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Ecole Supérieure en Sciences Appliquées



DÉPARTEMENT :

SECOND CYCLE

POLYCOPIÉ DE :

POLITIC ECONOMIC AND SOCIAL ASPECTS OF RENEWABLE ENERGIES

KHERBOUCHE DJAMILA

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Course Overview & Objectives

This comprehensive course module (ELTEE907) is designed for final-year engineering students specialising in electrical engineering and renewable energies. It bridges the gap between the technical aspects of energy systems and the broader political, economic, and social contexts that shape the energy sector.

Energy systems do not exist in a vacuum. A wind farm cannot be built without financing, permits, regulatory approval, and community acceptance. A solar project in Algeria must navigate national energy policy, international investment frameworks, grid connection rules, and local socioeconomic priorities. This course equips students with the tools to understand and navigate this complex landscape.

Module Information

Item	Details
Module Code	ELTEE907
Full Title	Political, Economic & Social Aspects of Renewable Energies
Credit Hours	3 (1.5h lecture + 1.5h tutorial per week)
Semester	Semester 2 – Final Year
Language	English (bilingual support available)
Assessment	40% continuous assessment + 60% final examination
Prerequisites	Electrotechnique Fondamentale, Power Electronics, Management & Economics

Learning Outcomes

Upon successful completion of this module, students will be able to:

1. Analyse global energy production, consumption, and reserve data and interpret future energy scenarios.
2. Describe the specific energy resource endowment of Algeria, including its renewable energy potential.
3. Explain the geopolitical dimensions of energy, including the influence of resource geography on international relations.

4. Identify and describe the roles of key public, private, and international actors in the energy sector.
5. Apply the relevant Algerian and international legal frameworks governing renewable energy projects.
6. Evaluate the socioeconomic impacts of renewable energy deployment at local, national, and global scales.
7. Construct basic economic analyses for renewable energy projects, including LCOE, NPV, and IRR calculations.
8. Propose viable business models for renewable energy enterprises in the Algerian context.

Course Structure

Chapter	Title	Key Topics	Hours
1	Global Energy Landscape	Production, consumption, reserves, forecasts, CO_2 trends	4.5h
2	Energy in Algeria	Hydrocarbons, solar potential, PNREE 2030, energy balance	4.5h
3	Geopolitics of Energy	Energy security, resource conflicts, transition geopolitics	3h
4	Key Actors	International organisations, national agencies, private sector	3h
5	Laws & Regulations	International treaties, Algerian legislation, regulatory tools	4.5h
6	Socioeconomic Impacts	Jobs, health, energy access, gender, community development	4.5h
7	RE in the Economy	LCOE, financing, business models, macroeconomics	6h
—	Revision & Assessment	Problem-solving sessions, case studies, exam preparation	3h

General Introduction

Energy has never been a purely technical subject. The physical laws that govern a photovoltaic cell or a synchronous generator are identical everywhere in the world, yet the energy systems built upon those laws differ enormously from one country to another. What explains the difference is not physics but politics, law, economics and society. A wind farm that is technically excellent will never turn a single blade if it cannot obtain a permit, secure a tariff, convince a lender or win the consent of the community living next to it. This module begins from that observation and takes it seriously.

The scale of the transformation now under way makes the observation urgent. Between 2010 and 2023 the levelized cost of utility-scale solar photovoltaics fell by roughly 90%, from about USD 378/MWh to about USD 36/MWh (IRENA, 2024a). Global renewable capacity more than tripled over the same period to reach some 4,175 GW (IRENA, 2024b), and in 2023 worldwide investment in clean energy exceeded USD 1.7 trillion for the first time (IEA, 2023b). None of these figures is the result of a single technical breakthrough. They are the cumulative product of feed-in tariffs in Germany, competitive auctions in the Gulf and in North Africa, industrial policy in China, climate commitments negotiated under the Paris Agreement, and the daily work of engineers who learned to speak the language of regulators, lawyers and financiers.

For Algeria the stakes are specific and immediate. Hydrocarbons still provide approximately 95% of export revenues and a substantial share of the state budget (Sonatrach, 2023; IMF, 2023), while renewable sources supply barely 2% of electricity generation (CREG, 2023; Sonelgaz, 2023). At the same time the country holds one of the finest solar resources on the planet, with 2,000–2,700 kWh/m²/yr across most of its territory (CDER, 2022), and a national programme, the PNREE, targeting 22 GW of renewable capacity by 2030 (MEM, 2021). Fewer than 1 GW are installed today. The distance between the target and the reality is not a technical distance: the technology exists, the land exists, the sunlight exists in abundance. It is a distance made of tariffs, permits, contracts, financing structures and institutional capacity. Explaining that distance, and equipping future engineers to close it, is the purpose of this course.

The support is organised in seven chapters that move from the global to the national and from the descriptive to the operational. Chapter 1 establishes the quantitative picture: how much energy the world produces and consumes, what reserves remain, and what the principal scenarios project to 2050. Chapter 2 applies the same lens to Algeria, covering the hydrocarbon sector, the renewable resource base, the PNREE and the present electricity system. Chapter 3 turns to geopolitics and asks how control over resources, infrastructure and technology is converted into power, and how the energy transition is redistributing that power. Chapter 4 maps the actors — international organisations, national institutions, private companies and civil society — whose decisions determine whether a project advances or stalls. Chapter 5 sets out the legal and regulatory framework, from the Paris Agreement to Algerian Law 11-09 and the practical lifecycle of a project authorisation. Chapter 6 examines socioeconomic impacts: employment, health, energy access, gender and community development. Chapter 7 closes with economics, from the LCOE formula and project finance metrics to business models that an Algerian graduate could realistically pursue.

Each chapter combines concise analytical text with figures, tables, boxed case studies and worked numerical examples, and ends with a summary of key points and a set of review questions and exercises. Guidance answers to selected exercises, together with a sheet of key formulas and reference values for Algeria, are provided in two appendices. Figures and tables are numbered by chapter and every one of them carries its source immediately beneath it. Factual statements in the running text carry an author–date citation in brackets, for example (IEA, 2023a), which refers to the corresponding full entry in the Bibliography at the end of the document. Where a table presents an estimate or an elaboration rather than a published measurement, the source line states this explicitly, so that students can distinguish established data from indicative orders of magnitude. A glossary of key terms precedes the bibliography.

Two cautions should be kept in mind throughout. First, energy data are revised every year: the values reproduced here correspond to the 2023–2024 editions of the cited sources, and students should verify any figure they intend to use against the latest available edition. Second, the long-term scenarios presented in Chapter 1 are conditional projections built on explicit policy assumptions, not forecasts; they describe what would happen if certain decisions were taken, and their value lies in the comparison between them rather than in any single number.

By the end of the module students should be able to read an energy balance, interpret a scenario, identify the legal and institutional steps of a renewable energy project, estimate a levelized cost of energy, judge whether a project is bankable, and argue the socioeconomic case for or against a given investment. These competences correspond to the eight learning outcomes listed in the course overview and are assessed through continuous assessment (40%) and a final examination (60%).

Chapter 1 – Global Energy Production, Consumption, Reserves & Forecasts

Energy is the foundation of human civilisation. From the steam engines of the Industrial Revolution to today's digital economies, every stage of economic development has required increasing quantities of energy. Understanding where energy comes from, how it is consumed, and how much remains is the starting point for any analysis of the energy transition.

1.1 Global Primary Energy: An Overview

Primary energy refers to energy found in nature that has not yet been subjected to any conversion or transformation process. In 2023, the world consumed approximately 620 exajoules (EJ) of primary energy—equivalent to roughly 145,000 TWh of electricity, or burning 21 billion tonnes of oil equivalent (Gtoe) (IEA, 2023a).

Fossil fuels—coal, oil, and natural gas—still account for more than 80% of this total. However, this share is declining for the first time in history as renewable energy expands rapidly across all regions (IEA, 2023a; Energy Institute, 2023).

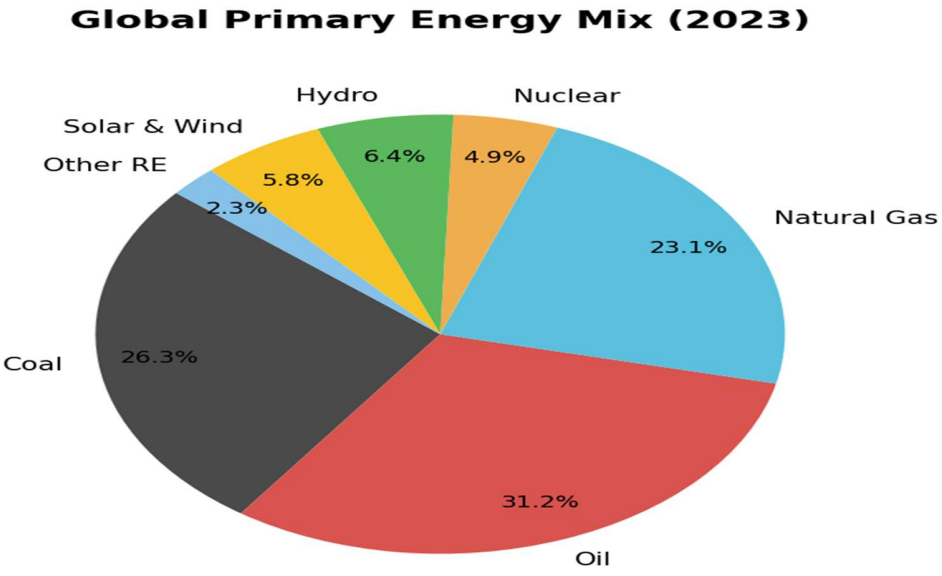


Figure 1.1 — Global Primary Energy Mix, 2023 (Source: compiled from IEA, 2023a, World Energy Outlook 2023)

Energy Source	EJ (2023)	Share (%)	Growth 2010–23 (%/yr)	CO_2 Intensity (gCO_2/kWh)
Oil	193	31.2	+0.8	260
Coal	163	26.3	-0.5	820

Energy Source	EJ (2023)	Share (%)	Growth 2010–23 (%/yr)	CO_2 Intensity (gCO_2/kWh)
Natural Gas	143	23.1	+1.4	490
Nuclear	30	4.9	+0.2	12
Hydropower	40	6.4	+1.7	4
Solar PV & Wind	36	5.8	+22.4	~0
Other Renewables	14	2.3	+8.1	<30
TOTAL	620	100.0	+1.1	—

Table 1.1 — Global Primary Energy Mix: Key Statistics 2023 (Source: compiled from IEA, 2023a and Energy Institute, 2023; lifecycle CO_2 intensities from IPCC, 2014, Annex III)

The present mix is the product of a long history. Figure 1.2 traces global primary energy consumption since 1965. Three features stand out. First, total demand has almost quadrupled in less than sixty years, from roughly 160 EJ to about 620 EJ, closely tracking population growth and the industrialisation of Asia. Second, every new source has so far been *added* to the existing ones rather than *substituted* for them: coal did not disappear when oil arrived, and oil did not disappear when natural gas spread. Historians of energy call this pattern "energy addition", and it explains why the absolute consumption of coal reached a record in 2023 even as its share declined (Energy Institute, 2023).

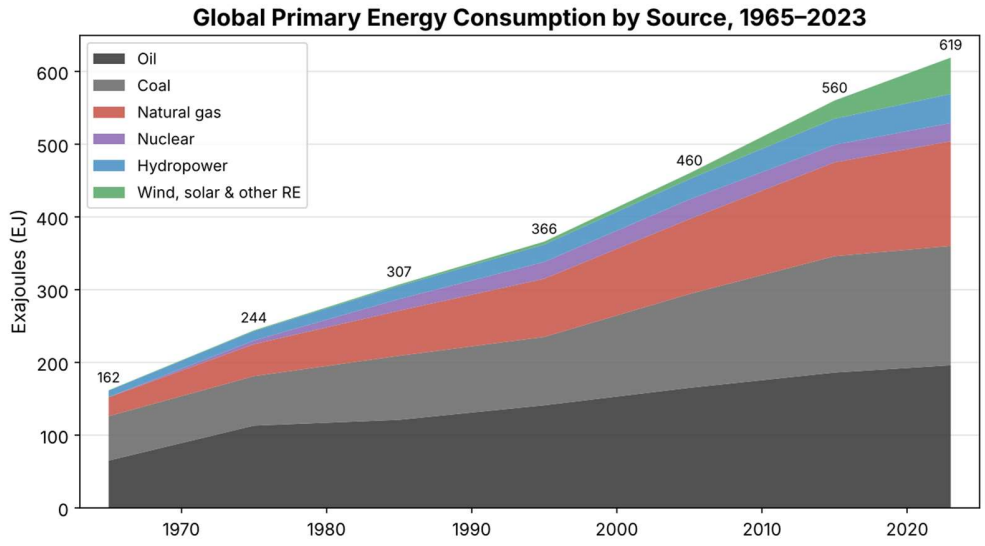


Figure 1.2 — Global Primary Energy Consumption by Source, 1965–2023, EJ (Source: approximate values rounded from Energy Institute, 2023, Statistical Review of World Energy; nuclear and renewables expressed on a primary-energy-equivalent basis)

Third, the wedge of wind, solar and other modern renewables is visibly widening at the top of the chart. Between 2015 and 2023 it doubled, and in several recent years renewables supplied the majority

of the *growth* in global electricity demand (IEA, 2023a). The energy transition can therefore be described in two complementary ways: as a slow change in shares, or as a rapid change at the margin. Students should be able to switch between the two perspectives, because public debates frequently confuse them — a technology can grow at 20% per year while still representing only a few percent of the total.

A methodological caution is necessary when comparing sources. Fossil fuels are measured by their heat content, whereas electricity from wind, solar or hydropower has no fuel. Statistical agencies therefore convert renewable electricity to "primary energy" using either the *physical energy content method* (1 TWh of electricity = 3.6 PJ) or the *substitution method*, which counts the fossil fuel that would have been needed to produce the same electricity (about 2.5 times more). The choice of method can more than double the apparent share of renewables, which is why figures from the IEA, the Energy Institute and IRENA do not always coincide (Energy Institute, 2023; IEA, 2023a).

1.2 Energy Consumption by Region

Energy consumption is highly unequal across the world. The Asia-Pacific region, led by China and India, now accounts for nearly half of global primary energy demand. Meanwhile, per-capita consumption remains vastly higher in North America and Europe than in Africa or South Asia (Energy Institute, 2023; World Bank, 2023a).

Region	Primary Energy (EJ)	Share of World (%)	Per Capita (GJ/person)	Population (Bn)
Asia Pacific	279	45.0	60	4.65
North America	111	17.9	216	0.51
Europe	82	13.2	100	0.82
Middle East	37	6.0	145	0.26
CIS (ex-Soviet)	34	5.5	131	0.26
South & Central America	31	5.0	48	0.65
Africa	28	4.5	18	1.43
WORLD	620	100	78	8.0

Table 1.2 — Primary Energy Consumption by World Region, 2023 (Source: compiled from Energy Institute, 2023; population data from World Bank Open Data)

> **Energy Inequality**

Africa has 17% of the world's population but consumes only 4.5% of global primary energy. Sub-Saharan Africa's per-capita energy use is less than 10% of the average for OECD countries. This energy poverty is a major obstacle to economic development and human wellbeing—and represents a massive opportunity for renewable energy deployment (World Bank, 2023a; Energy Institute, 2023).

Regional totals hide even larger differences between individuals. Figure 1.3 converts Table 1.2 into energy use per person. The average North American consumes about 216 GJ per year — more than twelve times the African average of 18 GJ and almost three times the world average. Europe and Japan achieve comparable or higher standards of living with roughly half the North American consumption, which shows that the relationship between energy and welfare is strong at low levels of consumption but weakens considerably above about 100 GJ per person (World Bank, 2023a).

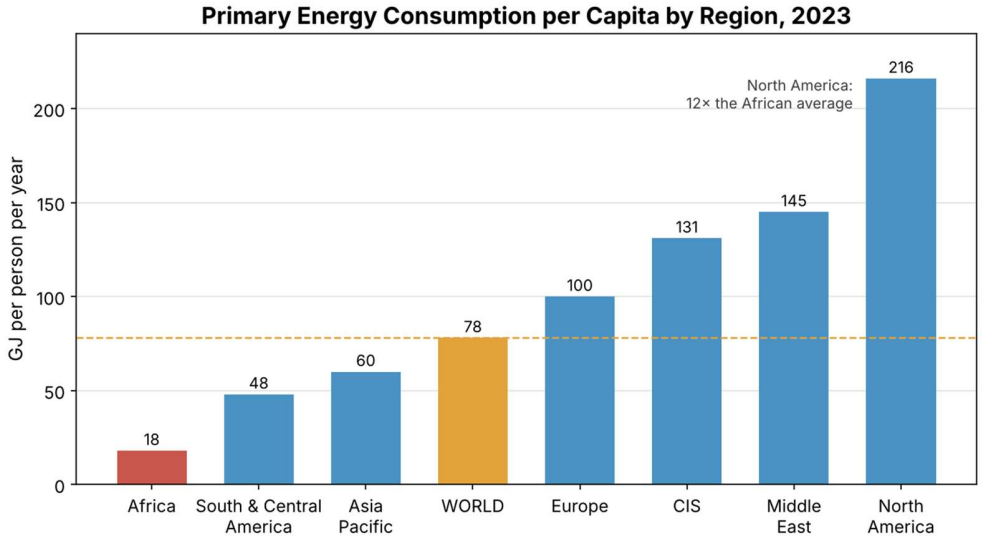


Figure 1.3 — Primary Energy Consumption per Capita by World Region, 2023, GJ/person/yr (Source: own elaboration from the data of Table 1.2; Energy Institute, 2023; World Bank Open Data)

Two policy messages follow. For low-consumption regions — most of Africa and South Asia — the priority is to *increase* energy services, and the question is whether this growth can be supplied by renewables rather than by the fossil path followed by today's industrialised economies. For high-consumption regions, the priority is to *decouple* welfare from energy through efficiency, electrification and structural change. Algeria, with roughly 55–60 GJ per person, sits close to the Asia-Pacific average and faces both challenges at once: demand for electricity and cooling is growing quickly, while the energy intensity of its economy remains high by international standards (APRUE, 2022; IEA, 2023a).

1.3 The Growth of Renewable Energy

Renewable energy capacity has grown dramatically over the past 15 years. Three technologies have dominated: solar photovoltaics (PV), wind power, and hydropower. The growth of solar PV in particular has exceeded virtually every forecast made a decade ago (IRENA, 2024b).

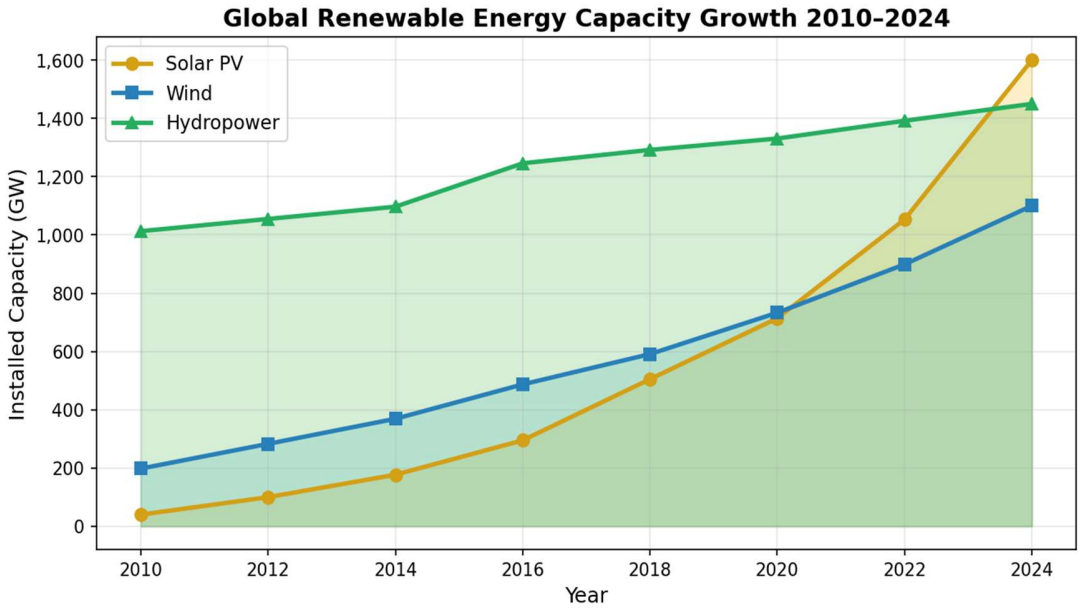


Figure 1.4 — Global Renewable Installed Capacity Growth 2010–2024, GW (Source: IRENA, 2024b, Renewable Capacity Statistics 2024)

Technology	2010 (GW)	2015 (GW)	2020 (GW)	2023 (GW)	Growth 2010–2023
Solar PV	40	227	714	1,631	+3,977%
Wind (total)	198	433	733	1,017	+414%
Hydropower	1,013	1,246	1,331	1,392	+37%
Bioenergy	73	88	107	119	+63%
Geothermal	11	13	14	15	+36%
Ocean	0.5	0.5	0.5	0.5	+0%
TOTAL RE	1,336	2,007	2,900	4,175	+212%

Table 1.3 — Global Renewable Energy Installed Capacity by Technology, GW (Source: IRENA, 2024b)

Three forces explain the speed of this growth. The first is cost: the price of PV modules has fallen by more than 90% since 2010, and onshore wind turbines have become larger, more efficient and cheaper

per megawatt-hour (IRENA, 2024a; see Chapter 7). The second is policy: feed-in tariffs in Europe, auctions in emerging markets and industrial policy in China created the initial markets that allowed manufacturers to scale up and move down their learning curves. The third is modularity. A solar plant is built from thousands of identical, factory-made components, so it can be deployed in months rather than years, in sizes from a few hundred watts on a rooftop to several gigawatts in a desert. This modularity reduces construction risk and allows learning to accumulate rapidly — a decisive advantage over large, bespoke plants such as nuclear reactors or hydropower dams.

Growth is nonetheless uneven. In 2023 China alone accounted for more than half of the world's new renewable capacity, while Africa — which holds about 60% of the best solar resources on the planet — received less than 2% of global renewable investment (IRENA & CPI, 2023; IEA, 2023b). The obstacle in Africa is not the resource but the cost of capital, a theme developed in Section 7.2 and illustrated quantitatively in Figure 7.6.

1.4 CO_2 Emissions and Climate Targets

The primary driver of the energy transition is the climate emergency. Burning fossil fuels for energy is the largest source of global greenhouse gas emissions, accounting for approximately 75% of all human-caused GHG emissions (IPCC, 2023; IEA, 2023c).

