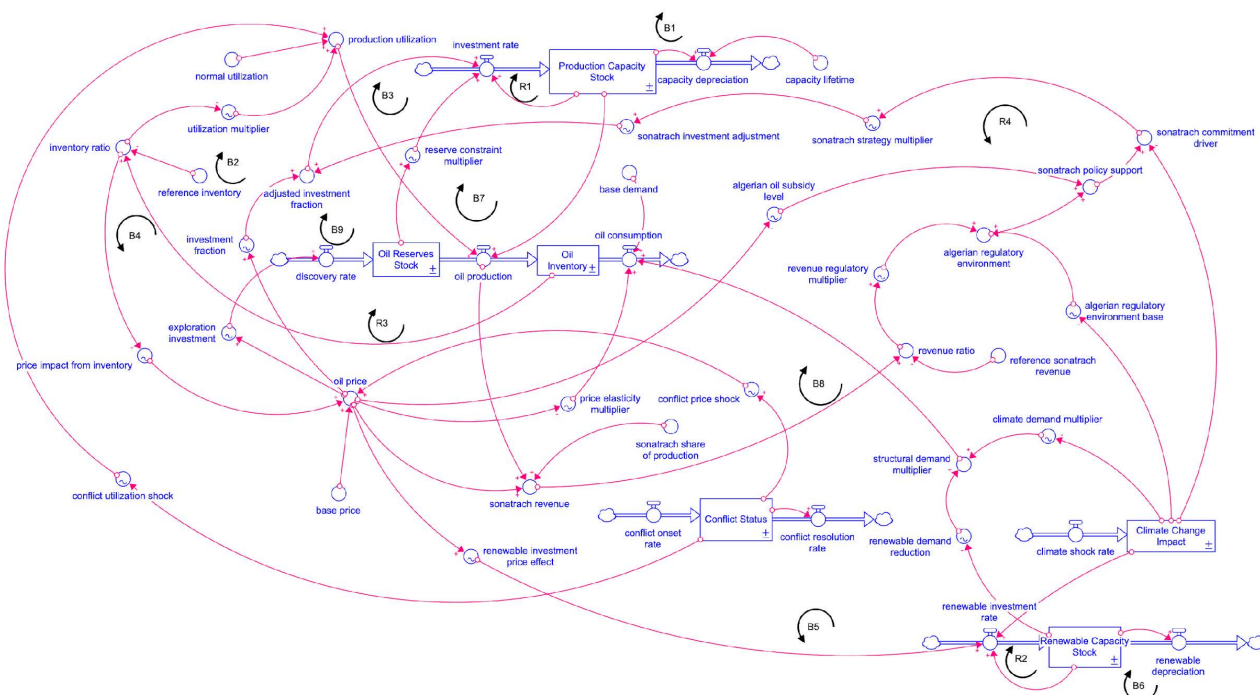
- *Sonatrach strategy multiplier* (this variable captures Sonatrach's commitment to oil investment, which is negatively driven by the accumulating *climate change impact*. As climate pressure rises, Sonatrach's focus on oil decreases);
- *Sonatrach Investment adjustment* (this variable translates Sonatrach's strategic focus into an adjustment factor for global investment. If Sonatrach maintains a high oil focus, it slightly boosts the global investment signal, if it shifts away, it slightly dampens it);
- *Adjusted investment fraction* (this new variable calculates the effective global investment fraction by multiplying the price-driven *investment fraction* by the *Sonatrach investment adjustment*).
- *Investment rate modification* (the equation for the *investment rate* flow was updated to use the *adjusted investment fraction* instead of the original *investment fraction*). This closes a balancing loop where increasing *climate impact* reduces *Sonatrach's oil* focus, which reduces *global investment*, slowing the growth of *global capacity*, and thus potentially mitigating future *climate impact*. It's an illustration of the Limits to Growth archetype (Diemer, 2022) applied to oil supply.
- *Algerian oil subsidy level* is modeled as a balancing factor, decreasing when the global oil price is high, as the government needs to intervene less.
- *Algerian regulatory environment* is introduced as a decreasing function of *climate change impact*, reflecting stricter laws as climate pressure mounts.
- *Sonatrach policy support* is the combination of *Algerian oil subsidy level* and *Algerian regulatory environment*. This support, along with the direct negative influence of *climate change impact*, determines the *Sonatrach commitment driver*.
- *Sonatrach commitment driver* serves as the input for the *Sonatrach strategy*

multiplier, replacing the direct link from climate change impact.