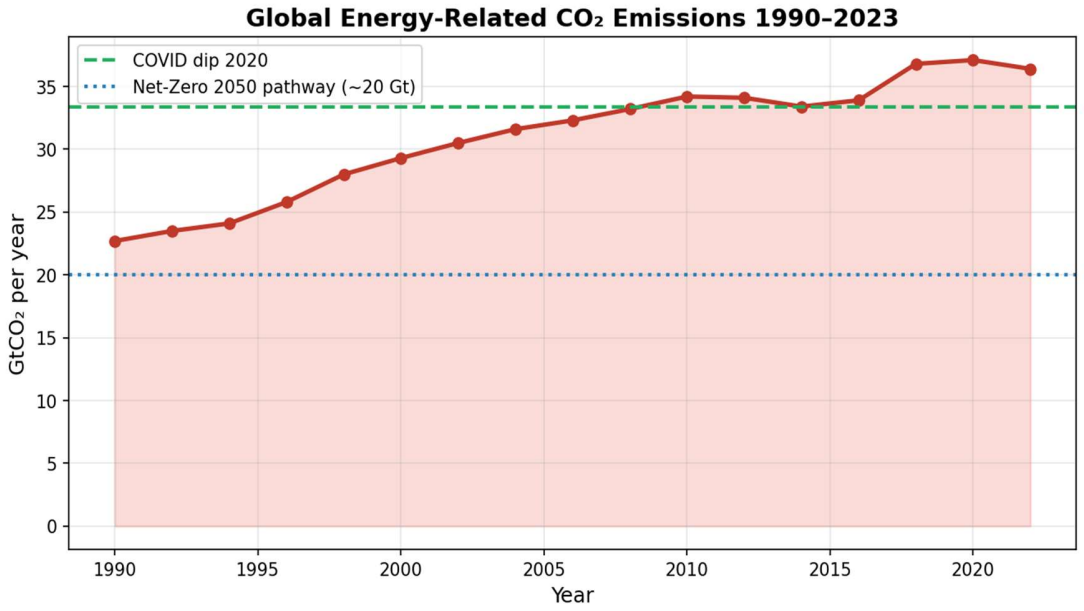


Figure 1.5 — Global Energy-Related CO_2 Emissions 1990–2023, $GtCO_2/yr$ (Source: IEA, 2023c, CO_2 Emissions in 2022; IEA, 2023a)

Climate Scenario	CO_2 in 2030 (Gt)	CO_2 in 2050 (Gt)	Temperature Outcome	RE Share 2030 (%)
Current Policies	40+	45+	+3.0°C or more	~20%

Climate Scenario	CO_2 in 2030 (Gt)	CO_2 in 2050 (Gt)	Temperature Outcome	RE Share 2030 (%)
Stated Policies (STEPS)	37	38	+2.5°C	~25%
Announced Pledges (APS)	33	28	+1.7°C	~35%
Net Zero Emissions (NZE)	23	~0	+1.5°C	~60%

Table 1.4 — IEA Climate Scenarios and Energy Outcomes (Source: IEA, 2023a, World Energy Outlook 2023)

The scenarios of Table 1.4 can be visualised as diverging trajectories. Figure 1.6 shows that the difference between policies already in force (STEPS) and a 1.5 °C-compatible pathway (NZE) is not a matter of fine-tuning: by 2030 the two paths are already 14 $GtCO_2$ apart — roughly the combined current emissions of the United States and the European Union — and by 2050 the gap reaches almost 40 Gt.

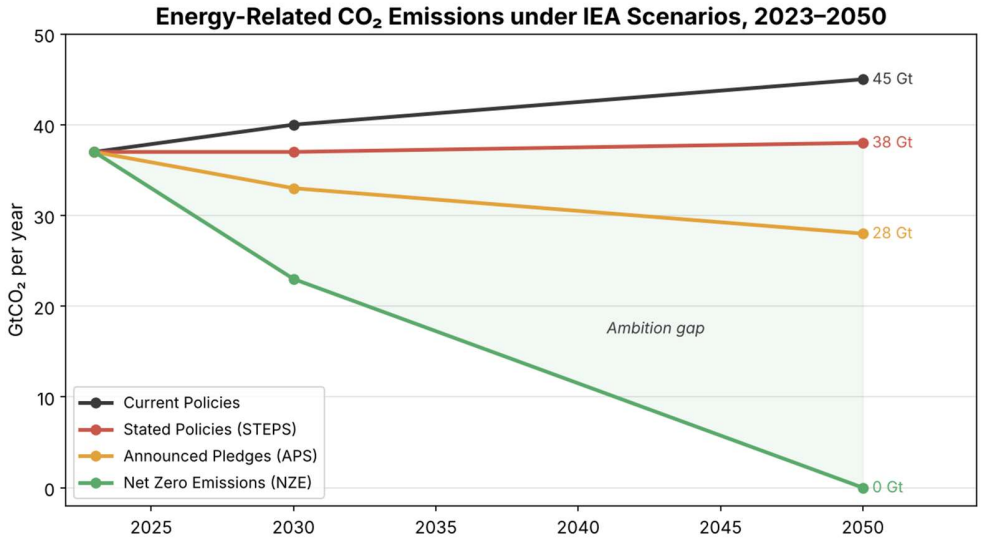


Figure 1.6 — Energy-Related CO_2 Emissions under the Four IEA Scenarios, 2023–2050, $GtCO_2$/yr (Source: own elaboration from the scenario values of Table 1.4; IEA, 2023a)

The concept that links these trajectories to physical climate outcomes is the **carbon budget**: the cumulative quantity of CO_2 that can still be emitted while keeping warming below a given threshold with a stated probability. The IPCC Sixth Assessment Report estimated the remaining budget for a 50% chance of limiting warming to 1.5 °C at about 500 $GtCO_2$ from the beginning of 2020 (IPCC, 2023). At current emission rates of about 40 $GtCO_2$ per year from all sources, this budget would be exhausted around the end of this decade. The arithmetic is simple but its consequences are profound:

the problem is not the *rate* of emissions in any single year but the *cumulative* total, so every year of delay makes the required subsequent reduction steeper.

1.5 Fossil Fuel Reserves and the Resource Curse

Despite decades of consumption, proven fossil fuel reserves remain large in absolute terms. The critical issue is not physical scarcity but the fact that burning all known reserves would far exceed the global carbon budget consistent with 1.5°C warming (Energy Institute, 2023; IEA, 2021).

Fossil Fuel	Proven Reserves	R/P Ratio	Carbon Budget Compatibility	Price Range (2023)
Crude Oil	1,732 Billion barrels	~54 years	<30% can be burned (IEA NZE)	$70–95/barrel
Natural Gas	188.1 Trillion m³	~48 years	<45% compatible	$2–15/MMBtu
Coal	1,074 Billion tonnes	~132 years	<15% compatible	$100–300/tonne

Table 1.5 — Global Fossil Fuel Reserves and Climate Compatibility (Source: reserves and R/P ratios from Energy Institute, 2023; carbon-budget compatibility from IEA, 2021)

> **The Resource Curse**
> Countries heavily dependent on fossil fuel exports often experience paradoxically low human development, institutional fragility, conflict, and economic volatility—a phenomenon known as the "resource curse" or "Dutch disease." Diversification into renewable energy can help hydrocarbon-dependent economies build more resilient, diversified economic structures (Yergin, 2020; IMF, 2023).

The reserves-to-production (R/P) ratio is frequently misread as the number of years “before oil runs out”. It is nothing of the kind. Reserves are an economic category, not a geological one: they comprise only the quantities that can be produced profitably with current technology and prices, and they are revised upwards whenever prices rise or technology improves. The world’s proven oil reserves were estimated at about 650 billion barrels in 1980, when the R/P ratio was roughly 30 years; four decades and more than 1,000 billion barrels of production later, reserves are larger than ever (Energy Institute, 2023). The binding constraint on fossil fuels in the 21st century is therefore not depletion but the atmosphere, as Figure 1.7 makes explicit.

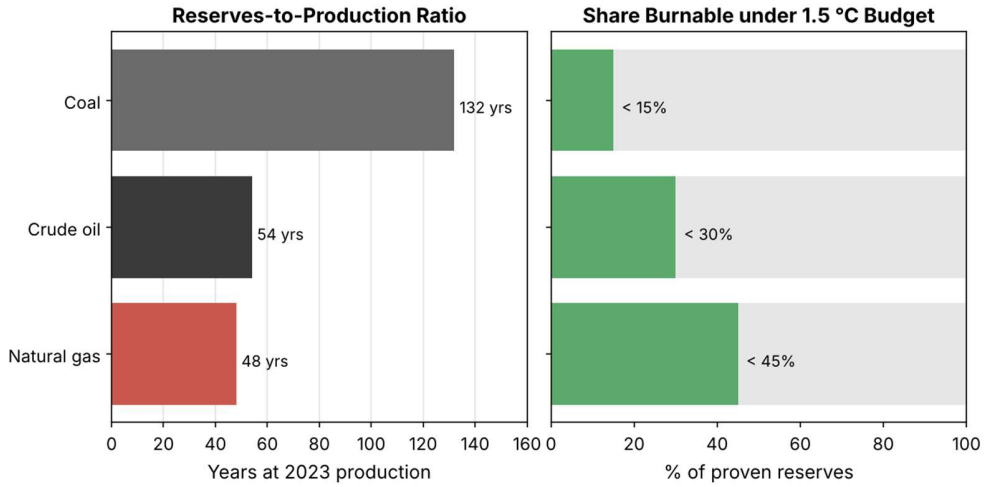


Figure 1.7 — Fossil Fuel Reserves-to-Production Ratios and the Share of Reserves Compatible with a 1.5 °C Carbon Budget (Source: own elaboration from Table 1.5; Energy Institute, 2023; IEA, 2021)

The right-hand panel introduces the notion of **unburnable carbon**: if the climate targets of the Paris Agreement are honoured, the majority of today's proven reserves — especially coal — must remain in the ground. For companies and states whose balance sheets are built on these reserves, this creates the risk of **stranded assets**, that is, investments that lose their value before the end of their expected economic life. The issue is directly relevant to Algeria, whose public finances depend on the long-term value of its gas and oil reserves, and is discussed in Chapter 3.

1.6 Energy Forecasts: The Road to 2050

Multiple authoritative scenarios project global energy out to 2050. The IEA, IRENA, and BP all publish long-term forecasts with differing assumptions about climate policy ambition (IEA, 2021; IRENA, 2023a).

Indicator	2023 (Actual)	2030 (NZE Target)	2050 (NZE Target)
Renewable share of electricity	30%	60%	>90%
Coal in power mix	36%	<10%	~0%
EV share of new car sales	18%	>60%	~100%
Green hydrogen production (Mt)	<1	>70	>400
Annual RE investment (USD Tn)	0.57	1.7+	4.5+
Energy intensity improvement (%/yr)	1.5	4.0	3.5

Table 1.6 — Key Energy Indicators: 2023 Actuals vs. IEA Net Zero Scenario Targets (Source: IEA, 2021 and IEA, 2023a)

The indicators of Table 1.6 measure the distance between where the world is and where it would need to be. Some indicators are broadly on track — the growth of solar PV and electric vehicle sales has exceeded most forecasts — whereas others, such as the rate of energy-intensity improvement or the production of low-emission hydrogen, lag far behind. A useful exercise for students is to classify each indicator as *on track*, *off track but accelerating* or *off track and stagnating*, and to identify for each one whether the main barrier is technological, economic, regulatory or social. The rest of this course provides the tools to answer that question.

1.7 Energy Units, Balances and Conversion Chains

Energy statistics are published in a bewildering variety of units: exajoules, tonnes of oil equivalent, barrels, cubic metres, British thermal units and kilowatt-hours. An engineer working in the energy sector must be able to move between them quickly and without error. Table 1.7 gathers the conversion factors used most often in this course. All are approximate, because the energy content of a fuel varies with its composition; national statistical offices publish country-specific factors that should be preferred for precise work.

Unit	Definition / use	Equivalent
1 kWh	Electricity metering	3.6 MJ
1 toe (tonne of oil equivalent)	Energy balances (IEA, APRUE)	41.868 GJ ≈ 11.63 MWh
1 barrel of crude oil	Oil markets (159 litres)	≈ 5.7–6.1 GJ ≈ 0.136 toe
1 m³ of natural gas	Gas markets (standard conditions)	≈ 36–38 MJ (higher heating value)
1 bcm of natural gas	Pipeline and LNG trade	≈ 0.9 Mtoe ≈ 36 PJ ≈ 35.7 million MMBtu
1 MMBtu	Gas prices (Henry Hub, LNG)	1.055 GJ ≈ 293 kWh
1 EJ (exajoule)	Global statistics	10^{18} J ≈ 277.8 TWh ≈ 23.9 Mtoe
1 GW × 1 year	Power plant output at 100% load	8.76 TWh

Table 1.7 — Common Energy Units and Conversion Factors (Source: own compilation from IEA and Energy Institute methodological notes; values rounded)

Energy also changes form several times between its extraction and its final use, and each conversion entails losses. Statisticians distinguish three stages. **Primary energy** is the energy contained in natural resources before any transformation (crude oil, coal, natural gas, uranium, solar radiation captured as electricity). **Final energy** is the energy delivered to the consumer — petrol at the pump, electricity at the meter, gas at the burner. **Useful energy** is the service actually obtained: heat in a room, motion of a vehicle, light from a lamp. Figure 1.8 shows the orders of magnitude for the world as a whole.

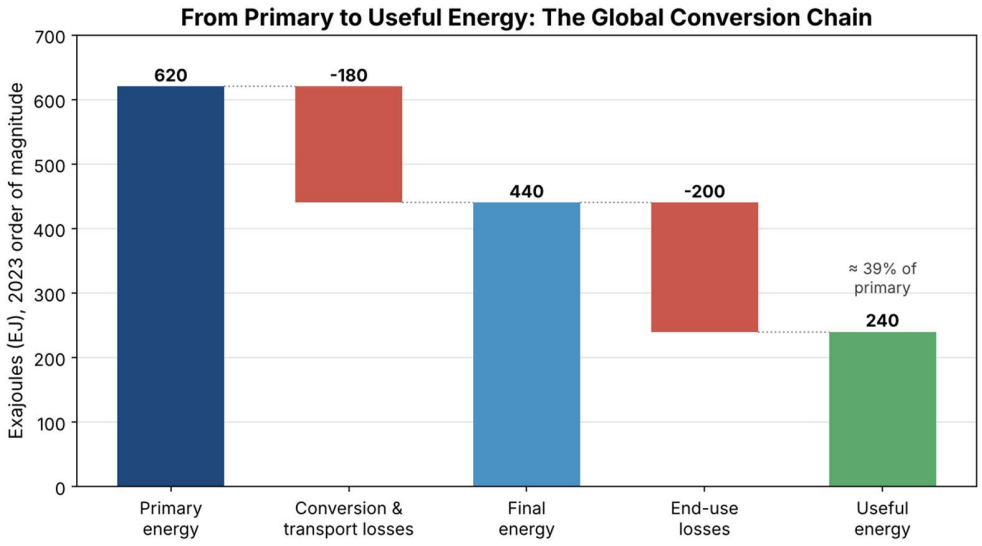


Figure 1.8 — Primary, Final and Useful Energy: The Global Conversion Chain, Indicative Orders of Magnitude, EJ (Source: own elaboration based on IEA, 2023a energy balances; useful energy estimated with typical end-use efficiencies)

The largest losses occur in two places: in thermal power stations, which convert only 35–60% of the heat of their fuel into electricity, and in internal combustion engines, which convert only 20–30% of the energy of petrol into motion. This observation explains a counter-intuitive feature of the energy transition. Because wind and solar produce electricity directly, and because electric motors and heat pumps are three to four times more efficient than combustion engines and boilers, an electrified energy system needs substantially *less* primary energy to deliver the same services. Scenario studies therefore project that total primary energy demand can stabilise or fall even as the global economy grows (IEA, 2021; IRENA, 2023a).

1.7.1 Reading an Energy Balance

An **energy balance** is a matrix that records, for a given country and year, the supply of each energy product (production, imports, exports, stock changes), its transformation (power plants, refineries, liquefaction plants) and its final consumption by sector (industry, transport, residential, services, agriculture). Reading a balance correctly requires attention to sign conventions — exports and transformation inputs are negative — and to the distinction between energy and non-energy uses (for example natural gas used as a feedstock for ammonia). Algeria's national balance, published annually by the Ministry of Energy, shows a characteristic structure: very large hydrocarbon production, of which a major share is exported; a transformation sector dominated by gas-fired power stations and LNG plants; and final consumption concentrated in the residential and transport sectors (APRUE, 2022).

Key Points of Chapter 1

- Global primary energy demand reached about 620 EJ in 2023; fossil fuels still supply over 80% of it, but their share is falling.
- Historically, new energy sources have been added to old ones rather than substituted for them; the transition requires a break with this pattern.
- Energy use is extremely unequal: per-capita consumption in North America is more than twelve times that of Africa.
- Solar PV and wind dominate capacity additions thanks to falling costs, supportive policy and modularity.
- The binding constraint on fossil fuels is the carbon budget, not geological depletion; much of today's reserves is "unburnable".
- Scenarios are conditional projections, not forecasts; their value lies in the comparison between them.
- Conversion losses between primary and useful energy are large; electrification reduces them.

Review Questions and Exercises — Chapter 1

1. Explain the difference between primary, final and useful energy, giving one example of each for an Algerian household.
2. Using Table 1.2, calculate the ratio between per-capita energy consumption in North America and in Africa. Discuss two reasons why this ratio overstates the difference in living standards.
3. Convert Algeria's gas exports of about 55 bcm per year into EJ, Mtoe and TWh using the factors of Table 1.7.
4. Why is the reserves-to-production ratio a poor indicator of the "time remaining" before a fuel runs out? Use the history of oil reserves since 1980 in your answer.
5. A 1 GW solar PV plant operates with a capacity factor of 22%. How many TWh does it produce per year? How much natural gas (in bcm) would a combined-cycle plant with 55% efficiency need to produce the same electricity?
6. Distinguish between the STEPS, APS and NZE scenarios of the IEA. Why should a scenario not be read as a forecast?
7. Explain the concept of a carbon budget and why cumulative, rather than annual, emissions determine long-term warming.

Chapter 2 – Energy Sources in Algeria

Algeria occupies a unique position in the global energy landscape. It is both one of Africa's most important hydrocarbon producers and a country endowed with one of the world's richest renewable energy resources—particularly solar irradiation. Understanding Algeria's energy profile is essential for any future energy professional working in the country.

2.1 Algeria's Hydrocarbon Sector

The Algerian economy is overwhelmingly dependent on hydrocarbons. Oil and gas account for approximately 95% of export revenues, 60% of government revenues, and 30% of GDP. Sonatrach, the state-owned energy company, is the largest company in Africa by revenue (Sonatrach, 2023; IMF, 2023).

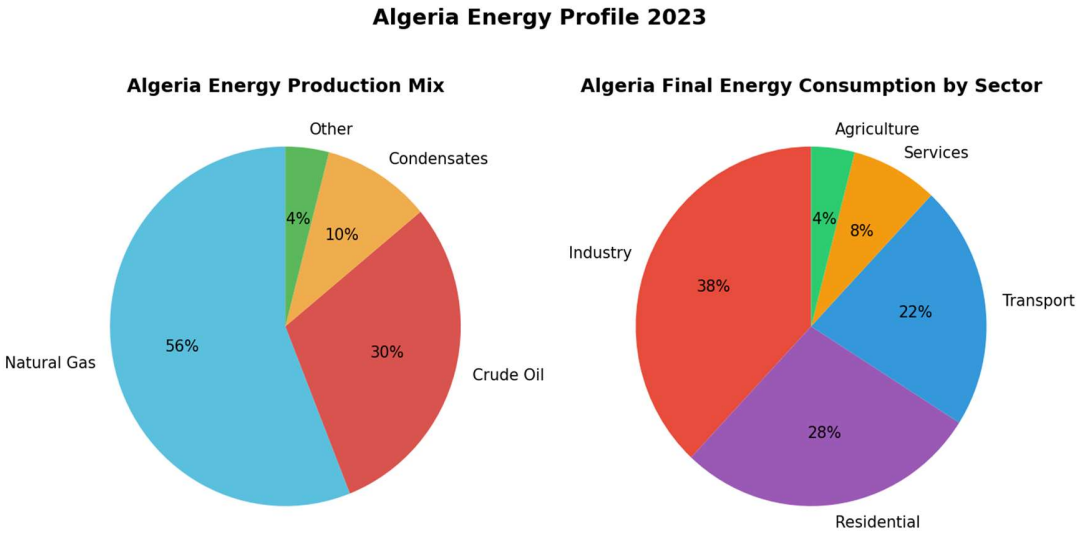


Figure 2.1 — Algeria Energy Production Mix and Final Consumption by Sector, 2023 (Source: compiled from Sonatrach, 2023; Sonelgaz, 2023; APRUE, 2022)

Indicator	Value	Rank	Notes
Natural gas reserves	2.37 Trillion m³	10th globally	Africa's largest gas producer
Crude oil reserves	12.2 Billion barrels	16th globally	Mature fields in Hassi Messaoud
Gas exports (2023)	~55 Bcm/yr	Major EU supplier	Via Medgaz & TransMed pipelines
Oil production	~1.05 Mb/d	OPEC+ member	Declining trend since 2008 peak

Indicator	Value	Rank	Notes
Sonatrach revenue (2022)	USD 50+ Billion	Africa's #1 company	Record year due to energy crisis
Hydrocarbon GDP share	~30%	Down from 42% (2011)	Diversification underway
Energy subsidy cost	~USD 12Bn/yr	~5% of GDP	Reform ongoing

Table 2.1 — Algeria Hydrocarbon Sector Key Indicators, 2023 (Source: compiled from Sonatrach, 2023; Energy Institute, 2023; OPEC, 2023; IMF, 2023)

The figures in Table 2.1 conceal an important dynamic: the rapid growth of domestic gas consumption. Figure 2.2 shows that, while marketed production has risen only moderately since 2010, the volume consumed inside Algeria has almost doubled, driven by power generation, the residential sector and new industrial users such as fertiliser, cement and steel plants. In some years, domestic consumption has approached the volume exported, a situation unthinkable two decades ago (Sonatrach, 2023; Energy Institute, 2023).

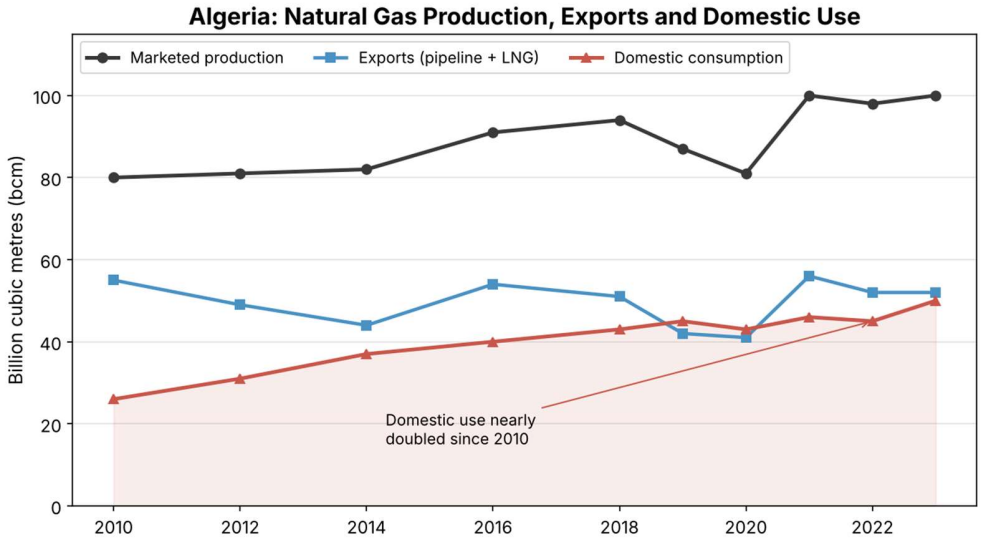


Figure 2.2 — Algeria: Natural Gas Marketed Production, Exports and Domestic Consumption, 2010–2023, bcm (Source: approximate values rounded from Energy Institute, 2023 and Sonatrach, 2023; the difference between production and the sum of exports and consumption corresponds to reinjection, losses and statistical differences)

This "domestic gas squeeze" is one of the strongest economic arguments for renewable energy in Algeria. Almost all electricity is generated from gas sold to power producers at regulated prices far below export parity. Every cubic metre burnt in a domestic power station is a cubic metre that cannot be sold to Italy or Spain at international prices. Renewable electricity therefore has a value for Algeria that goes beyond its own cost: it *frees up* gas for export. This logic is quantified in Section 2.6.

2.2 Algeria's Renewable Energy Resources

Algeria is endowed with exceptional renewable energy resources, particularly solar. The Saharan plateau receives some of the highest solar irradiation levels on Earth, making Algeria potentially one of the world's leading solar energy producers and exporters (CDER, 2022).