- *Sonatrach Revenue* is based on *oil production*, *oil price* and a new constant *Sonatrach share of production*. This revenue influences the Algerian regulatory environment. High revenue provides fiscal stability and incentive for the government to maintain favorable regulations for Sonatrach.

- *Structural change*: to integrate this variable, we split the original *Algerian regulatory environment* in two components: *Algerian regulatory environment base* (still driven negatively by *climate change impact*) and a new composite *Algerian regularity environment* which is the product of the base and a new *Revenue regulatory multiplier*. The multiplier is driven positively by the *revenue ratio*.

The new model has 13 closing loops, 8 Balancing loops (B1, B2, B3, B4, B5, B6, B7, B8, B9) et 4 reinforcing loops (R1, R2, R3, R4).



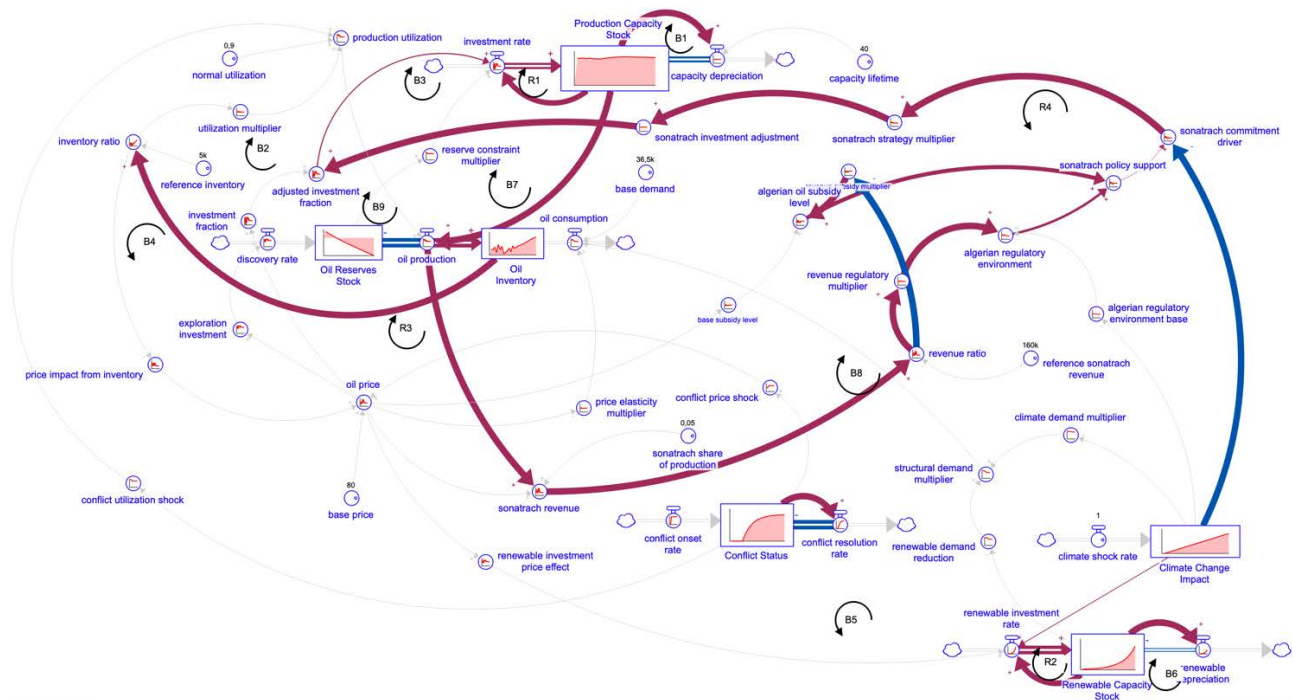
These new variables successfully close new feedback loops. For example:

1) **A new Balancing loop (B)**: Oil Price (-) → Subsidy Level (+) → Policy Support (+) → Commitment Driver (+) → Strategy Multiplier (+) → Investment Adjustment (+) → Investment Fraction (+) → Investment Rate (+) → Capacity Stock (+) → Oil Production (-) → Inventory Ratio (+) → Price Impact (+) → Oil Price. This loop represents how high prices reduce the need for subsidies, which eventually dampens Sonatrach's investment commitment, leading to lower future production and thus reinforcing the price increase (a balancing loop trying to stabilize the market, but with a delay).

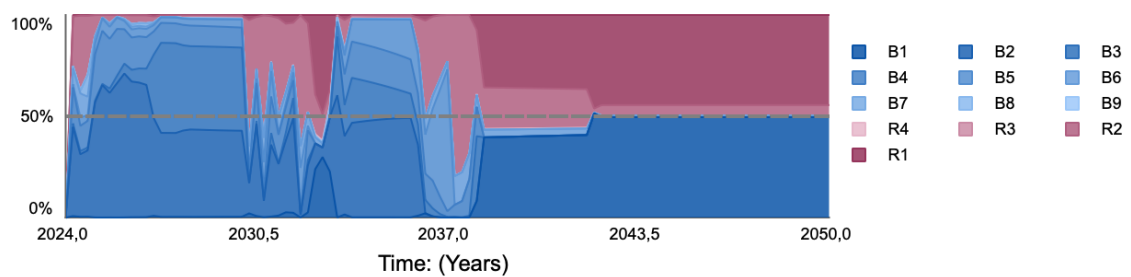
2) **A new Reinforcing loop (R)**: Increased *oil production* leads to higher *Sonatrach revenue*, which improves the *Algerian regulatory environment*. A better regulatory environment increases *Sonatrach policy support*, boosting *Sonatrach commitment*

driver and subsequently the *Sonatrach strategy multiplier*. This multiplier increases the *adjusted investment fraction*, driving the *investment rate* and ultimately increasing *production capacity stocks* and thus *oil production*. This loop connects the physical production system back to the policy environment, creating a “*Success to the Successful*” archetype for oil production.

The simulation process gives information on the dynamics of the system.



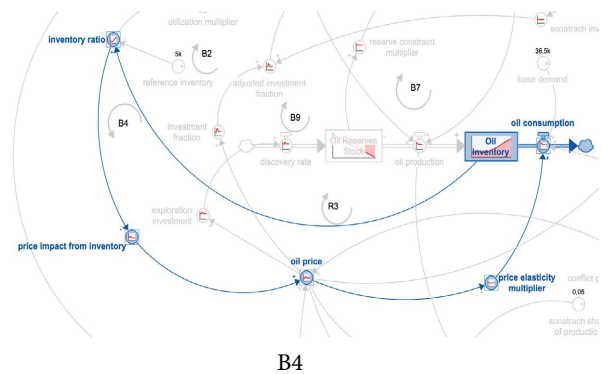
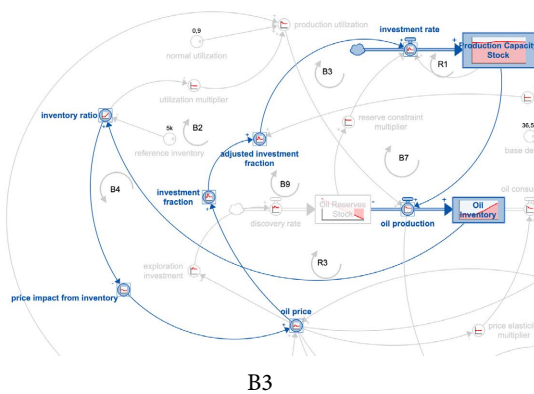
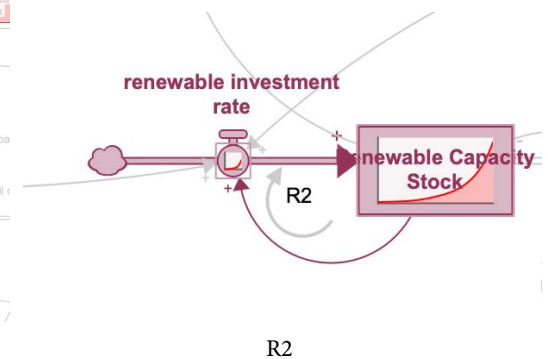
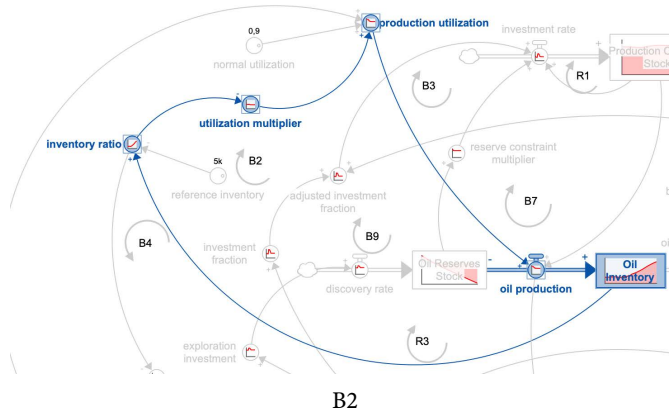
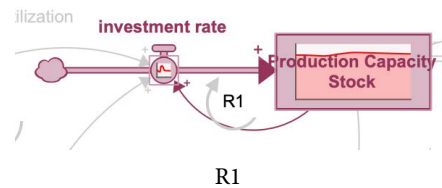
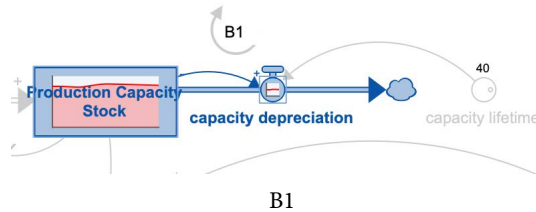
Loops B1, B2, B3, R1 and R2 are the dominant loops of the dynamics of the oil system.