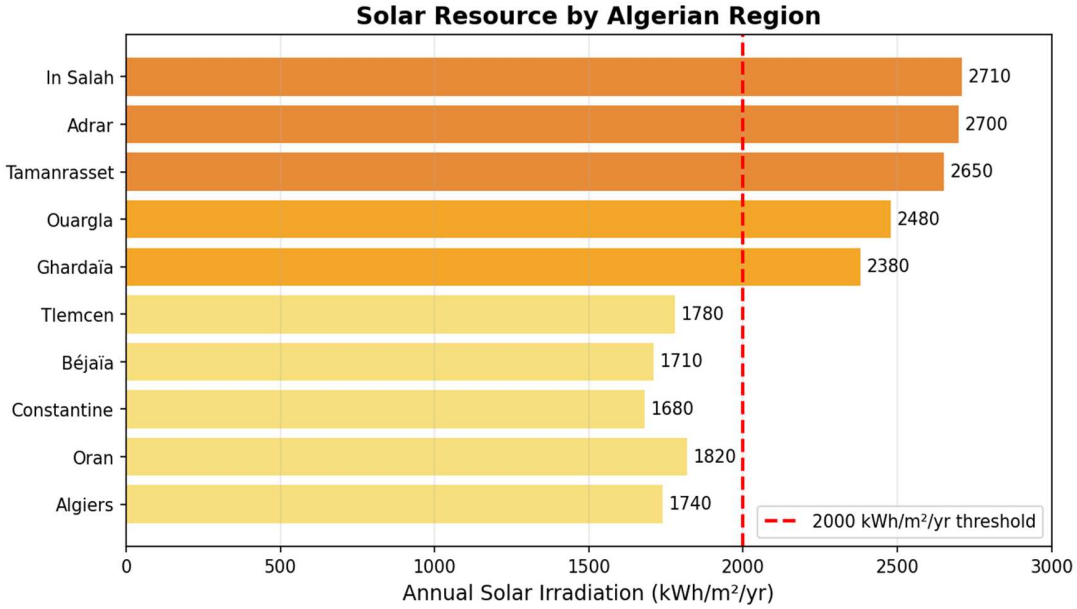


Figure 2.3 — Annual Solar Irradiation by Region in Algeria, kWh/m²/yr (Source: CDER, 2022, Atlas du Gisement Solaire de l'Algérie; Global Solar Atlas)

Resource	Technical Potential	Geographical Focus	Quality Assessment
Solar PV	>2,000 GW technical potential	Sahara, South Plateau	World-class (2,000–2,700 kWh/m²/yr)
Concentrated Solar (CSP)	500+ GW suitable land	Adrar, Ouargla, Tamanrasset	Excellent DNI: 2,500–2,750 kWh/m²/yr
Wind	~35 GW technical potential	Tindouf, Tiaret, Tlemcen	Good 6–8 m/s average wind speed
Geothermal	~1 GW potential	North-East (Guelma, Khenchela)	Low-enthalpy, 60–100°C
Hydropower	~400 MW remaining potential	Northern Tells (Oued Chéliff)	Limited; mostly developed

Resource	Technical Potential	Geographical Focus	Quality Assessment
Biomass	~3 GW potential	Agriculture zones, cities	Urban waste; agricultural residues
Hydrogen (Green)	Vast export potential	Sahara (solar-driven)	EU market strategy underway

Table 2.2 — Algeria's Renewable Energy Resource Inventory (Source: compiled from CDER, 2022 and MEM, 2021)

Annual totals give only part of the picture. Engineers designing a solar plant also need to know how the resource varies through the year. Figure 2.4 compares three representative sites. The coastal site of Algiers receives about 1,800 kWh/m² per year with a pronounced winter minimum, while the Saharan sites of Ghardaïa and Tamanrasset combine higher totals with a much flatter seasonal profile. A flatter profile is valuable: it means more stable production, smaller seasonal storage needs and a higher utilisation of grid connections.

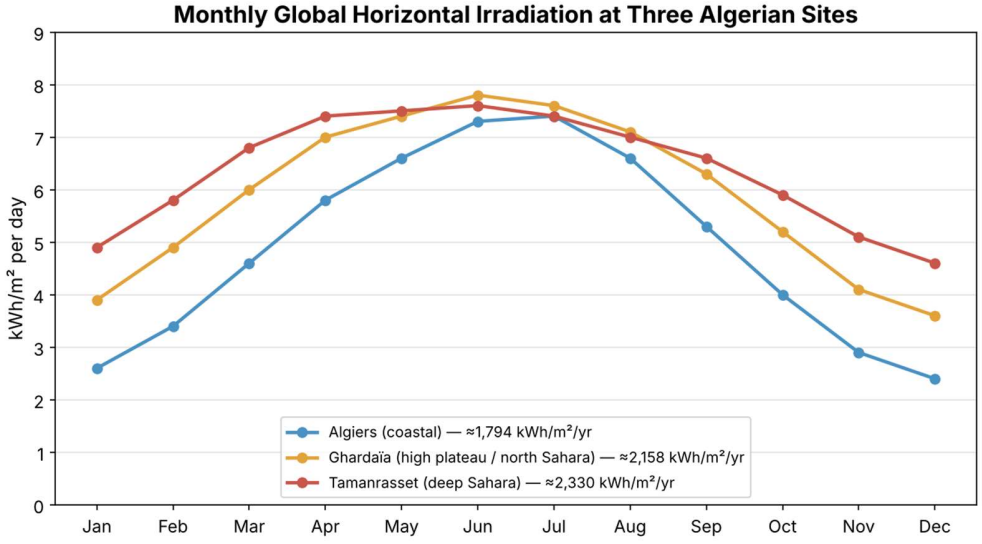


Figure 2.4 — Monthly Global Horizontal Irradiation at Three Representative Algerian Sites, kWh/m²/day (Source: indicative typical-year values derived from CDER, 2022 and the Global Solar Atlas, ESMAP, 2020)

2.2.1 Technical Considerations for Solar Plants in the Sahara

High irradiation is not the only parameter that determines the output of a solar plant. Three local factors partly offset the Saharan advantage and must be addressed at the design stage:

- **Temperature.** The efficiency of crystalline silicon cells falls by about 0.35–0.45% for each degree Celsius above 25 °C. In summer, module temperatures in the Sahara can exceed 65–70

°C, reducing instantaneous output by 15% or more. Bifacial modules, good ventilation and modules with lower temperature coefficients mitigate this loss.

- **Soiling.** Dust and sand deposits can reduce output by 0.3–1% per day without cleaning, and sandstorms can cause losses of 20% or more in a few hours. Cleaning strategies — robotic dry cleaning, scheduled washing, anti-soiling coatings — must be optimised against the scarcity of water.
- **Grid distance.** The best resources are often located hundreds of kilometres from the main load centres on the coast. Transmission lines add cost and losses, and the southern grids around Adrar, In Salah and Tindouf are only partly connected to the national network (Sonelgaz, 2023).

Concentrated solar power (CSP) faces additional constraints: it uses only the direct component of radiation (DNI), which is strongly reduced by atmospheric dust, and its conventional wet cooling requires large volumes of water. Dry cooling is possible but reduces efficiency by several percentage points. The great advantage of CSP is its ability to store heat cheaply in molten salt and generate electricity after sunset, a feature whose value increases as the share of PV in the system rises (see Section 2.7).

2.3 The National Renewable Energy Programme (PNREE 2030)

Algeria launched its National Renewable Energy and Energy Efficiency Programme (PNREE) in 2011 and has since revised it several times. The current target is 22 GW of installed renewable capacity by 2030, representing about 27% of the national electricity generation mix (MEM, 2021).

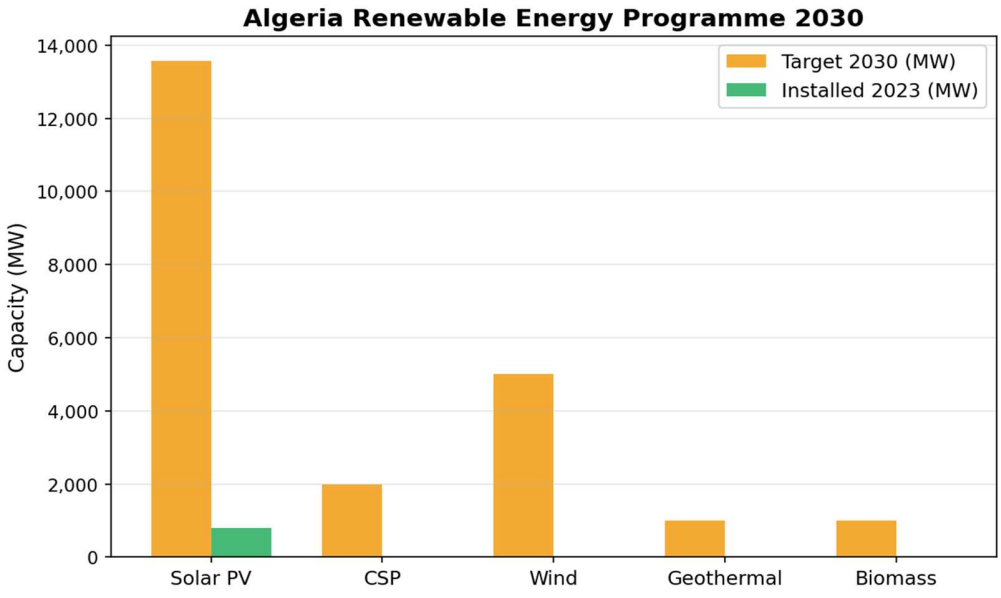


Figure 2.5 — Algeria Renewable Energy 2030 Targets vs. Current Installed Capacity, MW (Source: compiled from MEM, 2021, PNREE; CREG, 2023)

Technology	2030 Target (MW)	Projects Phase 1 (MW)	Current Installed (MW)	Investment Needed (USD Bn)
Solar PV (ground)	10,575	3,000	600	~9.5
Solar PV (rooftop)	3,000	400	200	~2.5
Concentrated Solar (CSP)	2,000	150	0	~5.0
Wind (onshore)	5,010	1,010	10	~5.5
Geothermal	1,000	50	5	~2.0
Biomass / Waste-to-Energy	1,000	100	5	~1.5
Cogeneration (CHP)	400	100	0	~0.5
TOTAL	22,985	4,810	820	~26.5

Table 2.3 — Algeria PNREE 2030 Detailed Breakdown (Source: MEM, 2021; installed capacity from CREG, 2023; investment needs are indicative estimates)

The programme has been implemented far more slowly than planned. The first phase (2011–2015) delivered around 340 MW of solar PV in the southern and high-plateau regions, largely through Sonelgaz's renewable-energy subsidiary SKTM, together with a 10 MW wind farm at Kabertène near Adrar and the 25 MW solar field integrated into the hybrid solar-gas plant of Hassi R'Mel (Sonelgaz, 2023; CREG, 2023). A successful call for tenders for 1,000 MW of PV was launched in 2021–2023 and is discussed as a case study in Chapter 7. The causes of the delays — financing structure, tariff level, land procedure, local-content rules and grid capacity — are examined in Chapters 4, 5 and 7.

Hybrid Solar–Gas: The Hassi R'Mel Plant

Commissioned in 2011, the Hassi R'Mel integrated solar combined-cycle plant combines about 130 MW of gas turbines with a 25 MW parabolic-trough solar field. The solar field produces steam that supplements the steam cycle during sunny hours, reducing fuel consumption. Although its solar share is modest, the project gave Algerian engineers early experience with CSP technology and demonstrated a pragmatic route — *hybridisation* — for introducing solar energy into a gas-based power system (Sonelgaz, 2023).

The Sahara Opportunity

> If Algeria were to install solar PV on just 0.1% of its Saharan surface, it could generate more electricity than the entire country currently consumes. The Sahara's solar potential has attracted major international interest: projects such as Desertec (European-African supergrid) and EU hydrogen import strategies identify Algeria as a key clean energy partner for the 21st century (CDER, 2022; MEM, 2021).

2.4 Current Electricity System

Algeria's electricity sector is dominated by natural gas-fired thermal power plants. The national grid (réseau interconnecté national, RIN) is managed by Sonelgaz and serves about 98% of the population—one of Africa's highest electrification rates (Sonelgaz, 2023; CREG, 2023).

Indicator	2023 Value	Trend	Target 2030
Installed capacity (total)	~26,000 MW	Growing	~50,000 MW
Electricity generated	~81 TWh/yr	Growing 5%/yr	~130 TWh
Renewable share of generation	~2%	Rising	27%
Gas in electricity mix	~97%	Declining	<70%
Electrification rate	98.3%	Stable	>99%
Transmission losses	~13%	High	<8%
Peak demand	~14,000 MW	Summer peak	~22,000 MW
Electricity subsidy (per kWh)	~0.02 USD	Under reform	Gradual increase

Table 2.4 — Algeria Electricity Sector Key Indicators, 2023 (Source: Sonelgaz, 2023; CREG, 2023)

Figure 2.6 summarises the generation mix. With natural gas supplying about 97% of electricity, Algeria has one of the least diversified power systems in the world. This structure has historical logic — gas is abundant, cheap for domestic users and burnt in efficient combined-cycle turbines — but it ties the electricity sector to the gas balance discussed above and exposes the national budget to the opportunity cost of not exporting that gas.

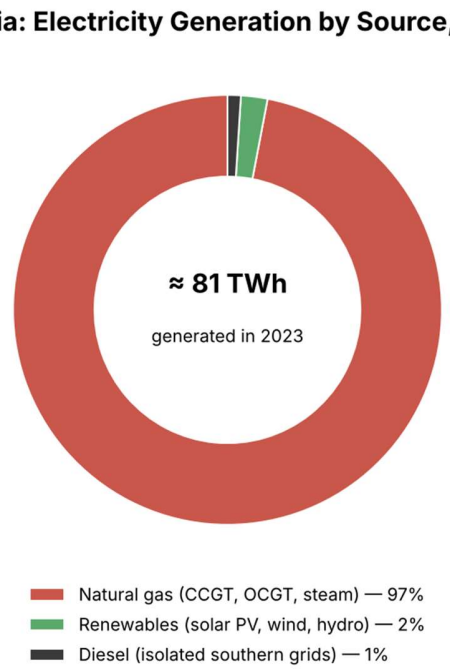


Figure 2.6 — Algeria: Electricity Generation by Source, 2023, % of Total (Source: own elaboration from Sonelgaz, 2023 and CREG, 2023; shares rounded)

Demand growth reinforces the challenge. Figure 2.7 shows that generation has increased by about 75% since 2010, an average of more than 4% per year, driven by population growth, rising household equipment rates and, above all, the spread of air-conditioning. The resulting summer peak is a defining characteristic of the Algerian system: peak demand occurs on hot afternoons and evenings in July and August, when gas turbines lose efficiency because of high ambient temperatures (Sonelgaz, 2023).

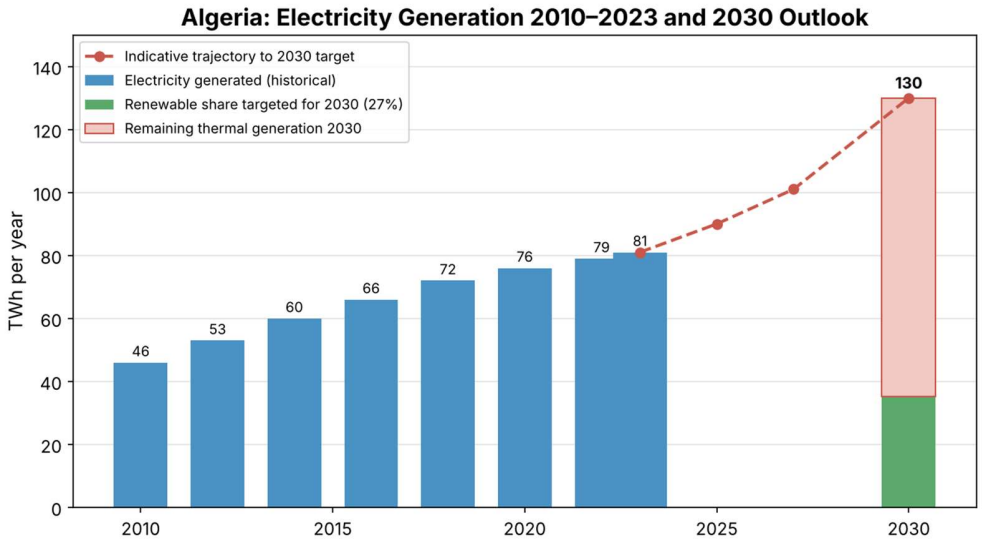


Figure 2.7 — Algeria: Electricity Generation 2010–2023 and Indicative 2030 Outlook with the 27% Renewable Target, TWh (Source: historical values approximate from Sonelgaz, 2023 and CREG, 2023; 2030 values from Table 2.4 and MEM, 2021)

High transmission and distribution losses — about 13% of generation, compared with 6–8% in well-managed European networks — are a further weakness. Part of these losses are technical (long lines, old transformers), part are commercial (unmetered or unpaid consumption). Reducing them is one of the cheapest ways of "producing" additional electricity and is fully part of the energy transition.

2.5 Energy Efficiency in Algeria

Energy efficiency is the "first fuel" of the energy transition—reducing waste is cheaper and faster than building new capacity. Algeria has made energy efficiency a central pillar of its energy policy (APRUE, 2022; IEA, 2023a).

Sector	Energy Intensity (kgoe/USD 1000 GDP)	Savings Potential	Key Measures
Buildings (residential)	High	30%	Insulation, LED, efficient appliances
Industry	Very High	25%	Motor efficiency, waste heat recovery
Transport	High	20%	Vehicle standards, public transport, EVs
Agriculture	Moderate	15%	Efficient irrigation, solar pumping

Sector	Energy Intensity (kgoe/USD 1000 GDP)	Savings Potential	Key Measures
Services / Public	Moderate	20%	Building retrofits, smart meters

Table 2.5 — Energy Efficiency Opportunities by Sector in Algeria (Source: APRUE, 2022; savings potentials are indicative estimates based on IEA, 2023a)

Case Study: Solar Street Lighting in Algeria

Algeria launched a national programme to install 120,000 solar street lights by 2025. Each unit replaces a conventional 250W sodium lamp with a 30W LED solar system, saving approximately 1,400 kWh per year per unit. At national scale this programme eliminates over 150,000 tonnes of CO_2 annually while reducing municipal electricity costs by up to 80% (APRUE, 2022).

2.6 The Domestic Gas Squeeze: Why Renewables Matter for Algeria's Exports

The economic case for renewable energy in Algeria is often presented in environmental terms. A more compelling argument for policymakers is fiscal. The calculation below — which every student should be able to reproduce — estimates the value of the gas that renewable electricity would liberate for export.

Worked Example 2.1 — Gas Saved by Renewable Electricity

Step 1 — Fuel per TWh. A gas power fleet with an average efficiency of 40% needs 1 / 0.40 = 2.5 TWh of fuel heat to produce 1 TWh of electricity, i.e. 2.5 × 3.6 = 9 PJ.

Step 2 — Gas volume. With a heating value of about 36 MJ/m³, 9 PJ correspond to 9×10^{15} / $36 \times 10^{6} = 0.25 \times 10^{9}$ m³, i.e. **0.25 bcm of gas per TWh**.

Step 3 — Renewable output in 2030. If renewables reach 27% of a 130 TWh system, they produce about 35 TWh per year.

Step 4 — Gas saved. 35 TWh × 0.25 bcm/TWh ≈ **8.8 bcm per year**, about one-sixth of current exports.

Step 5 — Export value. At an export price of USD 7–8.5/MMBtu (≈ USD 0.25–0.30 per m³), 8.8 bcm are worth roughly **USD 2.2–2.6 billion per year**.

Result: the renewable programme would generate, every year, an export value of the same order as its annualised investment cost. This "gas-for-export" argument is one of the strongest justifications for the PNREE (own calculation based on MEM, 2021 and Energy Institute, 2023).

The calculation contains simplifications that students should identify: the efficiency of the gas fleet varies with load and ambient temperature; the export price fluctuates widely; additional export volumes require available pipeline or LNG capacity and buyers; and renewable variability means that some gas capacity must remain available as backup. None of these caveats changes the order of magnitude of the result.

2.7 Matching Solar Supply to Algerian Demand

A particular advantage of solar energy in Algeria is the coincidence between solar production and electricity demand. Air-conditioning, which drives the summer peak, is used precisely when the sun is strongest. Figure 2.8 illustrates this relationship on a typical summer day. Solar PV can cover a large share of the midday load, reducing gas consumption at the hours when gas turbines are least efficient. After sunset, however, the residual or *net load* — demand minus solar output — rises steeply towards an evening peak that solar cannot serve without storage.

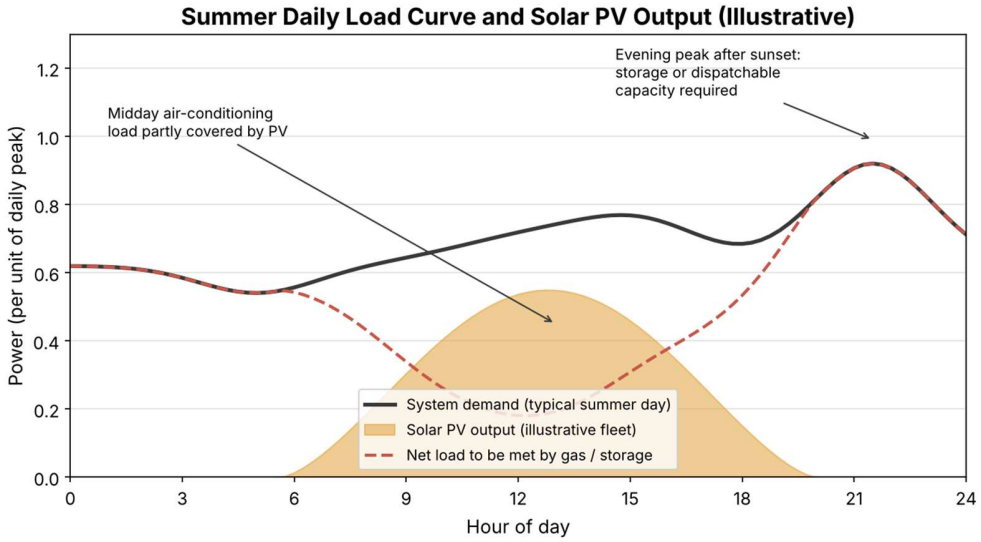


Figure 2.8 — Typical Summer Load Curve, Solar PV Output and Resulting Net Load in a Solar-Rich System, Per Unit (Source: own illustrative elaboration; shape of the load curve inspired by published Sonelgaz daily load profiles)

As solar penetration grows, this shape — often called the "duck curve" after its appearance in California — imposes new requirements on the power system: flexible gas turbines able to ramp quickly, battery storage to shift midday solar to the evening, CSP plants with thermal storage, demand response from large consumers, and stronger interconnections with neighbouring countries. Planning for flexibility is therefore as important as planning for megawatts. Battery costs have fallen by about 90% since 2010, and four-hour lithium-ion systems are now commonly combined with new solar plants in the Middle East and North Africa (IRENA, 2024a).

Key Points of Chapter 2

- Hydrocarbons provide about 95% of Algeria's export revenues; Sonatrach is the economic backbone of the country.
- Domestic gas consumption has nearly doubled since 2010 and increasingly competes with exports.
- Algeria has a world-class solar resource (1,800–2,700 kWh/m²/yr) and a significant wind resource in the south-west and high plateaus.
- The PNREE targets 22 GW of renewables by 2030, but less than 1 GW is installed; the gap is institutional and financial rather than technical.
- Each TWh of renewable electricity frees about 0.25 bcm of gas for export.
- Solar output coincides with the summer air-conditioning peak, but the evening peak requires storage and flexibility.

Review Questions and Exercises — Chapter 2

1. Describe the main components of Algeria's hydrocarbon sector and explain why its economy is considered vulnerable to oil and gas price fluctuations.
2. Using Figure 2.4, explain why a solar plant in Tamanrasset may require less seasonal backup than a plant on the coast near Algiers.
3. List three local factors that reduce the output of PV plants in the Sahara and propose a technical mitigation for each.
4. Reproduce Worked Example 2.1 assuming a gas fleet efficiency of 50% and an export price of USD 10/MMBtu. Comment on the sensitivity of the result.
5. What is the "net load"? Sketch its shape on a summer day in a system with a high share of solar PV and explain the flexibility needs it creates.
6. Why are transmission and distribution losses considered part of the energy-efficiency agenda? Estimate the energy that would be saved if Algeria reduced its losses from 13% to 8% of 81 TWh.
7. Discuss the advantages and limitations of hybrid solar–gas plants such as Hassi R'Mel as a transition technology.

Chapter 3 – Geopolitics of Energy

Geopolitics is the study of the influence of geographical factors (location, resources, climate, topography) on political power. Energy geopolitics examines how control over energy resources, infrastructure, and technologies shapes international relations, national security, and global governance.

3.1 Energy as a Strategic Asset

Control over energy resources has been a central driver of international conflict and cooperation throughout the 20th and 21st centuries. The following principles govern energy geopolitics: (Yergin, 2020)

- Resource endowment creates leverage: countries with large hydrocarbon reserves can use energy exports as an instrument of foreign policy.
- Infrastructure is power: whoever controls pipelines, tankers, or electricity cables controls the flow of energy—and can exploit or disrupt this flow.
- Import dependency creates vulnerability: countries that rely heavily on energy imports are exposed to supply disruption, price shocks, and political coercion.
- Technology leadership confers advantage: countries at the frontier of clean energy technology (solar panels, wind turbines, batteries) gain new forms of economic and political influence.

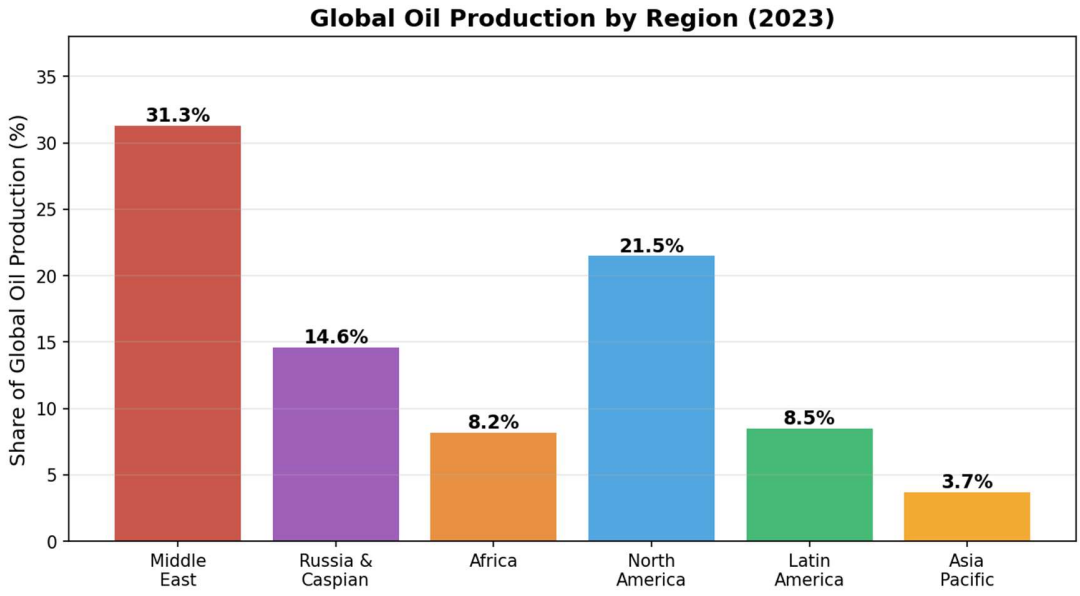


Figure 3.1 — Global Oil Production by Region, 2023 (Source: Energy Institute, 2023, Statistical Review of World Energy)

Major Geopolitical Event	Year	Energy Dimension	Global Impact	Policy Response
Arab Oil Embargo	1973–74	OPEC oil embargo against Western countries	Oil price quadrupled; global recession	IEA created; strategic petroleum reserves
Iranian Revolution	1979	Second oil shock; Iranian exports halted	Further price surge; stagflation	Energy efficiency programmes; coal switch
Gulf War	1990–91	Iraq invades Kuwait (major oil producer)	Oil spike to $40/barrel	UN intervention; US military presence in Gulf
Asian Financial Crisis	1997–98	Oil demand collapsed; prices crashed	Oil at $10/barrel; OPEC weakened	OPEC+ formed with Russia
September 11 Attacks	2001	Middle East security deteriorated	Military spending; energy security focus	Diversification strategies accelerated
2008 Financial Crisis	2008	Oil hit $147/barrel then crashed	Demand destruction; shale revolution	Green stimulus packages (US, EU)
Arab Spring	2011	Libya civil war disrupted exports	Oil price spike; Brent over $125	North Africa security engagement
Paris Agreement	2015	Global 1.5°C temperature target	Fossil fuel "stranded asset" risk raised	NDCs; renewable investment surge
Russia-Ukraine War	2022	Russia cuts gas to Europe	European energy crisis; gas prices ×10	REPowerEU; LNG diversification; RE boom

Table 3.1 — Major Geopolitical Events and Their Energy Dimensions (Source: compiled from Yergin, 2020; IEA, 2023a; Energy Institute, 2023)

The price of crude oil is the most visible indicator of these events. Figure 3.2 shows the annual average price of Brent crude since 1970 and associates its main movements with the episodes of Table 3.1. Two lessons emerge. First, the price of oil is extremely volatile: it has repeatedly halved or doubled within two or three years. Second, the largest price shocks have political rather than geological causes — embargoes, revolutions, wars and coordinated production decisions.

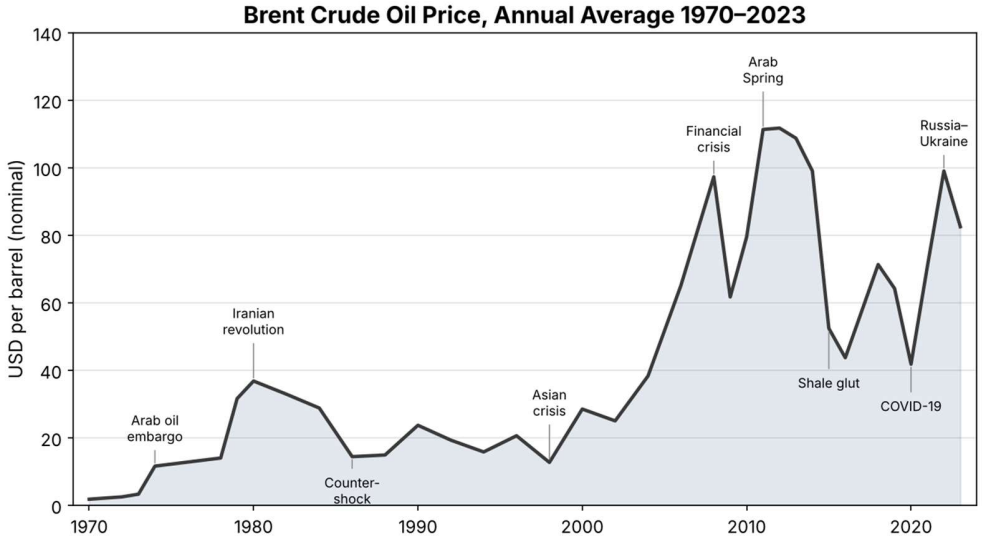


Figure 3.2 — Brent Crude Oil Price, Annual Average 1970–2023, USD/barrel, Nominal, with Major Geopolitical Events (Source: approximate annual averages from Energy Institute, 2023; event labels from Table 3.1)

For a hydrocarbon exporter such as Algeria, this volatility translates directly into fiscal instability. When the oil price fell from over USD 100 per barrel in 2014 to about USD 44 in 2016, Algeria's hydrocarbon revenues collapsed, the budget deficit widened sharply and foreign exchange reserves — close to USD 180 billion in 2014 — declined by more than half within five years (IMF, 2023). Economists use the concept of the **fiscal break-even oil price**, the price at which the state budget is balanced, to measure this vulnerability; for Algeria it has frequently been estimated well above prevailing market prices (IMF, 2023). Diversifying both the energy mix and the economy is therefore a matter of macroeconomic security, not only of climate policy.

3.2 OPEC and the Politics of Oil Production

The Organization of the Petroleum Exporting Countries (OPEC), founded in 1960, is the world's most influential energy cartel. Its decisions on production quotas directly influence global oil prices and the economic health of both oil exporters and importers (OPEC, 2023).

OPEC+ Member	Oil Production (Mb/d, 2023)	Proven Reserves (Bn bbl)	Government Revenue Dependency
Saudi Arabia	9.7	267	~65%
Russia	9.5	80	~40%
Iraq	4.2	145	~90%
UAE	3.0	98	~40%
Kuwait	2.5	102	~90%
Iran	3.0	208	~50%
Algeria	1.05	12.2	~60%
Nigeria	1.3	37	~65%
Venezuela	0.8	303	~90%

Table 3.2 — OPEC+ Key Producers: Production, Reserves and Government Dependency, 2023 (Source: OPEC, 2023, Annual Statistical Bulletin; Energy Institute, 2023; revenue dependency from IMF country reports)

OPEC's influence rests on its spare capacity — the ability of a few members, chiefly Saudi Arabia, to increase or decrease production quickly — and on the cohesion of its members. Cohesion has often been difficult to achieve, because members with large populations and limited reserves prefer high prices today, whereas members with very large reserves are more concerned about long-term demand. Algeria has historically played a mediating role: the Algiers meeting of September 2016 produced the agreement in principle that led, a few months later, to the first coordinated production cut between OPEC and ten non-OPEC producers including Russia — the arrangement now known as **OPEC+** (OPEC, 2023).

The energy transition raises a strategic dilemma for OPEC+. If oil demand is expected to peak and then decline, producers with low production costs have an incentive to produce as much as possible while demand lasts, which would push prices down; producers with high costs would then be the first to see their reserves stranded. Whether producers cooperate to manage a gradual decline or compete for market share is one of the major uncertainties of the coming decades (IEA, 2023a).

3.3 Energy Security Concepts

Energy security is broadly defined as the uninterrupted availability of energy sources at an affordable price. It has four key dimensions, often described as the "4 As": (APERC, 2007; IEA, 2023a)

Dimension	Definition	Measurement	Renewable Energy Contribution
Availability	Physical access to sufficient energy resources	Reserve-to-production ratio	Domestic RE replaces imported fossil fuels
Accessibility	Physical infrastructure to deliver energy	Grid coverage; pipeline networks	Distributed RE improves access for remote areas
Affordability	Energy prices that consumers can pay	Energy poverty rates; household spend	Falling RE costs reduce bills
Acceptability	Social, environmental & political acceptance	Public opinion; regulatory stability	RE has broad social licence; lower pollution

Table 3.3 — The Four Dimensions of Energy Security (Source: adapted from APERC, 2007 and IEA, 2023a)

3.4 The Energy Transition as Geopolitical Transformation

The shift from fossil fuels to renewable energy is not merely a technological change—it is a fundamental redistribution of geopolitical power. Countries that were marginalised in the fossil fuel era because they lacked oil and gas may become winners in the clean energy era if they have solar, wind, geothermal, or hydropower resources (IRENA, 2019a).

Geopolitical Dimension	Fossil Fuel Era (20th Century)	Clean Energy Era (21st Century)
Primary resource	Oil, natural gas, coal	Solar irradiation, wind, water, land
Dominant exporters	OPEC, Russia, Norway	China (equipment), USA (tech), RE-rich nations
Critical materials	Crude oil, natural gas	Lithium, cobalt, nickel, rare earth elements
Key infrastructure	Pipelines, tankers, refineries	Cables, electrolysers, batteries, smart grids

Geopolitical Dimension	Fossil Fuel Era (20th Century)	Clean Energy Era (21st Century)
Leverage mechanism	Supply disruption (embargo)	Technology control; critical material supply
Import dependency risk	Oil & gas importers vulnerable	Equipment importers vulnerable (esp. China PV)
North-South dynamics	South supplies North (raw energy)	South can generate & potentially export green energy
Conflict risk areas	Persian Gulf, Caspian, South China Sea	DRC (cobalt), Lithium Triangle (Chile-Bolivia-Arg.)

Table 3.4 — Geopolitical Transformation: Fossil Fuel Era vs. Clean Energy Era (Source: adapted from IRENA, 2019a, A New World: The Geopolitics of the Energy Transformation)

Algeria's Geopolitical Position

Algeria is well-positioned in both the old and new energy geopolitics. As a gas supplier to Europe via the Medgaz and TransMed pipelines, it currently holds significant leverage. In the emerging clean energy era, its vast solar resource, proximity to European markets, and existing pipeline infrastructure position it as a potential major exporter of green hydrogen and solar electricity—giving it continued strategic importance (IRENA, 2019a).

3.5 Critical Minerals and the New Dependencies

The clean-energy economy replaces flows of fuel with stocks of equipment. A gas power station must be supplied with fuel every day of its life; a solar plant needs no fuel but requires, once and for all, large quantities of silicon, silver, copper, aluminium and glass. An electric vehicle needs about six times more minerals than a conventional car, and an onshore wind farm about nine times more than a gas plant of the same capacity (IEA, 2021). As a result, geopolitical leverage is shifting from those who control fuels to those who control the manufacturing of equipment and the extraction and processing of minerals.

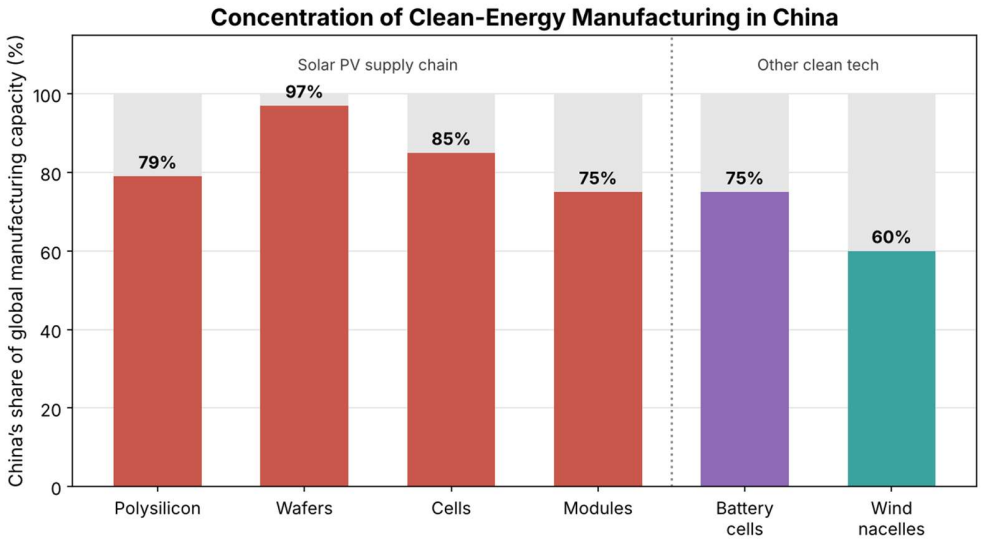


Figure 3.3 — China's Share of Global Manufacturing Capacity for Key Clean-Energy Technologies (Source: IEA, 2022, Solar PV Global Supply Chains; battery and wind values approximate from IEA, 2023a)

Figure 3.3 shows the degree of concentration reached by China in clean-energy manufacturing. For every stage of the solar PV supply chain — polysilicon, wafers, cells and modules — China accounts for between three-quarters and almost all of global capacity. This concentration was built through two decades of industrial policy, cheap finance, economies of scale and continuous innovation, and it is the main reason for the dramatic fall in module prices. It also creates a dependency: in 2022 the IEA warned that the world would rely on a single country for the supply of key building blocks of solar panels until at least 2025 (IEA, 2022).

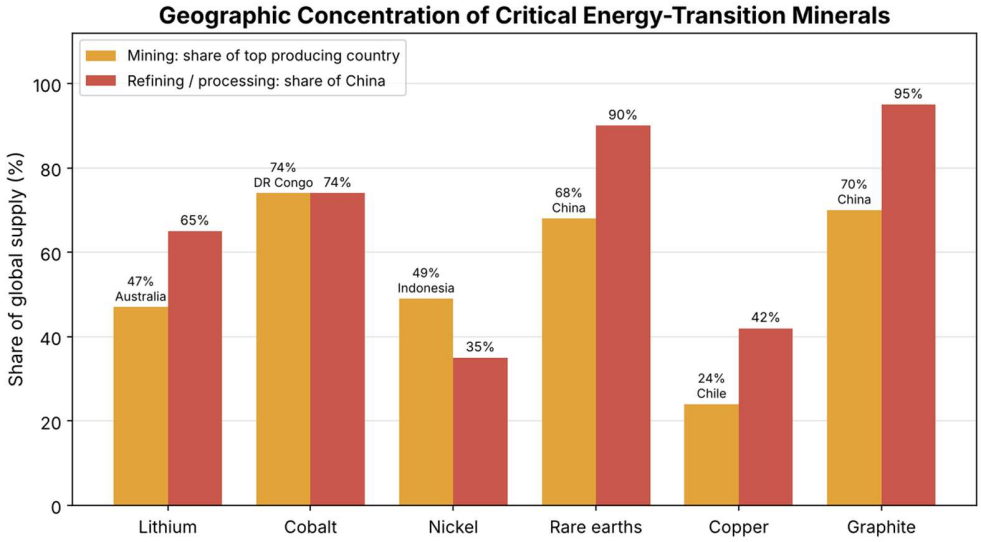


Figure 3.4 — Geographic Concentration of Mining and Processing for Critical Energy-Transition Minerals, % of Global Supply (Source: approximate values from IEA, 2023d, Critical Minerals Market Review 2023)

The concentration is even more pronounced for minerals (Figure 3.4). The Democratic Republic of Congo produces about three-quarters of the world's cobalt, Indonesia about half of its nickel and Australia almost half of its lithium; for refining and processing, China's share exceeds 60% for lithium and cobalt and approaches 90% or more for rare earths and graphite. Governments have responded with strategies to diversify supplies: the European Critical Raw Materials Act, the United States Inflation Reduction Act and a growing number of bilateral mineral partnerships. For Algeria, which has deposits of phosphate, iron, zinc, lead and some rare earths, and an existing industrial base, the question is whether it can position itself in some segments of these new value chains rather than remaining an importer of finished equipment.

3.6 Algeria–Europe Energy Relations: Pipelines, Hydrogen Corridors and Interconnectors

Geography makes Algeria a natural energy partner of southern Europe. Figure 3.5 presents the main corridors schematically. Three gas pipelines were built across the Mediterranean: the **TransMed** (Enrico Mattei) pipeline to Italy via Tunisia, commissioned in 1983 and the largest, with a capacity of about 32 bcm/yr; the **Maghreb–Europe (GME)** pipeline to Spain via Morocco, commissioned in 1996 and closed by Algeria in 2021 when the transit contract expired amid diplomatic tensions with Morocco; and the direct **Medgaz** pipeline from Beni Saf to Almería, commissioned in 2011 and expanded to about 10.5 bcm/yr. LNG exported from Arzew and Skikda complements the pipelines and gives access to more distant markets (Sonatrach, 2023).

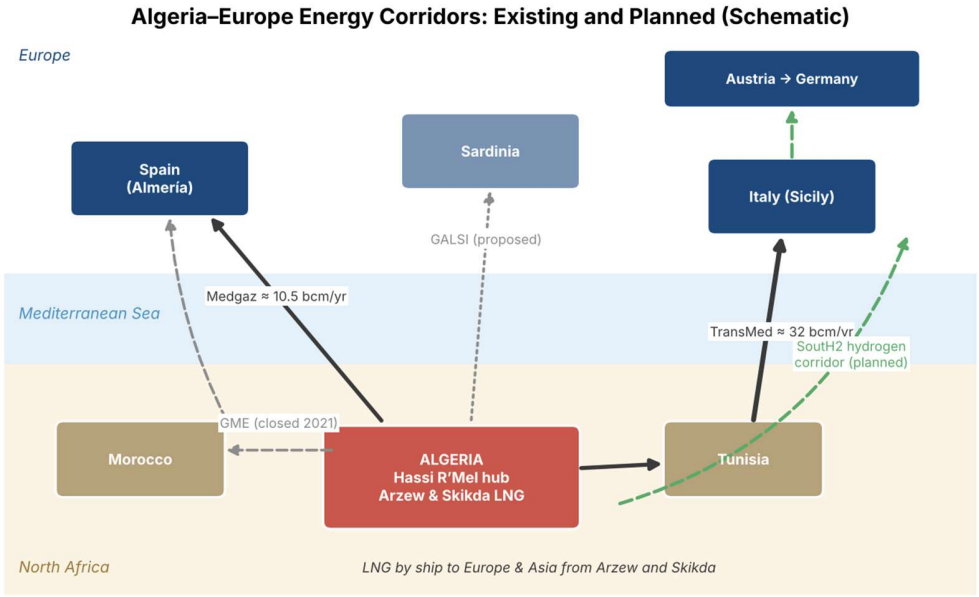


Figure 3.5 — Algeria–Europe Energy Corridors: Existing Gas Pipelines and Planned Hydrogen Corridor (Schematic, Not to Scale) (Source: own elaboration from Sonatrach, 2023 and public project information)

Since Russia's invasion of Ukraine in 2022, Europe has sought to replace Russian gas, and Algeria has become Italy's first gas supplier. At the same time, the European Union aims to reduce its total gas consumption sharply by 2030 and to import large volumes of renewable hydrogen. The **SoutH2 Corridor**, a project promoted by gas transmission operators in Italy, Austria and Germany together with partners in Algeria and Tunisia, would transport hydrogen produced in North Africa to central Europe, partly by repurposing existing pipelines. Electricity interconnectors are also being studied; the ELMED cable between Tunisia and Sicily, supported by the EU, is the first in the central Mediterranean.

These projects illustrate the central geopolitical bet of the Algerian transition: that the infrastructure, relationships and know-how built for gas can be progressively converted into a renewable export economy. The bet is not without risk. Hydrogen is expensive to produce and transport, European demand is uncertain, and competitors — Morocco, Egypt, the Gulf states, Australia, Chile — pursue the same strategy. Algeria's advantages are its resource, its existing pipelines to Europe and the industrial capacity of Sonatrach; its weaknesses are the cost of capital and the slow pace of renewable deployment at home.

3.7 Risks of the Transition for Hydrocarbon Exporters

The transition creates specific risks for countries such as Algeria. Table 3.5 summarises the main channels through which falling global demand for hydrocarbons could affect an exporting economy, together with possible policy responses.

Risk channel	Mechanism	Possible policy response
Revenue risk	Lower volumes and prices reduce export earnings and fiscal revenues	Sovereign wealth fund; fiscal rules; tax diversification
Stranded assets	Fields, pipelines and LNG plants lose value before end of life	Prioritise low-cost, low-emission reserves; avoid over-investment
Trade barriers	Carbon border taxes (e.g. EU CBAM) penalise carbon-intensive exports	Decarbonise export industries; carbon accounting
Methane & flaring	Buyers increasingly demand low-methane gas	Leak detection and repair; flaring reduction
Skills & employment	Jobs in hydrocarbons decline in producing regions	Retraining; renewable and hydrogen industries in same regions
Opportunity	New exports of green electricity, hydrogen and ammonia	Early investment; partnerships; certification of green products

Table 3.5 — Transition Risks for Hydrocarbon-Exporting Economies and Possible Responses (Source: own elaboration based on IRENA, 2019a; IEA, 2023a and IMF, 2023)

Key Points of Chapter 3

- Energy geopolitics is about control of resources, infrastructure and technology.
- Oil prices are highly volatile, and the largest shocks have political causes; exporters face fiscal instability as a result.
- OPEC+ manages supply but faces a strategic dilemma as long-term demand becomes uncertain.
- In the clean-energy era, leverage shifts to the control of manufacturing and critical minerals, in which China is dominant.
- Algeria is linked to Europe by gas pipelines that could be partly repurposed for hydrogen; it is well placed in both the old and new geopolitics.
- Hydrocarbon exporters face revenue, stranded-asset and trade risks that require proactive diversification.

Review Questions and Exercises — Chapter 3

1. Define energy security using the "4 As" framework and illustrate each dimension with an Algerian example.
2. Using Figure 3.2, identify three periods of sharp oil price decline and explain their consequences for Algeria's public finances.
3. What is the fiscal break-even oil price? Why is it an important indicator for a country such as Algeria?

4. Explain why the energy transition shifts geopolitical leverage from fuels to equipment and minerals. Is a dependency on imported solar panels comparable to a dependency on imported gas? Argue both sides.
5. Describe the three gas pipelines that link Algeria to Europe and explain the circumstances in which the GME pipeline was closed.
6. Evaluate the opportunities and risks of the SoutH2 hydrogen corridor for Algeria.
7. Choose one risk from Table 3.5 and write a one-page policy memo proposing measures to mitigate it.

Chapter 4 – Key Actors in the Renewable Energy Sector

The energy sector is shaped by a complex ecosystem of actors operating at international, national, and local levels. Understanding who these actors are, what their objectives are, and how they interact is essential for anyone working in the renewable energy field.

4.1 International Organisations

Several international organisations play pivotal roles in shaping global energy policy, providing finance, generating data, and setting standards for the renewable energy sector (IRENA, 2023a).