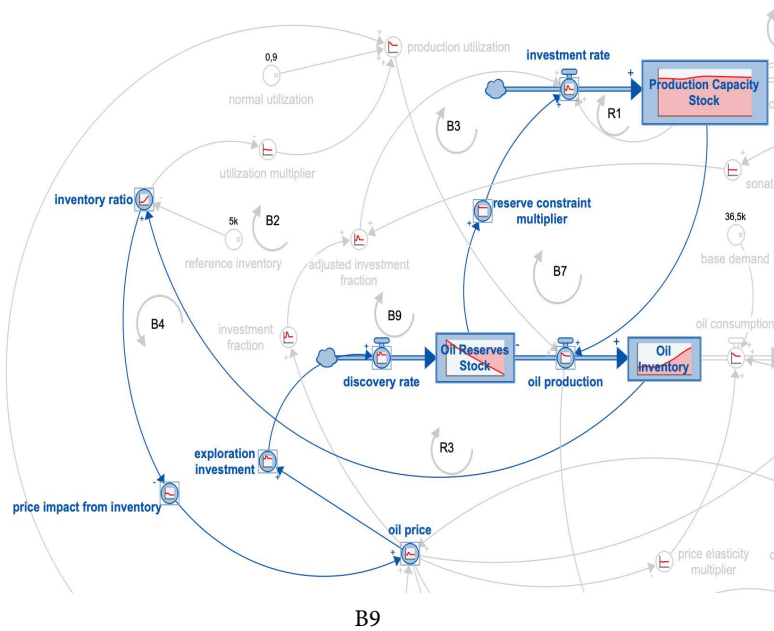
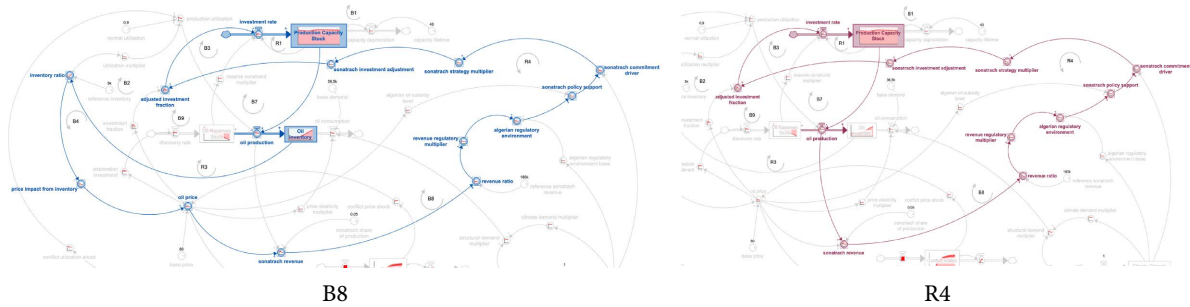
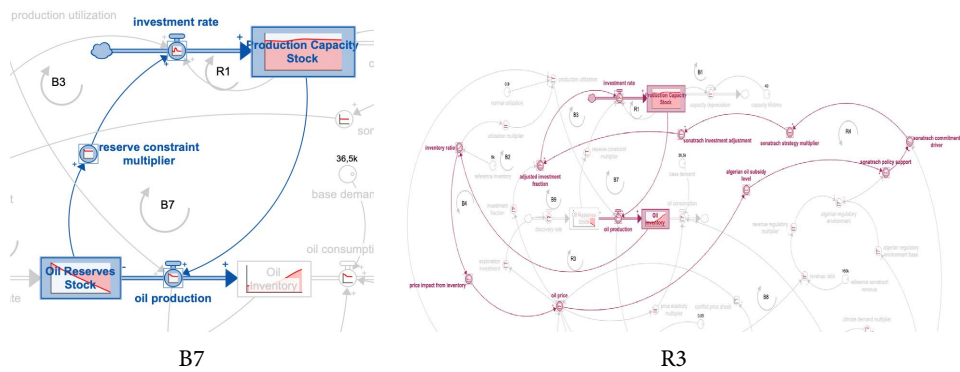
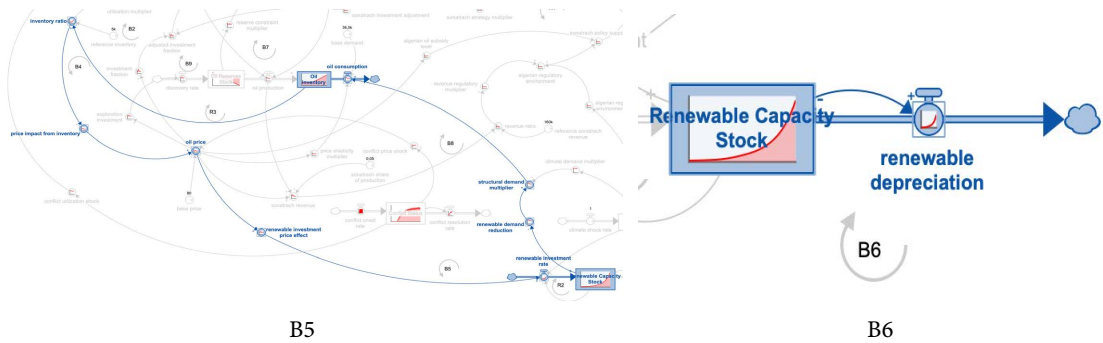