Organisation	Founded	Mandate	Key Publications / Actions	Relevance to RE
IEA (Int'l Energy Agency)	1974	Energy security & analysis for OECD	World Energy Outlook; Tracking Clean Energy Progress	Scenario modelling; technology tracking
IRENA (Int'l Renewable Energy Agency)	2009	Promote global RE adoption	REMAP 2050; Renewable Power Cost Report	Data on costs, jobs, capacity
UNFCCC	1992	Climate change governance	Paris Agreement; Annual COPs	Climate targets drive RE investment
World Bank / IFC	1944	Development financing	Scaling Solar; ESMAP programme	Concessional loans; de-risking
African Development Bank	1964	African development	Desert to Power (300 GW Sahel solar)	Major Africa RE financier
European Investment Bank	1958	EU project finance	Climate Bank roadmap; green bonds	Finances Algeria-EU energy links
OPEC	1960	Oil production management	OPEC World Oil Outlook	Influences fossil competition to RE

Organisation	Founded	Mandate	Key Publications / Actions	Relevance to RE
African Union	1963	African unity & development	Agenda 2063; ASEM electricity market	Continental RE coordination

Table 4.1 — Key International Organisations and Their Role in Renewable Energy (Source: compiled from the official mandates, statutes and publications of the organisations listed)

4.2 National Actors in Algeria

Algeria's energy sector is dominated by state actors, though private investment is increasingly encouraged. The main national actors are: (MEM, 2021; CREG, 2023)

Actor	Type	Founded	Role in Energy Sector	Role in RE Transition
Sonatrach	State-owned enterprise	1963	Production & export of oil, gas, LNG	Developing solar & green hydrogen projects
Sonelgaz	State utility	1969	Electricity generation, T&D	Grid integration of RE; owns some RE plants
CREG	Regulatory commission	2002	Tariff regulation, licensing, market rules	Sets FIT tariffs; issues RE licences
APRUE	Energy efficiency agency	1985	Energy efficiency programmes	EE campaigns; training; audits
CDER	Research centre	1988	RE research & development	Resource assessment; pilot projects; R&D
Ministry of Energy & Mines	Government ministry	1962	Energy policy & legislation	Authors PNREE; oversees RE strategy

Actor	Type	Founded	Role in Energy Sector	Role in RE Transition
Ministry of Finance	Government ministry	1962	Public finance, subsidies	Controls energy subsidies; green finance
Algerian Customs (DGD)	Government agency	1963	Trade regulations	Tariff regime on RE equipment imports
ANDI	Investment promotion agency	2001	Attract foreign investment	Facilitates RE project investment

Table 4.2 — Key National Actors in Algeria's Renewable Energy Sector (Source: compiled from MEM, 2021; CREG, 2023; Sonelgaz, 2023; Sonatrach, 2023 and institutional websites)

The relationships between these actors are summarised in Figure 4.1. Since the reforms that followed Law 02-01, the Sonelgaz group has been organised as a holding company with specialised subsidiaries for generation (SPE), transmission (GRTE), system operation (OS) and distribution, and with SKTM in charge of renewable plants and isolated networks in the south. CREG, as the independent regulator, sets tariffs, grants licences and supervises market rules, while the ministry in charge of energy defines policy and targets. The creation in 2019 of the **Commissariat aux Energies Renouvelables et à l'Efficacité Energétique (CEREFE)**, attached to the Prime Minister's office, and in 2020 of a dedicated **Ministry of Energy Transition and Renewable Energies** reflected the political will to accelerate the programme, although institutional responsibilities have since been reorganised several times.

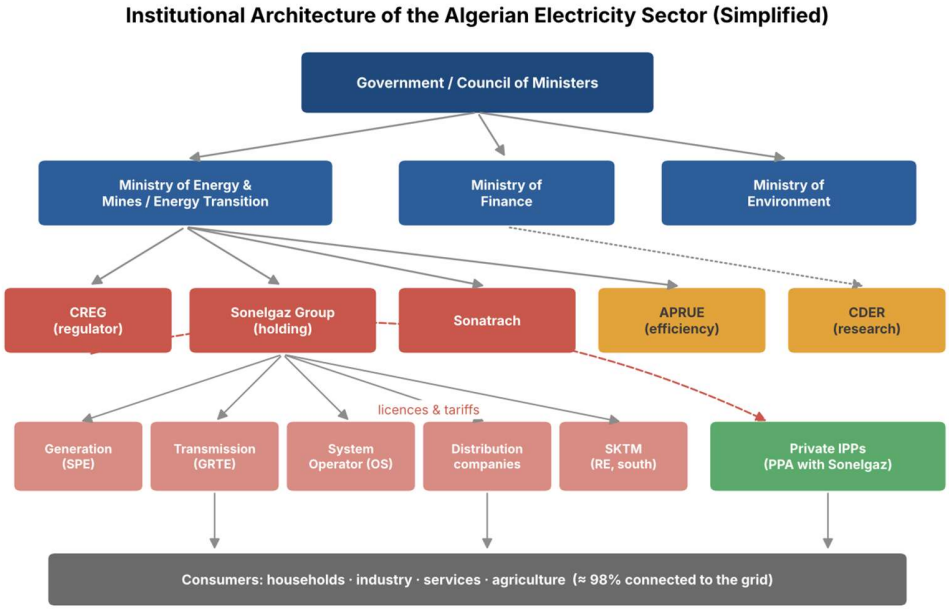


Figure 4.1 — Institutional Architecture of the Algerian Electricity Sector, Simplified (Source: own elaboration based on Law 02-01, CREG, 2023 and Sonelgaz, 2023)

Two structural features of this architecture deserve attention. First, the same group — Sonelgaz — is simultaneously the main generator, the transmission and system operator, the distributor and the single buyer of electricity from independent producers. This concentration simplifies coordination but can create conflicts of interest when private producers compete with the incumbent's own plants. Second, the financial health of the whole chain depends on regulated retail tariffs that do not cover costs; the difference is financed by the state budget. The creditworthiness of Sonelgaz as an *offtaker* is therefore a key question for any investor, as discussed in Chapter 7.

4.3 Private Sector Actors

Private companies—local, regional, and international—play an increasingly important role in the renewable energy sector. Their participation is essential to mobilising the investment needed to achieve Algeria's 2030 targets (IRENA & CPI, 2023).

Type of Private Actor	Role	Examples (Global)	Barriers in Algeria
Independent Power Producers (IPPs)	Finance, build, own, operate RE plants	Engie, ACWA Power, EDF Renewables	Limited PPA framework; land access
Engineering, Procurement & Construction (EPC)	Design and build RE projects	Siemens Gamesa, Eiffage, Shandong Electric	Local content requirements

Type of Private Actor	Role	Examples (Global)	Barriers in Algeria
Equipment Manufacturers	Supply turbines, panels, inverters, batteries	Vestas, First Solar, SMA, CATL	Import tariffs; local manufacturing gap
Banks & Financial Institutions	Project finance, bonds, equity	HSBC, BNP Paribas, JBIC	Currency risk; regulatory uncertainty
Operations & Maintenance (O&M)	Maintain RE assets over lifetime	Statkraft, Falck Renewables	Skills shortage; local capacity building needed
Consultants & Developers	Project origination, feasibility, permits	Wood Mackenzie, DNV, local firms	Administrative complexity
Technology Start-ups	Innovation in RE, storage, digitisation	Various Algerian and regional firms	Access to capital; regulatory sandbox needed

Table 4.3 — Private Sector Actors in Renewable Energy (Source: own elaboration based on IRENA, 2023a and IRENA & CPI, 2023)

4.4 Civil Society and Other Stakeholders

- Non-Governmental Organisations (NGOs): advocate for faster energy transition, climate justice, and social inclusion in energy projects. Examples: Greenpeace, WWF, local Algerian environmental associations.
- Academic and Research Institutions: universities, research centres (CDER, CDTA) that produce knowledge, train professionals, and evaluate technologies. The University of Tlemcen, USTHB, and ENP are key Algerian institutions.
- Media: shapes public perception of renewable energy, covers energy policy debates, and holds governments and companies accountable.
- Local Communities: the "social licence to operate" of any RE project depends on community acceptance. Communities can be advocates, opponents, or partners depending on how projects are designed and implemented.
- Consumers: households, businesses and industries that use energy. Their choices (efficiency investments, rooftop solar, EVs) aggregate into significant market signals.

The Stakeholder Engagement Imperative

International best practice requires that major RE projects conduct thorough stakeholder engagement before and during project development. Projects that skip this step risk delays, opposition, and cancellation. The IFC Performance Standards and Equator Principles (adopted by most international project finance banks) require demonstrated free, prior, and informed consent from affected communities for major infrastructure projects (IFC, 2012; Equator Principles Association, 2020).

4.5 Stakeholder Analysis: A Practical Tool

Knowing who the actors are is only the first step. Project developers, public agencies and NGOs use **stakeholder analysis** to decide how to engage with each actor. The most common tool is the power–interest grid, which classifies stakeholders according to their influence over the project and the degree to which the project affects them. Figure 4.2 applies the grid to a hypothetical 200 MW solar project in the Algerian high plateaus.

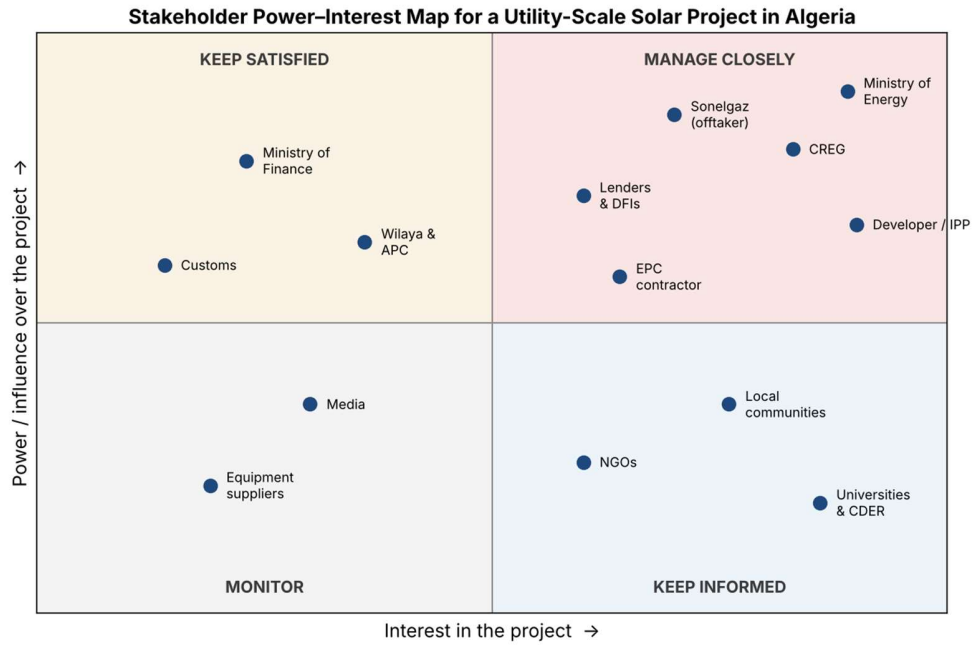


Figure 4.2 — Stakeholder Power–Interest Map for a Hypothetical Utility-Scale Solar Project in Algeria (Source: own elaboration based on the Mendelow power–interest matrix and IFC, 2012)

Each quadrant calls for a different engagement strategy:

- **Manage closely** (high power, high interest): the ministry, CREG, Sonelgaz as offtaker, lenders and the developer itself. These actors can stop the project; they require continuous, formal engagement and early resolution of disagreements.
- **Keep satisfied** (high power, lower interest): the Ministry of Finance, customs and local authorities (Wilaya, APC). Their decisions — on guarantees, import duties, land and permits

— are decisive at specific moments; they must be informed in good time and their requirements anticipated.

- **Keep informed** (lower power, high interest): local communities, NGOs, universities. They may have limited formal power, but their support or opposition shapes the social licence to operate and can influence the decisions of powerful actors.
- **Monitor** (lower power, lower interest): media and equipment suppliers in the early phases. Their position can change rapidly — for example, a media campaign after an incident can move the media into a much more influential position.

A stakeholder map is not static. The power and interest of actors change across the project lifecycle: lenders are decisive before financial close but less involved during operation, while communities become more interested once construction begins. Good practice is therefore to update the map at each project milestone, as recommended by the IFC Performance Standards (IFC, 2012).

4.6 Actors Across the Project Lifecycle

Table 4.4 shows which actors play the leading role at each stage of a renewable energy project. It provides a bridge between this chapter and the regulatory lifecycle presented in Chapter 5.

Project stage	Lead actors	Supporting actors	Key output
Planning & targets	Ministry of Energy; CEREFE	CDER; Sonelgaz; CREG	National programme; site zoning
Procurement / tender	Sonelgaz or ministry; CREG	Advisers; DFIs	Tender documents; award
Development	Developer / IPP	Consultants; Wilaya; communities	Permits; ESIA; grid study
Financing	Lenders; equity investors	Ministry of Finance; insurers	Financial close
Construction	EPC contractor	Suppliers; customs; local subcontractors	Commissioned plant
Operation	O&M contractor; IPP	Sonelgaz (OS, GRTE); CREG	Electricity; revenues
Decommissioning	Owner	Ministry of Environment; recyclers	Site restoration; recycling

Table 4.4 — Lead and Supporting Actors at Each Stage of a Utility-Scale Renewable Energy Project in Algeria (Source: own elaboration based on Tables 4.1–4.3 and 5.7)

Key Points of Chapter 4

- The renewable energy sector involves international organisations, national institutions, private companies and civil society.

- IRENA, the IEA, the World Bank group and regional development banks shape data, standards and finance.
- In Algeria, the state dominates through the ministry, CREG, Sonelgaz and Sonatrach; private participation is growing but constrained.
- Sonelgaz's dual role as incumbent producer and single buyer is a key issue for independent power producers.
- Stakeholder analysis (power–interest grid) helps decide how to engage each actor and must be updated throughout the project lifecycle.

Review Questions and Exercises — Chapter 4

1. Compare the mandates of the IEA and IRENA. Why might their scenarios and data sometimes differ?
2. Draw the institutional chart of the Algerian electricity sector from memory and explain the role of each Sonelgaz subsidiary.
3. What is meant by a "single buyer" model? Discuss its advantages and disadvantages for private renewable energy investors.
4. Build a power–interest grid for a 50 MW wind farm near Tiaret. Which stakeholders would you place in the "manage closely" quadrant, and why?
5. Explain why local communities with little formal power can nonetheless determine the success of a project.
6. Identify three barriers faced by private EPC contractors in Algeria and propose a policy measure for each.

Chapter 5 – Laws and Regulations Governing Renewable Energies

A clear, stable and transparent legal and regulatory framework is the single most important factor in attracting renewable energy investment. Investors, developers and financiers need certainty about the rules of the game before committing billions of dollars to long-term infrastructure projects.

5.1 International Legal Framework for Climate and Energy

Several international legal instruments form the backbone of the global response to climate change and shape national energy policies worldwide (UNFCCC, 2015).

Instrument	Year Adopted	Parties	Key Provisions	Enforcement
UNFCCC	1992	198	Common but differentiated responsibilities; climate finance; reporting obligations	Soft; voluntary compliance
Kyoto Protocol	1997	192	Legally binding emission targets for developed nations; flexible mechanisms (CDM, JI, ET)	First legally binding climate targets
Paris Agreement	2015	196	1.5°C goal; nationally determined contributions (NDCs); 5-year ratchet mechanism; climate finance USD 100Bn/yr	Soft enforcement; transparency mechanism
Energy Charter Treaty	1994	54	Investment protection in energy sector; dispute resolution	Binding; ISDS mechanism
Kigali Amendment (Montreal Protocol)	2016	155	Phase-down of HFCs (potent greenhouse gases used in cooling)	Legally binding with trade measures
Glasgow Climate Pact (COP26)	2021	197	Coal phase-down; fossil fuel subsidy elimination; USD 100Bn/yr reaffirmed	Political commitment
Sharm el-Sheikh Implementation Plan (COP27)	2022	197	Loss & damage fund established; mitigation targets maintained	Political commitment

Instrument	Year Adopted	Parties	Key Provisions	Enforcement
UAE Consensus (COP28)	2023	197	Transitioning away from fossil fuels; tripling RE by 2030; doubling EE by 2030	Political commitment

Table 5.1 — International Legal Instruments Governing Climate and Energy (Source: compiled from UNFCCC, 1992; UN, 1997; UNFCCC, 2015; Energy Charter Secretariat, 1994 and UNFCCC COP decisions 2021–2023)

5.2 The Algerian Legal Framework for Renewable Energy

Algeria has developed a growing body of legislation specifically aimed at enabling and regulating renewable energy production, investment, and grid connection. The legal framework has evolved considerably since the early 2000s (JORADP; CREG, 2023).

Legal Text	Year	Type	Key Provisions
Law 02-01	2002	Primary law	Electricity sector liberalisation; independent generation authorised; network access rules
Law 04-09	2004	Primary law	Energy efficiency obligation; energy audits for major consumers; APRUE mandate
Law 11-09	2011	Primary law	Renewable energy & energy efficiency promotion; priority grid access for RE; feed-in tariff principle
Executive Decree 11-218	2011	Decree	Created CREG with regulatory powers over electricity tariffs and RE authorisations
Executive Decree 14-91	2014	Decree	Conditions and procedures for selling RE electricity to Sonelgaz at preferential tariffs
Executive Decree 15-288	2015	Decree	Updated hydrocarbons exploration & production code; Sonatrach reform

Legal Text	Year	Type	Key Provisions
Law 15-08	2015	Primary law	New hydrocarbons code; production sharing contracts; unconventional resources
Ministerial Order on Solar Tariffs	2021	Order	Feed-in tariff rates for solar PV; eligibility criteria; contract duration (20 years)
Green Hydrogen Strategy	2023	Policy document	Export targets; pilot projects; international partnerships (EU, Germany, Italy)
Law on Investment	2022	Primary law	Improved investor protection; tax incentives for RE; simplified procedures via ANDI

Table 5.2 — Algerian Legal Framework for Renewable Energy, Chronological (Source: Journal Officiel de la République Algérienne, JORADP; CREG, 2023)

Figure 5.1 places the main Algerian texts alongside the international milestones of Table 5.1. The comparison shows that national legislation has generally followed international momentum: the 2011 law on renewables and the launch of the PNREE came during a period of strong international interest in Mediterranean solar projects, and the recent revision of investment rules and the hydrogen strategy coincide with the European search for alternative gas and hydrogen suppliers after 2022.

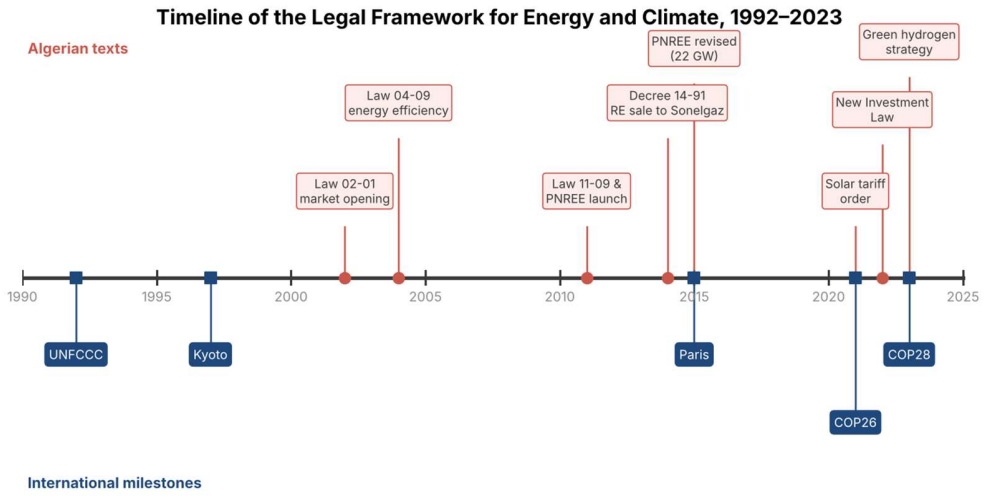


Figure 5.1 — Timeline of Algerian Energy Legislation and International Climate Milestones, 1992–2023 (Source: own elaboration from Tables 5.1 and 5.2; JORADP; UNFCCC)

Algeria ratified the UNFCCC in 1993, the Kyoto Protocol in 2005 and the Paris Agreement in 2016. Its Nationally Determined Contribution commits the country to reduce greenhouse gas emissions by

7% by 2030 compared with a business-as-usual scenario using domestic resources, and by up to 22% conditional on international support in the form of finance, technology transfer and capacity building (UNFCCC, 2015). The renewable target of the PNREE and the energy-efficiency programme are the main instruments for meeting this commitment.

5.3 Key Regulatory Instruments and Mechanisms

5.3.1 Feed-in Tariffs (FITs)

A Feed-in Tariff is a policy mechanism that guarantees RE generators a fixed, above-market price for electricity fed into the grid over a defined period (typically 15–25 years). FITs provide revenue certainty that enables project financing (REN21, 2023; IRENA, 2024a).

Country	FIT for Solar PV (USD¢/kWh)	Duration	Result
Germany	55¢ (2004); 9¢ (2023)	20 years	Global leader in solar adoption (2000–2013)
Morocco	8–10¢	20–25 years	Attracted major international projects (Noor, Dakhla)
South Africa	9–11¢ (REIPPPP)	20 years	6.4 GW RE procured; competitive auctions
Algeria	~15¢ (solar, 2021 order)	20 years	Limited uptake; permitting barriers remain
Tunisia	9–12¢ (ELMED framework)	20 years	Growing private sector pipeline
France	6–9¢	20 years	Mature market; now using competitive tenders

Table 5.3 — Comparative Feed-in Tariff Rates for Solar PV, Selected Countries (Source: compiled from REN21, 2023; IRENA, 2024a; CREG, 2023)

5.3.2 Competitive Auctions / Tenders

Many countries have shifted from administratively-set FITs to competitive auctions (or tenders) where developers bid for the right to sell RE electricity at the lowest price. Auctions have driven spectacular cost reductions globally (IRENA, 2024a; REN21, 2023).

Country	Auction Record Price (Solar PV)	Year	Context
UAE (Al Dhafra)	1.35 USD¢/kWh	2020	2 GW project; world record at time of award
Saudi Arabia (Sudair)	1.04 USD¢/kWh	2021	1.5 GW; lowest ever utility solar bid
India	2.1 USD¢/kWh	2023	Aggressive competition; domestic content requirement
Brazil	2.8 USD¢/kWh	2023	Hybrid solar-wind-storage auction
Morocco	2.5 USD¢/kWh	2023	Competitive market; Masen-managed auctions
Algeria	N/A – FIT model used	—	Competitive auctions not yet introduced

Table 5.4 — Global Record Auction Prices for Solar PV (Source: IRENA, 2024a; REN21, 2023)

The contrast between these prices and administratively set tariffs is striking. Figure 5.2 compares record auction results with the Algerian feed-in tariff of 2021. The difference is not explained by the solar resource, which is comparable in Saudi Arabia, the UAE and southern Algeria. It reflects the scale of the projects (often more than 1 GW), the intensity of competition among international developers, very low financing costs backed by strong state offtakers, and the transfer of some risks to the public side — land, grid connection and sometimes currency risk.

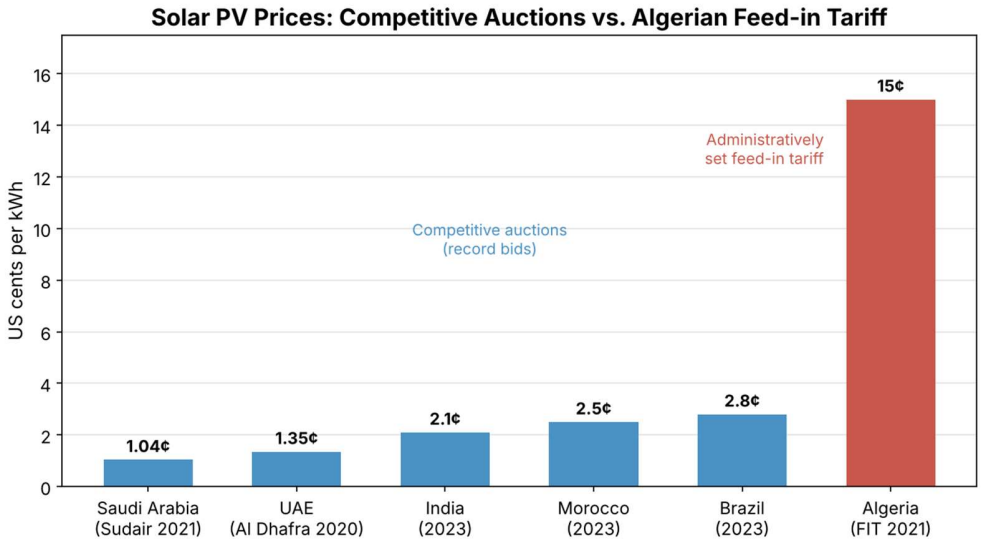


Figure 5.2 — Solar PV Electricity Prices: Record Competitive Auctions Compared with the Algerian Feed-in Tariff, US¢/kWh (Source: own elaboration from Tables 5.3 and 5.4; IRENA, 2024a; REN21, 2023)

Auctions are not a universal remedy. Very aggressive bids can lead to projects that are never built because the winner cannot reach financial close — a phenomenon observed in several countries. Good auction design therefore balances competition with *realisation*: it requires bid bonds and completion guarantees, pre-qualifies bidders on technical and financial capacity, and allocates risks to the party best able to manage them. The main design choices are summarised in Table 5.5.

Design element	Options	Effect on outcome
Volume	Fixed MW; budget cap; multi-round schedule	Predictable schedules attract more bidders and lower prices
Site selection	Developer-selected vs. state-prepared sites	State-prepared sites reduce risk and bid prices
Qualification	Technical & financial pre-qualification	Filters non-credible bidders; protects realisation rate
Price formation	Pay-as-bid vs. uniform pricing	Pay-as-bid is most common for PV and wind
Guarantees	Bid bond; performance bond; penalties for delay	Discourages unrealistic bids
Local content	Mandatory share; scoring bonus	Develops industry but can raise prices
Currency	Tariff in local or hard currency; indexation	Hard-currency tariffs lower the cost of foreign capital

Table 5.5 — Key Design Elements of Renewable Energy Auctions (Source: own elaboration based on IRENA, 2024a and REN21, 2023)

5.3.3 Net Metering

Net metering allows electricity consumers who generate their own renewable energy (e.g., rooftop solar) to feed excess electricity into the grid and receive a credit against their consumption. This makes self-generation economically attractive (REN21, 2023).

Several variants of this mechanism exist. Under **pure net metering**, each kilowatt-hour exported offsets one kilowatt-hour imported, so the grid acts as a free battery. Under **net billing**, exported energy is credited at a lower price — typically the avoided cost of wholesale generation — than imported energy. Under **self-consumption** schemes, exports are not remunerated at all, and the economics depend entirely on the share of production consumed on site. Net metering is simple and attractive for consumers, but when the share of prosumers becomes large it shifts the fixed costs of the network onto households without solar panels, which are often poorer. Many countries have therefore moved from net metering to net billing as their rooftop markets matured (REN21, 2023).

In Algeria, low regulated retail tariffs make self-generation unattractive for most households, whatever the remuneration mechanism, as the worked example in Section 7.7 demonstrates. Self-consumption is more promising for commercial and industrial consumers, agricultural pumping and isolated sites, where the alternative is diesel generation or costly grid extension.

5.3.4 Renewable Portfolio Standards (RPS)

Also called Renewable Energy Standards (RES), these regulations require electricity utilities to source a minimum percentage of their power from renewable sources. Non-compliance triggers financial penalties. Used widely in the USA, EU, and increasingly in Africa (REN21, 2023).

5.3.5 Carbon Pricing Mechanisms

Carbon pricing—through carbon taxes or emissions trading systems (ETS)—makes fossil fuel electricity more expensive, improving the competitive position of renewables without direct subsidies (World Bank, 2023b).

Mechanism	How It Works	Examples	Current Price Range (2023)
Carbon Tax	Fixed tax per tonne of CO_2 emitted	Sweden, Canada, Chile	USD 10–130/tCO_2
Emissions Trading System (ETS)	Cap-and-trade; companies buy/sell allowances	EU ETS, UK ETS, California	USD 20–100/tCO_2
Carbon Border Adjustment	Tax on imports from non-carbon-priced countries	EU CBAM (from 2026)	Linked to EU ETS price

Mechanism	How It Works	Examples	Current Price Range (2023)
Internal Carbon Price	Companies voluntarily price carbon internally	BP, Shell, many multinationals	USD 30–150/tCO_2 (internal)

Table 5.6 — Carbon Pricing Mechanisms: Types and Examples (Source: World Bank, 2023b, State and Trends of Carbon Pricing 2023)

Regulatory Risk: The #1 Barrier to RE Investment

Surveys of renewable energy investors consistently identify regulatory and policy risk as the most important barrier to investment—ahead of technology risk, resource risk, or construction risk. This includes: retrospective changes to tariffs (Spain reduced FITs retroactively in 2013, triggering USD 7Bn in arbitration claims), currency inconvertibility, arbitrary permitting delays, and unclear grid connection rules. Stable, predictable and transparent regulation is therefore the most important gift a government can give to its RE sector (IRENA & CPI, 2023; REN21, 2023).

5.4 The Regulatory Lifecycle of a Renewable Energy Project in Algeria

A renewable energy project in Algeria passes through several regulatory stages from conception to operation. Understanding this process is essential for developers and investors (CREG, 2023; JORADP).

Phase	Duration (typical)	Key Regulatory Steps	Issuing Authority
Project Identification	3–6 months	Site identification; resource assessment; preliminary feasibility	Developer
Environmental & Social Impact Assessment (ESIA)	6–18 months	ESIA study; public consultation; environmental permit	Ministry of Environment; ANDI
Grid Connection Study	3–12 months	Connection request; technical study; connection agreement	Sonelgaz

Phase	Duration (typical)	Key Regulatory Steps	Issuing Authority
Construction Permit (Permis de Construire)	3–6 months	Building permit application; local authority review	Local Wilaya/APC
Generation Licence (Autorisation d'Exploitation)	3–6 months	Licence application; technical review	CREG
Power Purchase Agreement (PPA)	3–12 months	PPA negotiation; CREG approval; signing	Sonelgaz + CREG
Financial Close	6–18 months	Debt & equity secured; conditions precedent satisfied	Banks + Investors
Construction	12–36 months	EPC contract; inspections; commissioning	Developer + Authorities
Commercial Operation (COD)	Ongoing	Grid energisation; performance testing; FIT payments begin	Sonelgaz

Table 5.7 — Regulatory Lifecycle of an RE Project in Algeria (Source: own elaboration based on Law 11-09 and Executive Decree 14-91, JORADP, and CREG, 2023; durations are indicative)

Because several stages can run in parallel, the total development time is shorter than the sum of the durations in Table 5.7. Figure 5.3 presents an indicative schedule. In the most favourable case a project can reach commercial operation about three and a half years after identification; delays in the environmental assessment, the grid study or the negotiation of the PPA can easily extend this to five years or more. For investors, time is money: each year of delay before financial close adds development costs and postpones revenues, raising the tariff needed for the project to be profitable.

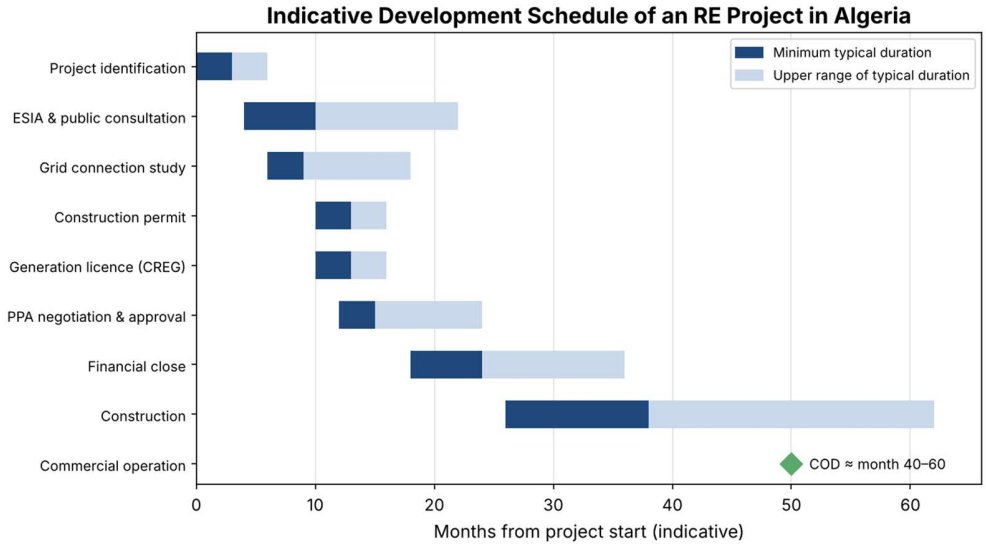


Figure 5.3 — Indicative Development Schedule of a Utility-Scale Renewable Energy Project in Algeria, Showing Minimum and Upper Typical Durations (Source: own elaboration from Table 5.7; durations are indicative)

Governments can shorten this schedule through a **one-stop shop** that coordinates permits, through *pre-developed sites* for which land, resource data, environmental baseline studies and grid connection are prepared in advance by a public agency, and through standardised contracts that avoid negotiating each PPA from scratch. Morocco's agency Masen and the Scaling Solar programme of the World Bank group have applied these principles successfully (World Bank, 2018).

5.5 Comparing Policy Instruments: Strengths and Failure Modes

No support instrument is best in all circumstances. The choice depends on the maturity of the market, the institutional capacity of the state, the target segment (utility-scale or small-scale) and the financial situation of the public offtaker. Table 5.8 compares the main instruments presented in Section 5.3.

Instrument	Main strengths	Characteristic failure modes	Best suited to
Feed-in tariff	Revenue certainty; simple; attracts small investors	Tariff set too high (cost to budget) or too low (no uptake); retroactive cuts	Early-stage markets; small and medium projects
Competitive auction	Price discovery; cost-efficient; controlled volumes	Underbidding; stop-and-go schedules; excludes small actors	Utility-scale projects in maturing markets
Net metering / billing	Empowers consumers; uses existing roofs	Shifts network costs; weak when tariffs are subsidised	Rooftop PV for households and businesses
Portfolio standard (RPS)	Market-based; flexible for utilities	Volatile certificate prices; needs liquid market	Liberalised markets with several utilities
Carbon pricing	Technology-neutral; raises revenue	Politically difficult; prices often too low	Economies with broad tax and monitoring capacity
Tax incentives	Easy to implement through existing tax system	Benefit only taxable investors; fiscal cost	Complement to other instruments

Table 5.8 — Comparison of Renewable Energy Support Instruments (Source: own elaboration based on REN21, 2023; IRENA, 2024a and World Bank, 2023b)

5.6 The EU Carbon Border Adjustment Mechanism and Its Implications for Algeria

The European Union's **Carbon Border Adjustment Mechanism (CBAM)**, established by Regulation (EU) 2023/956, will require importers of certain goods into the EU to purchase certificates corresponding to the carbon emissions embedded in those goods, at a price linked to the EU ETS. A transitional reporting-only phase began in October 2023; financial obligations are scheduled to apply progressively from 2026 (European Union, 2023). The mechanism initially covers iron and steel, aluminium, cement, fertilisers, hydrogen and electricity.

Several of these sectors matter for Algeria. The country has become a significant exporter of nitrogen fertilisers (ammonia and urea, produced from natural gas), of cement and of steel products, a large part of which is sold in Europe. Under CBAM, the competitiveness of these exports will depend on their carbon intensity. Producers that can document low emissions — for example by using renewable electricity, capturing process CO_2 or, in the case of ammonia, switching to green hydrogen — will be advantaged. CBAM thus transforms decarbonisation from a domestic policy choice into a condition of market access, and it strengthens the case for renewable electricity supplied to industrial zones.

5.7 Environmental and Social Impact Assessment

In Algeria the framework law on environmental protection in the context of sustainable development (Law 03-10 of 2003) requires that projects likely to affect the environment be subject to a prior impact

study or impact notice, depending on their size and nature; the content of these studies and the approval procedure are specified by executive decree (Decree 07-145, as amended). A renewable energy project must therefore document its effects on land use, biodiversity, water, landscape, noise, waste and local communities, and propose mitigation measures. Projects financed by international lenders must in addition comply with the IFC Performance Standards and the Equator Principles, which impose requirements on stakeholder engagement, labour conditions, land acquisition and biodiversity that often go beyond national law (IFC, 2012; Equator Principles Association, 2020).

Key Points of Chapter 5

- International climate law (UNFCCC, Kyoto, Paris) sets objectives; national law turns them into projects.
- Algeria's framework rests on Law 02-01 (market opening), Law 04-09 (efficiency) and Law 11-09 (renewables), with implementing decrees and tariff orders.
- Feed-in tariffs, auctions, net metering, portfolio standards and carbon pricing each have distinct strengths and failure modes.
- Auctions have achieved record-low prices but require careful design to ensure that awarded projects are built.
- Development timelines of 3.5–5 years can be shortened by one-stop shops, prepared sites and standard contracts.
- The EU CBAM makes the carbon intensity of Algerian exports a matter of market access.

Review Questions and Exercises — Chapter 5

1. Summarise the main obligations of the Paris Agreement and explain the role of Nationally Determined Contributions.
2. Compare feed-in tariffs and competitive auctions. Under what conditions would you recommend that Algeria move from one to the other?
3. Why can very low auction bids be a problem? List three auction design elements that protect the realisation rate.
4. Explain the difference between net metering, net billing and self-consumption. Which would you recommend for Algeria today, and why?
5. Using Figure 5.3, identify the critical path of a renewable project and propose two measures to shorten it.
6. Which Algerian export sectors are covered by the EU CBAM? Explain how renewable electricity could protect their competitiveness.
7. What are the main contents of an environmental and social impact assessment for a solar plant in the Sahara?

Chapter 6 – Socioeconomic Impacts of Renewable Energies

The value of renewable energy extends far beyond reducing greenhouse gas emissions. RE generates profound economic, social, and human development benefits at local, national, and global scales. Understanding these impacts allows policymakers, developers, and civil society to design projects that maximise benefits and minimise negative consequences.

6.1 Employment Generation

Renewable energy is a major and growing source of employment worldwide. According to IRENA's annual review, the sector employed 16.2 million people globally in 2023—nearly triple the number a decade earlier. Algeria has the potential to capture a significant share of these jobs through local manufacturing, installation, and O&M activities (IRENA & ILO, 2023).

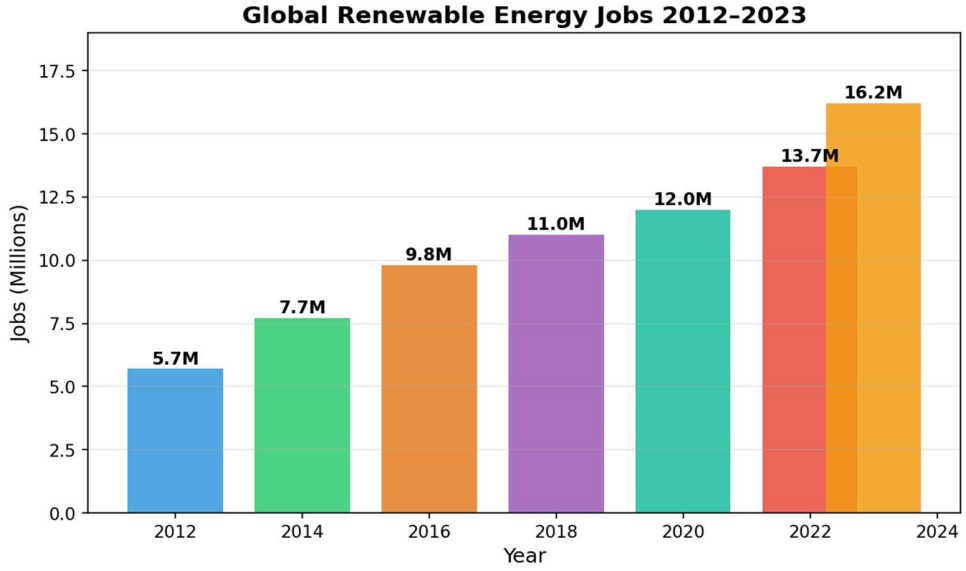


Figure 6.1 — Global Renewable Energy Jobs 2012–2023, Millions (Source: IRENA & ILO, 2023, Renewable Energy and Jobs — Annual Review 2023)

Technology	Jobs (Millions, 2023)	Share of Total (%)	Job Type	Leading Countries
Solar PV	6.32	39.0%	Manufacturing, installation, O&M	China, India, USA, EU
Liquid Biofuels	2.43	15.0%	Agriculture, processing, logistics	Brazil, USA, Indonesia

Technology	Jobs (Millions, 2023)	Share of Total (%)	Job Type	Leading Countries
Hydropower	2.22	13.7%	Construction, O&M, administration	China, Brazil, India
Wind Energy	1.39	8.6%	Manufacturing, installation, O&M	China, USA, Germany, India
Solar Thermal / CSP	0.86	5.3%	Construction, O&M	China, EU, India
Biogas / Solid Biomass	1.51	9.3%	Agriculture, processing, plant ops	China, EU, India
Small Hydropower	0.86	5.3%	Construction, maintenance	China, South/SE Asia
Geothermal	0.13	0.8%	Drilling, plant operations	USA, Kenya, Indonesia, Philippines
Ocean Energy	0.05	0.3%	R&D, installation	UK, France, South Korea
TOTAL	16.20	100%	—	60+ countries

Table 6.1 — Global Renewable Energy Jobs by Technology (Source: IRENA & ILO, 2023)

Figure 6.2 ranks the technologies by employment. Solar PV is by far the largest employer, with almost four jobs in ten, followed by liquid biofuels and hydropower. Employment is concentrated geographically: China alone accounts for about 40% of global renewable energy jobs, reflecting its dominance in manufacturing (IRENA & ILO, 2023).

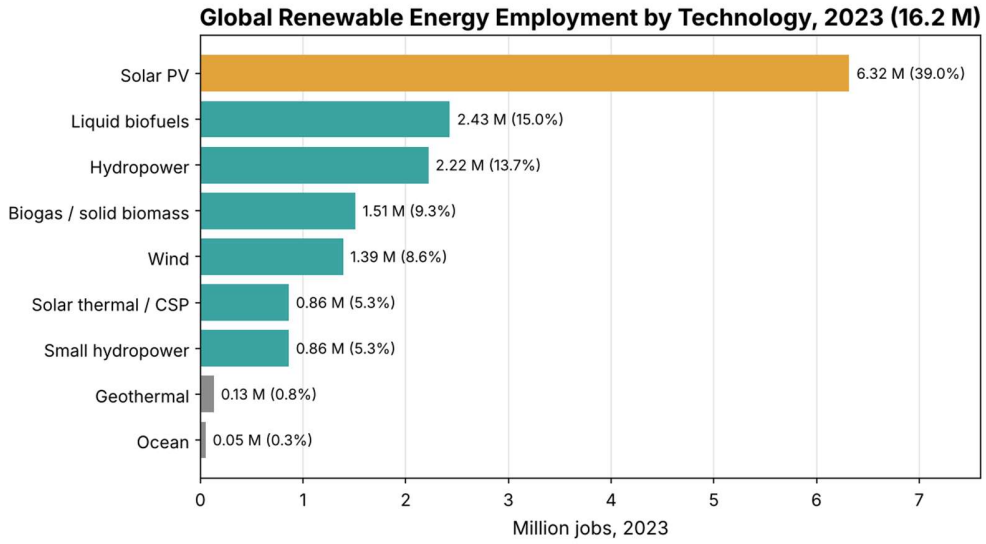


Figure 6.2 — Global Renewable Energy Employment by Technology, 2023, Million Jobs and Share of Total (Source: own elaboration from Table 6.1; IRENA & ILO, 2023)

The distribution of jobs along the value chain matters as much as their total number. For a typical utility-scale solar project, IRENA estimates that manufacturing represents about 20–25% of the labour required, construction and installation about 55–60%, and operation and maintenance the remainder; but construction jobs are temporary, whereas manufacturing and O&M jobs last for years (IRENA & ILO, 2023). A country that imports all its equipment captures mainly installation jobs, which disappear when the construction programme slows down. This is the economic rationale for local-content policies — and also their risk, since forcing local manufacturing before a market reaches sufficient scale can raise costs and delay deployment.

6.2 Job Creation Potential in Algeria

Algeria's ambitious PNREE 2030 programme has significant job creation potential. Based on international benchmarks (jobs per MW installed), the programme could create tens of thousands of direct and indirect jobs across manufacturing, construction, operations, and the supply chain (own estimates based on IRENA & ILO, 2023 and MEM, 2021).

Technology	2030 Target (MW)	Direct Jobs/MW (construction)	Direct Jobs/MW (O&M)	Estimated Total Jobs
Solar PV (ground + rooftop)	13,575	8–12	0.3–0.5	115,000–165,000
Concentrated Solar (CSP)	2,000	12–18	0.8–1.2	25,000–40,000

Technology	2030 Target (MW)	Direct Jobs/MW (construction)	Direct Jobs/MW (O&M)	Estimated Total Jobs
Wind (onshore)	5,010	5–8	0.2–0.4	25,000–40,000
Biomass / Biogas	1,000	6–10	0.5–0.8	6,000–12,000
Geothermal	1,000	10–15	0.8–1.2	10,000–18,000
TOTAL PNREE 2030	22,985	—	—	181,000–275,000

Table 6.2 — Estimated Job Creation from Algeria PNREE 2030 Programme (Source: own estimates, applying the employment factors of IRENA & ILO, 2023 to the PNREE targets of MEM, 2021)

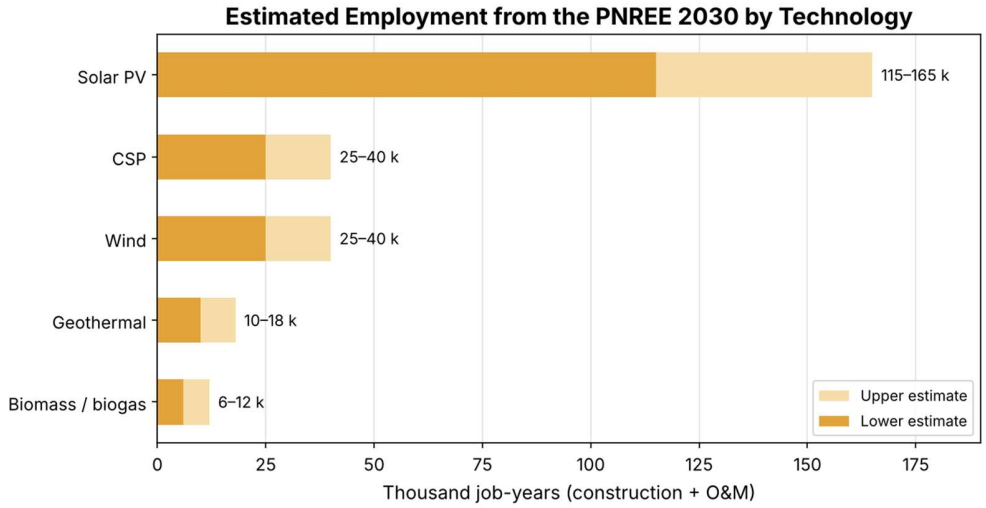


Figure 6.3 — Estimated Employment from the PNREE 2030 by Technology, Lower and Upper Estimates, Thousand Jobs (Source: own elaboration from Table 6.2; employment factors from IRENA & ILO, 2023)

These estimates should be interpreted with care. Construction employment factors are expressed in *job-years*: 10 jobs per MW over a one-year construction period means 10 people employed for one year, not 10 permanent jobs. Once construction is complete, only the O&M jobs remain — roughly 0.3–0.5 per MW for PV, i.e. about 4,000–7,000 permanent jobs for the solar part of the PNREE. The largest sustainable employment gains would come from local manufacturing of components (structures, cables, transformers, inverters and eventually modules), from services and from the industries that use cheap renewable electricity.

6.3 Health and Environmental Impacts

Air pollution from fossil fuel combustion is one of the leading causes of premature death globally. The World Health Organization estimates that 7 million people die prematurely each year from air pollution, the vast majority from indoor and outdoor burning of fossil fuels (WHO, 2022).