	Loop	Loops Agg.	T = 2050,00	Total 0.514%
1	B1 1 stock 2 variables	1	-49,55%	-22,59%
2	R1 1 stock 2 variables	1	44,48%	+20,94%
3	B2 1 stock 5 variables	1	0,00%	-19,55%
4	R2 1 stock 2 variables	1	5,25%	+14,02%
5	B3 2 stocks 9 variables	1	0,00%	-8,20%

	Loop	Loops Agg.	T = 2050,00	Total 0.2%
6	B4 1 stock 6 variables	1	0,00%	-6,83%
7	B5 2 stocks 10 variables	1	0,00%	-4,75%
8	B6 1 stock 2 variables	1	-0,72%	-2,61%
9	B7 2 stocks 5 variables	1	0,00%	-0,19%
10	R3 2 stocks 13 variables	1	0,00%	+0,12%

	Loop	Loops Agg.	T = 2050,00	Total 0%
9	B7 2 stocks 5 variables	1	0,00%	-0,19%
10	R3 2 stocks 13 variables	1	0,00%	+0,12%
11	B8 2 stocks 16 variables	1	0,00%	-0,12%
12	R4 1 stock 12 variables	1	0,00%	+0,08%
13	B9 3 stocks 11 variables	1	0,00%	-0,00%





The situation of a company like Sonatrach can be analyzed in a particularly illuminating way using systems dynamics. This approach highlights the complex interactions, feedback loops, and time lags that shape investment decisions in the oil sector. It is particularly relevant for understanding the contradiction between continued fossil fuel investment and carbon neutrality goals.