Environmental Indicator	Coal	Oil/Gas	Solar PV	Wind	Hydropower
GHG emissions (gCO_2eq/kWh, lifecycle)	820	490	43	11	24
SOx emissions (mg/kWh)	700–1,400	200–400	0	0	0
NOx emissions (mg/kWh)	600–1,200	200–500	0	0	0
Particulate matter (PM2.5)	High	Moderate	None (ops)	None	None
Water consumption (L/MWh)	1,250–2,000	600–800	~0	~0	1,500–2,000
Land disturbance (m^2/MWh)	Very high (mining)	High	Moderate	Low (tower only)	High (reservoir)
Noise (decibels at 500m)	70–85 dB	60–75 dB	<40 dB	35–45 dB	Variable
Radioactive waste	Some (fly ash)	None	Minimal	None	None

Table 6.3 — Comparative Environmental Footprint by Energy Technology, Lifecycle Analysis (Source: lifecycle GHG values from IPCC, 2014, Annex III; air pollutant, water and land indicators compiled from IEA, 2023a and WHO, 2022)

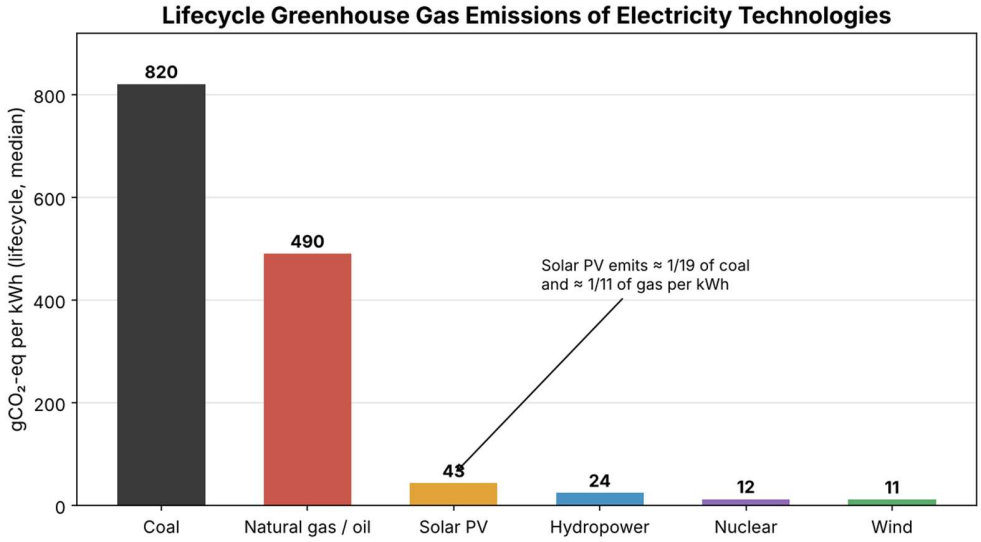


Figure 6.4 — Lifecycle Greenhouse Gas Emissions of Electricity Generation Technologies, gCO_2-eq/kWh (Source: own elaboration from Tables 1.1 and 6.3; IPCC, 2014, Annex III)

Lifecycle analysis (Figure 6.4) accounts for emissions at every stage — mining, manufacturing, transport, construction, operation and decommissioning. Even including the energy used to manufacture panels, solar PV emits roughly one-nineteenth as much CO_2 per kWh as coal and about one-eleventh as much as gas. Most of the remaining emissions of PV come from the electricity used to produce polysilicon; they are therefore lower when panels are manufactured with low-carbon electricity, and they continue to fall as manufacturing becomes more efficient.

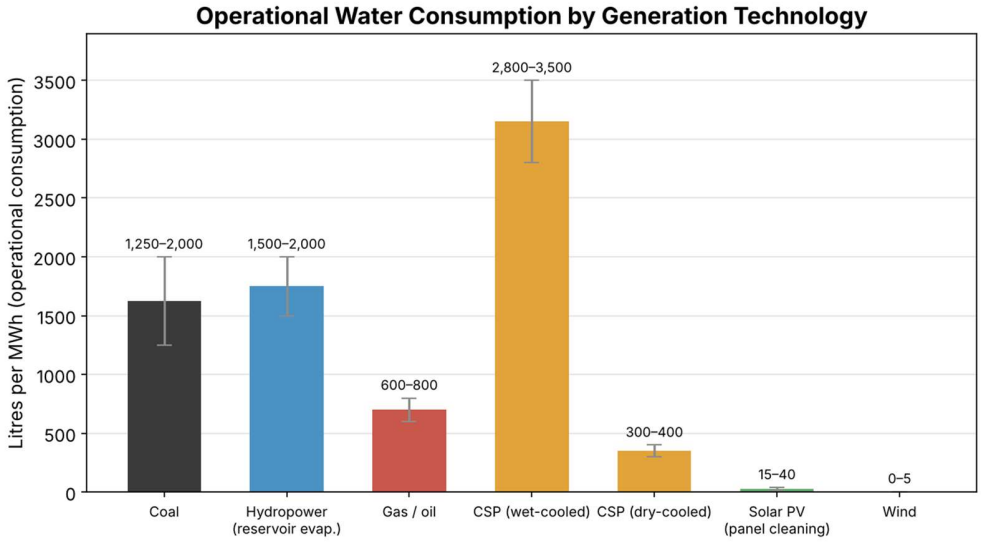


Figure 6.5 — Operational Water Consumption by Electricity Generation Technology, Litres per MWh (Source: indicative ranges compiled from IEA, 2023a and Table 6.3; CSP values depend on cooling technology)

Water is a critical resource in Algeria, which is among the most water-stressed countries in the world. Figure 6.5 shows that thermal power plants with wet cooling and CSP plants with wet cooling consume large volumes of water, whereas PV and wind need almost none — only the water used to clean panels. For desert locations, this makes PV the natural choice and argues for dry cooling in any CSP plant. Conversely, solar energy can *produce* water: Algeria's large seawater desalination plants are major electricity consumers, and supplying them with solar electricity would link the energy and water transitions.

Health Benefits of Solar Energy in Algeria

Algeria's cities—particularly Algiers, Oran, and Constantine—regularly exceed WHO air quality guidelines for PM2.5, SO_2, and NO_2. Replacing gas-fired power plants with solar PV and deploying solar water heaters to replace wood-burning stoves (widely used in rural areas) would significantly reduce respiratory disease, saving the healthcare system hundreds of millions of dinars annually while improving quality of life for millions of Algerians (WHO, 2022).

6.4 Energy Access and the Right to Energy

Access to reliable, affordable electricity is increasingly recognised as a fundamental human right and a prerequisite for achieving virtually all Sustainable Development Goals (SDGs). Renewable energy—particularly off-grid and mini-grid solutions—is the most cost-effective pathway to universal energy access in the developing world (UN, 2015; World Bank, 2023a).

SDG Goal	SDG Target	Renewable Energy Contribution
SDG 1: No Poverty	End poverty in all forms	Energy access enables productive income-generating activities
SDG 2: Zero Hunger	Sustainable agriculture	Solar irrigation; cold chains for food storage
SDG 3: Good Health	Universal healthcare	Electrified health clinics; no indoor air pollution
SDG 4: Quality Education	Inclusive education	Electrified schools; digital learning; study after dark
SDG 5: Gender Equality	Women's empowerment	Clean cooking saves 2–6 hrs/day for women; new jobs
SDG 6: Clean Water	Universal water access	Solar pumping for water supply systems

SDG Goal	SDG Target	Renewable Energy Contribution
SDG 7: Affordable Clean Energy	Universal energy access	RE is primary vehicle for SDG 7 achievement
SDG 8: Economic Growth	Decent work	RE sector jobs; productive use of energy
SDG 13: Climate Action	Combat climate change	RE is central to mitigation; adaptation co-benefits

Table 6.4 — Renewable Energy Contribution to the Sustainable Development Goals (Source: own elaboration based on UN, 2015 and World Bank, 2023a, Tracking SDG7)

6.5 Gender and Social Inclusion in Renewable Energy

Women represent only 32% of the global renewable energy workforce—below the economy-wide average of 48%. Ensuring gender equality and social inclusion in the energy sector is both a moral imperative and an economic necessity (IRENA, 2019b).

Dimension	Current Situation	Best Practice / Target
Women in RE workforce	32% globally; lower in technical roles	Targets of 40–50%; mentoring programmes
Women in leadership (RE)	~28% of senior roles	Board-level targets; gender-responsive procurement
Access to clean cooking	2.3 billion people lack clean cooking	Solar cookers; LPG/biogas expansion
Rural women & energy poverty	Women most affected by energy poverty	Community solar; mobile payment schemes
Gender-responsive project design	Often absent from RE projects	Mandatory social impact assessments; consultation

Table 6.5 — Gender Dimensions of Renewable Energy (Source: IRENA, 2019b, Renewable Energy: A Gender Perspective; World Bank, 2023a)

6.6 Community Development and Social Licence to Operate

Renewable energy projects—particularly large utility-scale installations—must obtain and maintain a "social licence to operate" from affected communities. This is not a formal legal document but a

reflection of ongoing community acceptance and trust (IFC, 2012; Equator Principles Association, 2020).

- Community benefit funds: RE developers contribute a portion of revenue to local development funds (schools, health centres, roads).
- Local employment and procurement preferences: prioritising local labour and supply chains maximises community economic benefit.
- Equity participation: community ownership stakes (even minority shares) transform residents from passive observers into active stakeholders.
- Regular consultation: meaningful, ongoing dialogue—not just a one-time public meeting—is essential to maintain trust.
- Land rights: transparent land acquisition processes respecting existing land use rights are critical to avoid conflict.

6.7 Negative Impacts and Trade-Offs

Renewable energy is not free of environmental and social impacts. An honest assessment must recognise them, both because they are real and because ignoring them undermines public trust. Table 6.6 lists the main issues and the measures used to manage them.

Impact	Description	Mitigation
Land use	Utility-scale PV needs about 1.5–2.5 ha per MW; competition with grazing or agriculture	Use degraded land; agrivoltaics; rooftop and car-park PV
Biodiversity	Habitat disturbance; bird and bat collisions with wind turbines	Siting studies; curtailment during migration; monitoring
End-of-life waste	Up to 60–78 Mt of PV panel waste globally by 2050	Recycling obligations; design for recycling; second-life use
Mineral extraction	Mining impacts and labour issues in supply chains	Supply-chain due diligence; recycling; material efficiency
Landscape & noise	Visual impact of turbines and lines; turbine noise	Setback distances; community consultation; benefit sharing
Grid integration costs	Variability requires flexibility, storage and new lines	System planning; storage; interconnections; demand response
Distributional effects	Subsidies or net metering may favour wealthier households	Targeted support; tariff reform with social protection

Table 6.6 — Negative Impacts of Renewable Energy and Mitigation Measures (Source: own elaboration based on IFC, 2012; IRENA, 2023a and IEA, 2023d)

6.8 A Just Transition for Hydrocarbon Regions

The concept of a **just transition**, recognised in the preamble of the Paris Agreement, holds that the costs and benefits of moving away from fossil fuels should be shared fairly, and that workers and communities dependent on fossil industries should not be left behind (UNFCCC, 2015). In Algeria, entire towns — Hassi Messaoud, Hassi R'Mel, In Amenas, Arzew, Skikda — owe their existence to the hydrocarbon industry. Their workforce possesses skills directly transferable to the new energy economy: electrical and mechanical engineering, project management, health and safety, pipeline operations, process chemistry. Locating solar plants, hydrogen production and ammonia synthesis in these regions, and organising retraining programmes with Sonatrach, Sonelgaz and the universities, would turn a potential social risk into an industrial opportunity.

Key Points of Chapter 6

- Renewable energy employed 16.2 million people worldwide in 2023, 39% of them in solar PV.
- Construction jobs are temporary (job-years); permanent jobs depend on manufacturing, O&M and services.
- Over their lifecycle, solar and wind emit 10–70 times less CO_2 per kWh than fossil generation, and PV and wind use almost no water.
- Renewable energy supports most Sustainable Development Goals, especially SDG 7.
- Negative impacts — land use, waste, minerals, distributional effects — exist and must be managed transparently.
- A just transition requires that hydrocarbon regions and workers benefit from the new energy economy.

Review Questions and Exercises — Chapter 6

1. Explain the difference between a job and a job-year. Recalculate the permanent employment created by 13,575 MW of PV using an O&M factor of 0.4 jobs/MW.
2. Why is lifecycle analysis necessary to compare the emissions of different technologies? What stage dominates the lifecycle emissions of solar PV?
3. A 100 MW CSP plant with wet cooling produces 350 GWh per year. Using Figure 6.5, estimate its annual water consumption, and compare it with dry cooling.
4. Choose three Sustainable Development Goals and explain, with Algerian examples, how renewable energy contributes to them.
5. Discuss the gender gap in the renewable energy workforce. Propose two measures that an Algerian university or company could take.
6. Identify the main negative impacts of a 500 MW solar park in the high plateaus and propose a mitigation plan.

7. What does “just transition” mean for Hassi Messaoud? Write a short proposal for a regional transition plan.

Chapter 7 – Renewable Energy in the Economy

Renewable energy has moved from a niche environmental technology to a mainstream economic force. Understanding the economics of renewable energy—from project-level financial analysis to macroeconomic impacts—is essential for engineers, policymakers, financiers, and entrepreneurs working in the sector.

7.1 The Levelized Cost of Energy (LCOE)

The Levelized Cost of Energy (LCOE) is the most widely used metric for comparing the cost-effectiveness of different electricity generation technologies. It represents the average revenue per unit of energy (USD/MWh) that a project must earn to break even over its lifetime, taking into account all costs (capital, operating, financing) and all energy produced (IRENA, 2024a; Lazard, 2023).

LCOE Formula:

$$\mathbf{LCOE = [Sum\ of\ (Costs_t\ /\ (1+r)\hat{}t)]\ /\ [Sum\ of\ (Energy_t\ /\ (1+r)\hat{}t)]}$$

Where: Costs_t = all costs in year t (CAPEX + OPEX + decommissioning); Energy_t = energy generated in year t; r = discount rate; t = year from 1 to lifetime.

Intuitively, the LCOE is the *constant* price per MWh that would make the present value of revenues exactly equal to the present value of costs. Discounting the energy in the denominator may seem strange, since energy is not money; it is a mathematical consequence of the fact that the revenue earned from each future MWh is itself discounted. When annual energy and operating costs are constant, the formula simplifies to the widely used annuity form:

$$\mathbf{LCOE \approx (CAPEX \times CRF + OPEX) / E, \quad with \quad CRF = r / [1 - (1 + r)^{(-n)}]}$$

where CRF is the **capital recovery factor**, which converts an initial investment into an equivalent constant annual payment over n years at discount rate r. For r = 8% and n = 25 years, CRF = 0.0937: every dollar invested costs 9.37 cents per year over the life of the plant. This form makes the structure of renewable costs transparent. For a solar plant, the first term (capital) typically represents 75–85% of the LCOE; for a gas plant, fuel dominates. Renewable energy is therefore a *capital-intensive* technology whose competitiveness depends decisively on the cost of capital — a point illustrated by the worked example in Section 7.7.

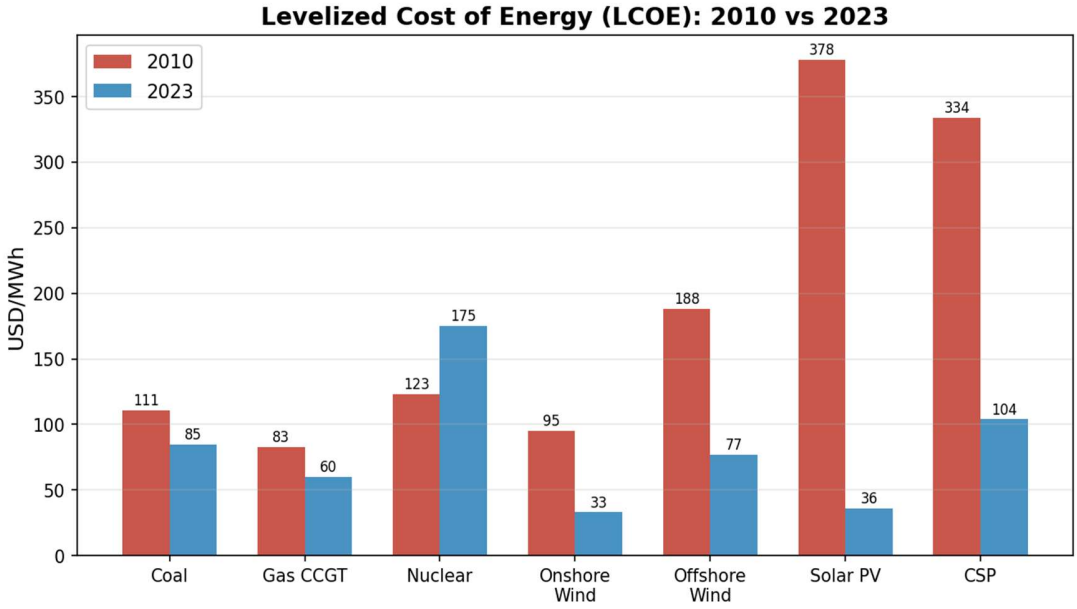


Figure 7.1 — LCOE Comparison 2010 vs. 2023 by Technology, USD/MWh (Source: IRENA, 2024a, Renewable Power Generation Costs in 2023)

Technology	CAPEX Range (USD/kW)	LCOE 2010 (USD/MWh)	LCOE 2023 (USD/MWh)	LCOE Reduction	Capacity Factor (%)
Onshore Wind	800–1,500	95	33	-65%	25–45%
Offshore Wind	2,500–4,500	188	77	-59%	40–60%
Solar PV (utility)	500–900	378	36	-90%	15–35%
Solar PV (rooftop)	700–1,200	450	60	-87%	12–20%
Concentrated Solar (CSP)	4,000–8,000	334	104	-69%	25–50%
Geothermal	2,000–5,000	70	65	-7%	85–95%
Hydro (large)	1,000–3,500	40	35	-13%	30–60%
Biomass	2,000–3,500	90	80	-11%	60–85%
Coal (new)	1,500–3,000	111	85	-23%	50–85%
Gas CCGT	800–1,500	83	60	-28%	40–80%

Technology	CAPEX Range (USD/kW)	LCOE 2010 (USD/MWh)	LCOE 2023 (USD/MWh)	LCOE Reduction	Capacity Factor (%)
Nuclear	5,000–15,000	123	175	+42%	80–95%

Table 7.1 — LCOE by Technology: CAPEX, Cost Evolution 2010–2023 and Capacity Factors (Source: IRENA, 2024a; conventional technologies from Lazard, 2023)

The cost reductions of Table 7.1 are not accidental. They follow a regular pattern known as the **learning curve** or **experience curve** (Wright's law): each time cumulative production of a technology doubles, its unit cost falls by a roughly constant percentage, the *learning rate*. Figure 7.2 plots the price of PV modules against cumulative installed capacity on logarithmic axes, where a constant learning rate appears as a straight line.

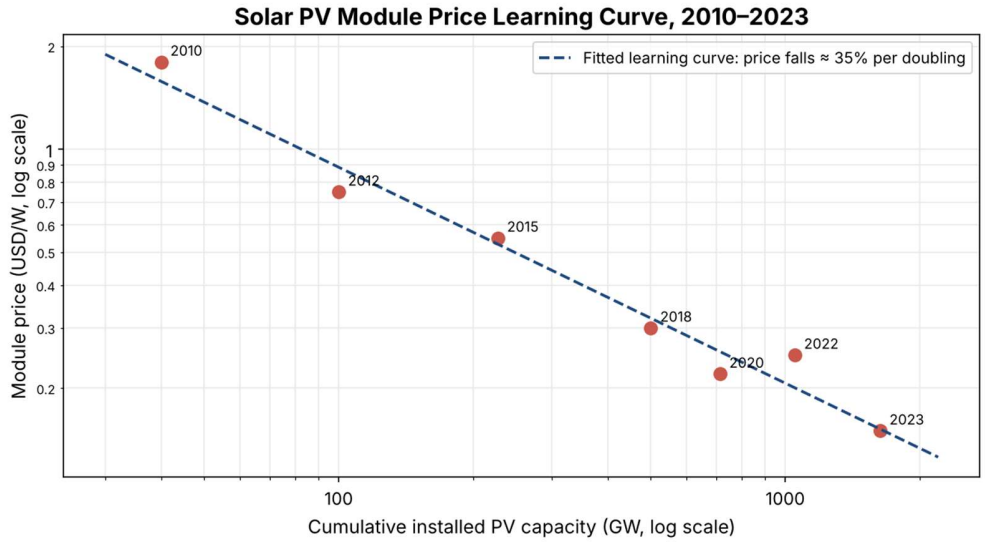


Figure 7.2 — Solar PV Module Price Learning Curve, 2010–2023: Module Price vs. Cumulative Installed Capacity, Logarithmic Scales (Source: own elaboration; capacities from Table 1.3 and IRENA, 2024b; module prices approximate from IRENA, 2024a)

Over 2010–2023 the fitted learning rate is about 35% per doubling — higher than the long-term average of roughly 20–25% reported since the 1970s, because the period included a phase of massive manufacturing scale-up and overcapacity in China (IRENA, 2024a). The learning curve has an important policy implication: early deployment support is an investment in future cost reductions that benefit all countries. The German feed-in tariff of the 2000s was expensive for German consumers, but it financed the learning that made solar the cheapest source of electricity for the rest of the world.

Solar PV: The Fastest Cost Decline in Energy History

> Between 2010 and 2023, the cost of utility-scale solar PV fell by over 90%—from USD 378/MWh to USD 36/MWh. This is the fastest cost decline of any energy technology in history. In over 80 countries, new solar PV is now the cheapest source of electricity ever—cheaper than running existing coal plants. This cost revolution has made the energy transition economically inevitable, not merely environmentally desirable (IRENA, 2024a).

7.2 Financial Analysis of Renewable Energy Projects

7.2.1 Key Financial Metrics

Beyond LCOE, several additional financial metrics are used to evaluate and compare renewable energy projects: (Masters, 2013; IRENA & CPI, 2023)

Metric	Definition	Formula	Typical Target
Net Present Value (NPV)	Present value of all future cash flows minus initial investment	NPV = Sum of [CFt/(1+r)^t] - CAPEX	NPV > 0 (positive)
Internal Rate of Return (IRR)	Discount rate that makes NPV = 0; measures project return	Solve: NPV = 0	IRR > WACC (typically 8–15%)
Payback Period	Years to recover initial investment from cash flows	CAPEX / Annual Net Cash Flow	Typically 5–15 years for RE
Debt Service Coverage Ratio (DSCR)	Ratio of cash flow to debt service; lender safety metric	DSCR = EBITDA / Debt Service	Lenders require DSCR ≥ 1.25
Capacity Factor (CF)	Actual energy produced / Maximum possible energy	CF = Actual MWh / (MW × 8760h)	Solar: 15–35%; Wind: 25–50%
Yield (P50/P90)	Energy generation probability estimates	Based on resource assessment	P50 = median; P90 = conservative

Table 7.2 — Key Financial Metrics for Renewable Energy Project Evaluation (Source: own elaboration based on Masters, 2013 and IRENA & CPI, 2023)

7.2.2 Project Finance Structure

Most utility-scale RE projects use "project finance"—a structure where debt is secured on the future cash flows of the project itself, not on the developer's balance sheet. This allows large projects to be financed with relatively small equity contributions (IRENA & CPI, 2023).

Component	Typical Range	Notes
Equity share	20–40%	Developer and equity investors; higher risk, higher return
Debt share	60–80%	Banks and DFIs; lower risk; secured on project cash flows
Debt tenor	15–25 years	Matched to PPA duration; longer = lower annual payments
Equity IRR target	10–18%	Higher in emerging markets due to country risk premium
Debt interest rate	4–10%	Depends on country risk, currency, lender type
PPA duration	15–25 years	Provides revenue certainty for lenders
Construction period	1–3 years	Key risk phase: EPC contractor manages construction risk
Contingency reserve	5–10% of CAPEX	Buffer for cost overruns
Debt Service Reserve	6–12 months	Cash reserve to service debt during low revenue periods

Table 7.3 — Typical Project Finance Structure for a Utility-Scale Solar PV Project (Source: own elaboration based on IRENA & CPI, 2023; ranges are indicative of emerging-market practice)

Project finance rests on a web of contracts that allocate each risk to the party best able to manage it. Figure 7.3 shows the typical structure. At its centre is a **special purpose vehicle (SPV)**, a company created solely to own and operate the plant. The SPV signs a power purchase agreement with the offtaker, a turnkey EPC contract with a builder who guarantees price, schedule and performance, an O&M agreement, supply contracts with warranties, a land lease and loan agreements with lenders. Because lenders have recourse only to the project’s cash flows, they scrutinise every contract before financial close.