A first feedback loop, known as “reinforcing,” concerns oil revenues. High levels of investment in exploration and production increase extraction capacity, which generates more revenue for the state⁹. This revenue then helps finance new investments, thereby fueling a self-sustaining dynamic of dependence on hydrocarbons. This loop explains why it is difficult to break away from an economic model based on oil rent.

A second, equally reinforcing loop is linked to oil prices. When prices are high, incentives to invest in new projects increase, which boosts future supply. However, after a certain lag, this increase in supply can contribute to a decline in prices, creating a classic cyclical dynamic in the oil market.

Conversely, a “balancing” loop can be identified on the climate policy side. The recommendations of the International Energy Agency and international commitments aim to reduce oil demand. A decline in demand ultimately leads to lower prices and reduced incentives to invest, which can slow the sector’s expansion. However, this loop operates with significant time lags and remains uncertain depending on political and technological trajectories.

Another balancing loop could be introduced, concerning the risk of “stranded assets.” If current investments become unprofitable in a low-carbon future, financial losses may limit future investment capacity and prompt a strategic reorientation. This loop plays a potential regulatory role, but it is often underestimated in short-term decisions.

The value of systems dynamics lies in making these interactions and contradictions visible. It allows us to simulate different scenarios looking ahead to 2050 and to assess the consequences of conflicting strategic choices. It also highlights the central role of time lags (between investment and production, or between climate policies and economic effects), which are often overlooked in traditional analyses.

However, this approach also has limitations. As John D. Sterman points out, the models rely on simplifying assumptions and parameters that are sometimes uncertain, particularly in an unstable geopolitical context. Quantifying variables

⁹Production capacity and investment in oil fields play an important role in the dynamics of the oil system, particularly in Algeria. Sonatrach occupies a central place in this system. On the one hand, it provides tax revenue to the state, and as a result, can initiate a national energy transition towards carbon neutrality. It can also direct its investments towards renewable energies. On the other hand, it receives subsidies from the Algerian state, which, in the absence of stronger environmental regulation, encourages it to invest in fossil fuels. These investments are part of an economic, social, and geopolitical dynamic. Economic because Algeria must continue to explore future deposits to cope with the decline in its production over the next 25 years. Socially, because the standard of living of Algerians depends largely on oil and gas export revenues. Geopolitically, because oil and gas enable Sonatrach and Algeria to play a major role in Africa and Europe (particularly since the conflict between Russia and Ukraine).

such as political decisions, technological innovations, or the behavior of actors remains challenging.

Furthermore, systems dynamics favors an aggregated view that can obscure significant differences among actors or regions. It does not predict the future but explores possible scenarios, which can limit its use in highly constrained decision-making contexts.

Finally, the quality of the results depends heavily on the quality of the data and the validation of the model. In your case, we insisted on the structure of the model and the dominant loops of the dynamics. We are aware that failing to validate a model can have significant consequences. First, the results produced may be unreliable, as causal relationships or parameters may be poorly specified. This can lead to misinterpretations of oil market dynamics and inaccurate projections of prices or demand. Second, strategic decisions made on this basis—for example, by Sonatrach—may be ill-suited or even counterproductive, reinforcing risky or unprofitable investments. The lack of validation also prevents the detection of structural errors in feedback loops or time lags, which distorts the understanding of the system. Finally, an unvalidated model loses credibility with decision-makers and stakeholders, limiting its usefulness as a decision-support tool. It may thus induce false confidence or, conversely, be completely ignored, rendering the modeling process entirely pointless. Despite these limitations, systems dynamics is a powerful tool for analyzing the current contradiction: an economic dependence on oil revenues that fuels fossil fuel investments, while coming into conflict with long-term climate goals. It thus offers a rigorous framework for informing strategic choices in a context of profound uncertainty.

10. Conclusion

The analysis conducted in this article highlights the gap between the Algerian government's ambitions to decarbonize its energy system and the operational strategy of the Sonatrach oil group. On the one hand, there is the government's energy transition roadmap, which sets out an ambitious path to carbon neutrality, with a very significant share of renewable energies (photovoltaic and wind power) in its energy mix by 2030-2050. On the other, there is Sonatrach, an oil company at the heart of the Algerian economy, which remains deeply rooted in the extractive industry, focused on fossil fuels, and continues to invest heavily in hydrocarbons.

Behind this divergence lies a central question: how can Algeria reconcile climate imperatives and its commitments under the Paris Agreement with a national economy that remains largely dominated by oil export revenues? According to [Hasni et al. \(2021\)](#), breaking Algeria's economy free from its dependence on fossil fuels is no longer a choice, but a necessity. It is becoming essential to rethink Sonatrach's strategic priorities, which requires consultation and collective work with all stakeholders, including the state, industrial operators, relevant institutions and organizations, private investors, and representatives of civil society. To ensure the diversification of Algeria's energy mix, levers have been identified to translate am-

bitions into reality. This involves integrating CSP solar thermal energy alongside photovoltaic and wind power, gradually reducing subsidies for fossil fuels, and updating the legal framework to make it more conducive to future investment. Because beyond the rhetoric, it is the consistency between public policies and industrial strategies that will determine the country's energy future.

Our system dynamics modeling exercise confirms the findings of [Hasni et al. \(2021\)](#). Algeria's energy transition towards carbon neutrality is hampered by the existence of an economy dependent on oil revenues and strong ties between the Algerian state and the oil company (it should be noted that the director of Sonatrach is appointed by the Minister of Mines). Maintaining production capacity and discovering new deposits remain national priorities, and Sonatrach has deployed a strategy to meet these two challenges. The existence of subsidies for fossil fuels, massive investments in the exploration of new deposits, environmental legislation that is still in its infancy, and investments in renewable energies that are still lagging behind are preventing the advent of a new paradigm that is more in line with the idea of carbon neutrality by 2050.

Now, one of the most important questions is how to translate the results of a system dynamics model into public policy recommendations. The goal here is to translate these dynamics into levers for action. The model highlights key feedback loops (revenue dependence, investment cycles, climate pressure). The challenge is to identify where to intervene to alter these loops. For example, if a reinforcing loop links oil revenues and reinvestment, a public policy could aim to "break" this dynamic by redirecting a portion of the revenues to other sectors. In the case of Sonatrach, several types of policy tools can be considered. Carbon taxes or production royalties can act as a balancing mechanism by reducing the incentive to invest heavily in new fossil fuel projects. However, in a country dependent on hydrocarbons, their introduction must be gradual to avoid an overly abrupt economic shock. Stricter regulation can also be considered, for example by limiting the issuance of new exploration permits or by imposing more stringent environmental criteria. This directly affects the sector's capacity for expansion and can slow the momentum of fossil fuel investment. This type of measure is consistent with the recommendations of the International Energy Agency, but requires strong political will.

At the same time, the model's results may justify policies to reallocate investments. This involves, for example, creating incentives (subsidies, public-private partnerships) to steer Sonatrach toward natural gas, hydrogen, or renewable energy. This helps transform a "fossil fuel" feedback loop into a "low-carbon" feedback loop.

However, system dynamics also highlight the importance of time lags: policy effects are often slow to materialize. It is therefore essential to combine multiple instruments (taxes, regulation, innovation support) rather than relying on a single measure. Furthermore, the scenarios generated by the model should be used as exploratory tools rather than as definitive predictions. Finally, any policy recom-

mendations must take political and social constraints into account. A policy that is too abrupt could destabilize the national economy. The value of the model lies precisely in helping to test different trade-offs between short-term revenues and long-term transition, in order to develop progressive, coherent, and robust policies in the face of uncertainty.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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