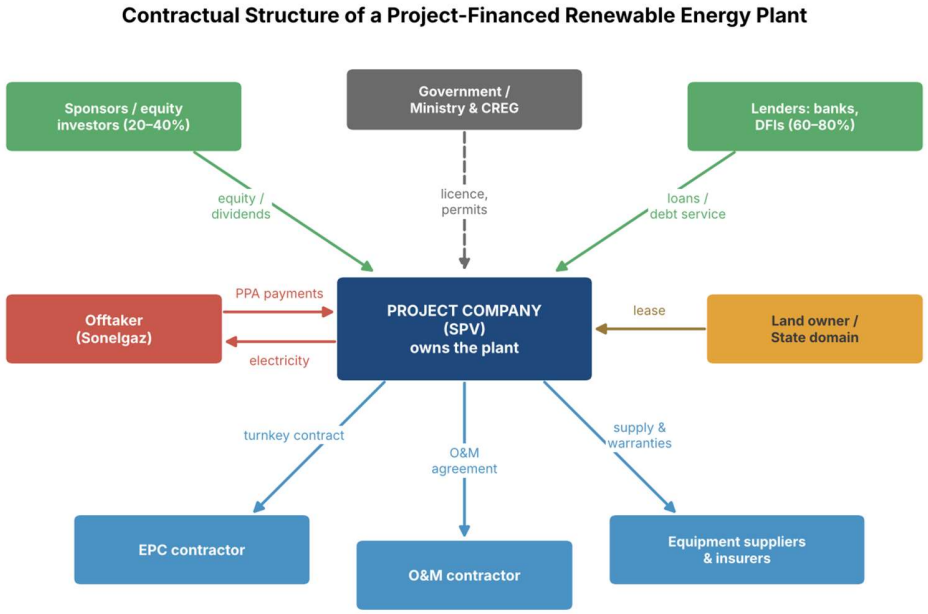


Figure 7.3 — Contractual Structure of a Project-Financed Renewable Energy Plant (Source: own elaboration based on IRENA & CPI, 2023)

Risk	Typical bearer	Contractual / financial instrument
Construction cost & delay	EPC contractor	Fixed-price turnkey contract; liquidated damages
Technology performance	EPC contractor; suppliers	Performance guarantees; module and inverter warranties
Resource (irradiation, wind)	Project company / equity	P50/P90 studies; debt sized on P90; reserve accounts
Offtaker payment	Lenders & equity; state	Sovereign guarantee; letters of credit; DFI cover
Currency convertibility	Lenders & equity; state	Hard-currency tariff; political risk insurance (MIGA)
Regulatory change	State	Stabilisation clauses; change-in-law provisions in PPA
Grid curtailment	Offtaker / state	Deemed-energy payments; take-or-pay clauses
Operation & maintenance	O&M contractor	Availability guarantees; performance bonuses

Table 7.4 — Risk Allocation in a Project-Financed Renewable Energy Project (Source: own elaboration based on IRENA & CPI, 2023)

7.3 Investment Flows in Renewable Energy

Global investment in renewable energy has grown enormously over the past decade. For the first time in 2023, annual investment in clean energy exceeded USD 1.7 trillion—surpassing fossil fuel investment by a significant margin (IEA, 2023b).

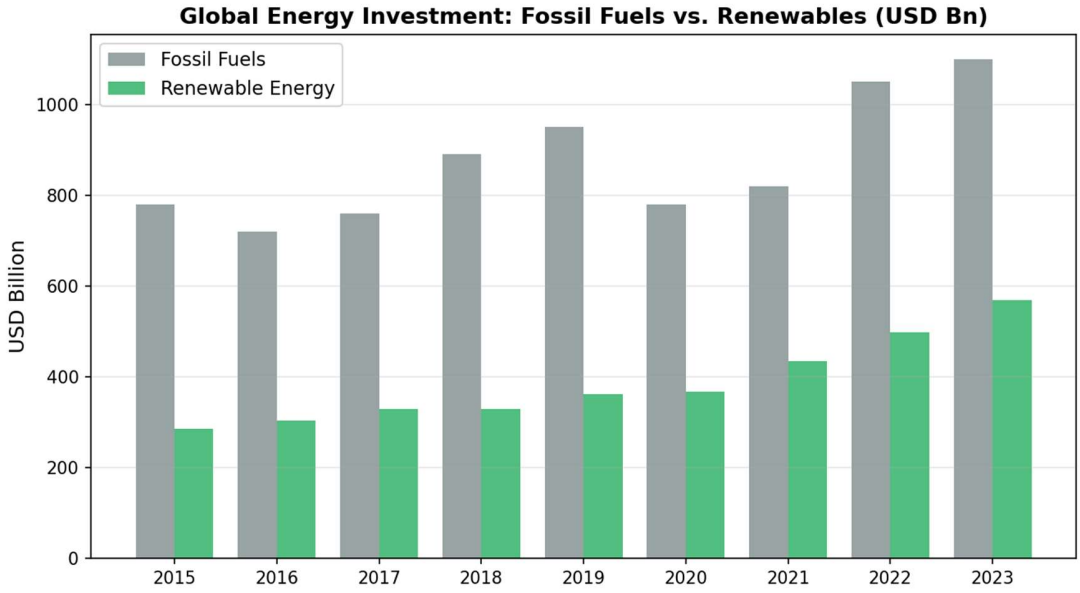


Figure 7.4 — Global Energy Investment: Fossil Fuels vs. Renewables 2015–2023, USD Billion (Source: IEA, 2023b, World Energy Investment 2023)

Financing Mechanism	Description	Volume (2023)	Key Players	Best Used For
Project Finance	Non-recourse debt on project cash flows	~USD 300Bn	Commercial banks, DFIs	Utility-scale solar, wind, hydro
Green Bonds	Debt labelled for green projects; listed on markets	~USD 500Bn	Corporates, sovereigns, DFIs	Portfolio RE projects; green infrastructure
Sovereign Green Bonds	Government bonds for national RE/climate programmes	~USD 90Bn	Governments	Public sector RE; climate resilience
Blended Finance	Concessional public funds leverage private capital	~USD 15Bn	DFIs, philanthropies, governments	Emerging market RE; reducing risk

Financing Mechanism	Description	Volume (2023)	Key Players	Best Used For
Private Equity / VC	Equity investment in RE firms and startups	~USD 80Bn	PE firms, VC funds, family offices	Early-stage tech; growth-stage developers
Crowdfunding / Community	Small-scale community ownership of RE projects	~USD 5Bn	Platforms, cooperatives	Community solar; rooftop PV
Carbon Markets	Revenue from carbon credits sold to offset buyers	~USD 2Bn RE-related	Verified carbon standard projects	Additional revenue stream for RE projects

Table 7.5 — Global Renewable Energy Financing Mechanisms, 2023 (Source: IRENA & CPI, 2023; green bond volumes from Climate Bonds Initiative, 2024; IEA, 2023b)

7.4 Macroeconomic Benefits of Renewable Energy

Beyond individual project economics, widespread renewable energy deployment generates significant macroeconomic co-benefits for national economies. These are particularly important for Algeria (IRENA, 2023a).

Benefit Category	Mechanism	Estimated Value for Algeria
Fossil fuel import savings	Domestic RE displaces imported refined petroleum products	USD 1.5–2.5Bn/yr (based on current import volumes)
Energy subsidy reduction	RE reduces need for gas subsidies in power sector	Up to USD 3Bn/yr by 2030
Export revenue (Green H_2)	Export green hydrogen/ammonia to EU markets	USD 3–7Bn/yr potential by 2035
Industrial development	Local RE manufacturing adds value; creates supply chains	GDP multiplier of 1.5–2.5x direct investment

Benefit Category	Mechanism	Estimated Value for Algeria
Job creation	Direct and indirect employment across RE value chain	180,000–275,000 jobs by 2030
Healthcare savings	Reduced air pollution cuts respiratory disease costs	USD 500M–1Bn/yr
Energy price stability	RE prices fixed at commissioning; immune to fuel price shocks	Lower long-term risk for planning
Skills development	Trains engineers, technicians, data scientists	Human capital spillovers across economy

Table 7.6 — Macroeconomic Co-Benefits of Renewable Energy for Algeria (Source: own estimates based on MEM, 2021; IMF, 2023 and IRENA, 2023a; values are indicative orders of magnitude)

7.5 Business Models in the Renewable Energy Sector

Entrepreneurs and engineers entering the RE sector can operate through a variety of business models. Each has different capital requirements, risk profiles, and return characteristics.

Business Model	Description	Capital Intensity	Revenue Source	Algerian Opportunity
Independent Power Producer (IPP)	Finance, build, own, operate RE plant; sell via long-term PPA	Very High	Electricity sales (USD/MWh)	Large-scale solar/wind farms
EPC Contractor	Design and construct RE projects for developers	Moderate	Construction fees (USD lump sum)	Build local RE construction companies
O&M Contractor	Operate and maintain RE plants for owners	Low	Annual service fees	Local workforce; critical for PNREE
Solar Equipment Distributor	Import and sell PV panels, inverters, batteries	Moderate	Product margin	Rooftop market; rural off-grid

Business Model	Description	Capital Intensity	Revenue Source	Algerian Opportunity
Energy-as-a-Service (EaaS)	Install RE with no upfront cost; sell kWh to client	High (developer-financed)	Monthly energy fees	Commercial rooftop; agri-solar
Solar Irrigation Service Provider	Provide solar-powered irrigation as a service to farmers	Moderate	Seasonal service fee or % crop value	High potential across agricultural zones
Green Hydrogen Producer	Produce H_2 via electrolysis powered by RE	Extremely High	H_2/NH_3 export contracts	Long-term Saharan export strategy
RE Consultancy / Development	Originate, develop, and sell RE projects to investors	Low–Moderate	Development fees; carried interest	Entry-level for new companies
Energy Storage / Grid Services	Provide battery storage, demand response, grid balancing	High	Capacity and ancillary service payments	Emerging as RE penetration rises

Table 7.7 — Business Models in the Renewable Energy Sector: Characteristics and Algerian Context (Source: own elaboration)

Starting a Renewable Energy Company in Algeria

The legal minimum capital for an SARL (limited liability company) in Algeria is DZD 100,000 (~USD 740). An RE consultancy or project development company can be started with modest capital, a strong technical team, and good relationships with land owners and local authorities. Key registration steps: (1) Register at Centre National du Registre du Commerce (CNRC); (2) Register with tax authorities (DGI); (3) Open a business bank account; (4) Register with social security (CNAS). Project development fees of USD 0.5–1M per GW of projects sold to investors can generate substantial returns for a well-positioned team (JORADP).

7.6 Case Studies in Renewable Energy Economics

Case Study 1: Morocco's Noor Ouarzazate CSP Complex

Noor I, II, III and IV together constitute the world's largest concentrated solar power complex at 580 MW. Developed by ACWA Power with financing from the World Bank, AfDB, EIB, and KfW, the project achieved groundbreaking LCOE levels for CSP and demonstrated that North African countries can host world-class RE megaprojects (World Bank, 2018; Masen, 2023).

Parameter	Noor I	Noor II	Noor III
Capacity (MW)	160	200	150
Technology	Parabolic Trough	Parabolic Trough	Power Tower
Storage Hours	3h TES	7h TES	7.5h TES
Tariff (USD¢/kWh)	~16.4¢	~14.4¢	~15¢
COD	2016	2018	2018
Financing	World Bank + KfW + AfDB + EIB + local	Same consortium	Same consortium
CO_2 saved/yr ($ktCO_2$)	~240	~430	~380

Table 7.8 — Noor Ouarzazate CSP Complex: Key Project Parameters, Morocco (Source: World Bank, 2018; Masen, 2023)

Case Study 2: Sonelgaz's 1,000 MW Solar PV Tender (Algeria, 2023)

In 2023, Sonelgaz launched its most ambitious RE procurement to date: a 1,000 MW solar PV programme across multiple Algerian wilayas. This programme, if successfully implemented, would more than double Algeria's current solar installed capacity and provides a critical test of Algeria's evolving RE regulatory framework (Sonelgaz, 2023; CREG, 2023).

Key challenges include: local content requirements, grid connection capacity, land tenure clarity, and availability of qualified EPC contractors. The programme is being closely watched as a signal of Algeria's seriousness about its 2030 targets.

Case Study 3: Egypt’s Benban Solar Park

The Benban solar park near Aswan, completed in 2019, is one of the largest PV installations in the world, with a total capacity of about 1.65 GW divided into some thirty plants built by different private developers on land prepared by the state. Projects were procured under the second round of Egypt’s feed-in tariff programme at about 7.8 US¢/kWh, with 25-year PPAs signed with the Egyptian Electricity Transmission Company and denominated in US dollars. A consortium of lenders arranged

by the IFC provided around USD 650 million for thirteen of the plants, and the European Bank for Reconstruction and Development, the African Development Bank and others financed most of the rest (IFC, 2019).

Benban offers three lessons directly relevant to Algeria. First, **state-prepared sites** with a shared substation and transmission line reduced the risks and costs for individual developers. Second, **hard-currency tariffs** and the involvement of development finance institutions made the projects bankable despite the macroeconomic risks of the host country. Third, a single large park attracted dozens of international and local companies and built a domestic ecosystem of EPC contractors, O&M providers and consultants within a few years.

7.7 Worked Examples

The following examples apply the tools of this chapter to realistic Algerian cases. Students are encouraged to reproduce them in a spreadsheet and then to modify the assumptions. All values are in constant (real) US dollars and taxes are ignored for simplicity.

7.7.1 LCOE and Profitability of a 50 MW Solar PV Plant

Consider a 50 MW ground-mounted PV plant in the northern Sahara with the assumptions of Table 7.9.

Parameter	Value	Comment
Installed capacity	50 MW	Ground-mounted, fixed tilt
Specific CAPEX	700 USD/kW	Total investment USD 35 million
Specific yield (year 1)	1,900 kWh/kWp	Capacity factor 21.7%; E_1 = 95,000 MWh
Degradation	0.5% per year	Typical crystalline silicon
OPEX	12 USD/kW/yr	USD 0.6 million per year
Lifetime	25 years	Equal to PPA duration
Discount rate (WACC)	8% real	Emerging-market utility-scale project
PPA tariff	45 USD/MWh	Flat, in hard currency
Debt	70% at 6%, 18 years	Annuity repayment

Table 7.9 — Assumptions of Worked Example 7.1: 50 MW Solar PV Plant (Source: own assumptions, consistent with the ranges of Tables 7.1–7.3)

Step 1 — Discounted costs. The present value of OPEX over 25 years is USD 6.40 million, so the present value of total costs is 35.00 + 6.40 = USD 41.40 million.

Step 2 — Discounted energy. Summing $E_1 \times (1 - 0.005)^{(t-1)} / 1.08^t$ over 25 years gives 973,672 “discounted MWh”.

Step 3 — LCOE. LCOE = 41.40 × 10^6 / 973,672 = **42.5 USD/MWh**. The simplified annuity formula, which ignores degradation, gives (35 × 10^6 × 0.0937 + 0.6 × 10^6) / 95,000 = 40.8 USD/MWh — close, but slightly optimistic.

Step 4 — Cash flows and profitability. In year 1, revenue is 95,000 × 45 = USD 4.28 million and net cash flow after OPEX USD 3.67 million. At an 8% discount rate the project's net present value is **USD +2.4 million** and its internal rate of return **8.8%**, slightly above the cost of capital. Simple payback occurs in year 10 and discounted payback in year 21. Figure 7.5 shows the cash-flow profile.

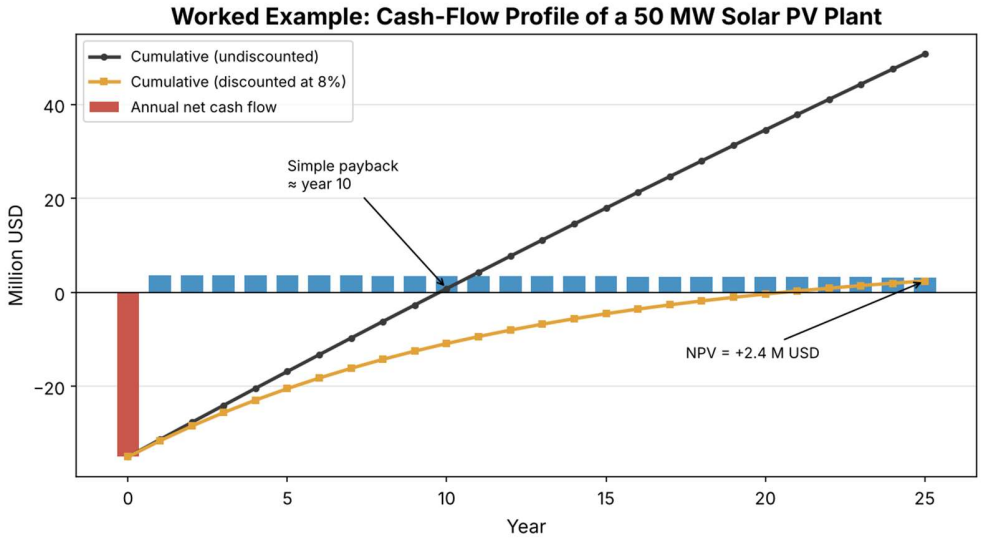


Figure 7.5 — Worked Example 7.1: Annual and Cumulative Cash Flows of a 50 MW Solar PV Plant, Million USD (Source: own calculation with the assumptions of Table 7.9)

Step 5 — Debt service and DSCR. Debt of 70% × 35 = USD 24.5 million at 6% over 18 years requires a constant annual payment of 24.5 × 0.06 / [1 − 1.06^(−18)] = USD 2.26 million. The debt service coverage ratio is 3.67 / 2.26 = **1.62** in year 1, falling to 1.47 in year 18 because of degradation — comfortably above the 1.25 minimum typically required by lenders. With leverage, the return on the USD 10.5 million of equity rises to about **13%**, which explains why sponsors favour project finance.

Because the LCOE depends on many uncertain parameters, analysts test its sensitivity. Figure 7.6 shows how the LCOE varies with the discount rate for three levels of CAPEX, and Figure 7.7 ranks the parameters by their influence.

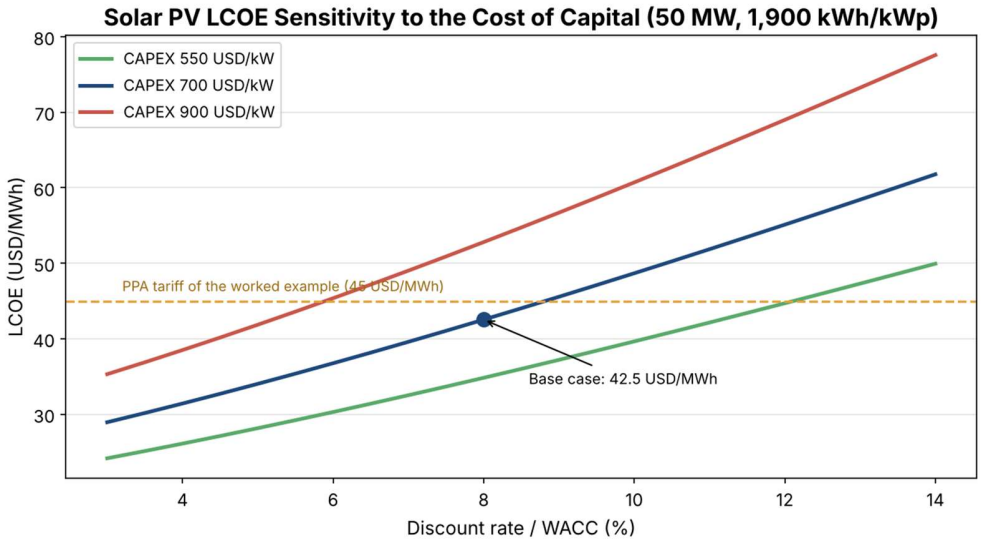


Figure 7.6 — Worked Example 7.1: Sensitivity of Solar PV LCOE to the Discount Rate for Three CAPEX Levels, USD/MWh (Source: own calculation)

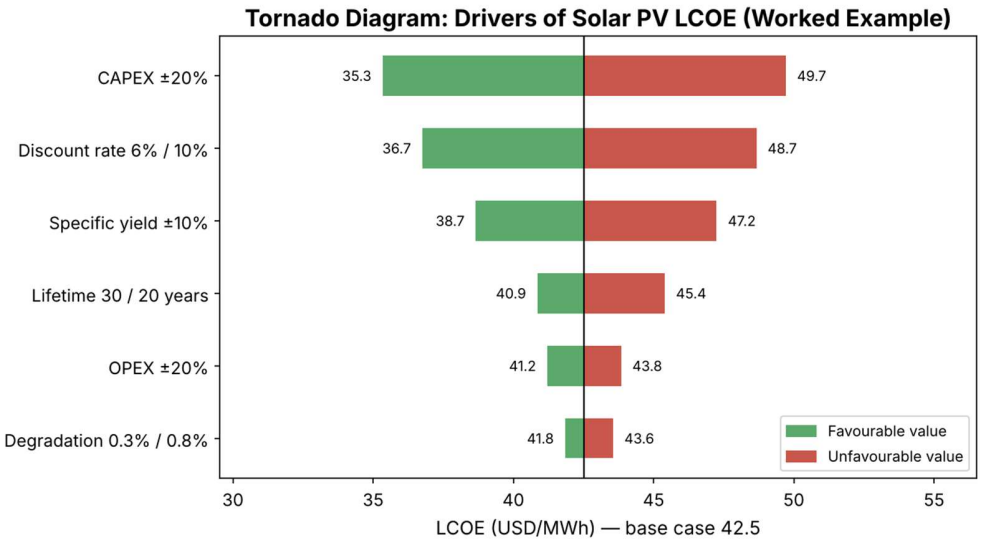


Figure 7.7 — Worked Example 7.1: Tornado Diagram of LCOE Sensitivity to Key Parameters, USD/MWh (Source: own calculation)

Two conclusions stand out. First, the cost of capital is almost as important as CAPEX itself: moving the discount rate from 6% to 10% raises the LCOE by about a third. Reducing country and offtaker risk — through guarantees, hard-currency contracts and a stable regulatory framework — is therefore one of the most powerful levers available to a government that wants cheap renewable electricity. Second, the specific yield matters: building in the best-resource zones, using single-axis trackers and minimising soiling can lower the LCOE by several dollars per MWh.

7.7.2 Rooftop PV for an Algerian Household: The Role of Tariffs

A household in Algiers considers a 3 kWp rooftop system costing about USD 900 per kWp installed (USD 2,700 in total) and producing about 1,550 kWh/kWp, i.e. 4,650 kWh per year. Its annual consumption is about 4,000 kWh, of which, without a battery, it can consume about 60% of the solar production directly (≈ 2,800 kWh). Table 7.10 compares two situations.

Item	Scenario A: subsidised tariff, no export remuneration	Scenario B: cost-reflective tariff with net metering
Electricity price	≈ USD 0.03/kWh	USD 0.10/kWh
Energy valued	2,800 kWh self-consumed	4,650 kWh (all production)
Annual saving	≈ USD 84	≈ USD 465
Simple payback	≈ 32 years (beyond lifetime)	≈ 5.8 years
Conclusion	Not viable for the household	Attractive investment

Table 7.10 — Worked Example 7.2: Simple Payback of a 3 kWp Residential Rooftop PV System under Two Tariff Regimes (Source: own calculation; tariff levels are indicative)

The example shows that the main obstacle to rooftop solar in Algeria is not the technology or the sunshine but the very low regulated retail tariff, which makes saved electricity almost worthless to the household — even though it is costly for the state, which pays the difference between the cost of supply and the tariff. A targeted reform, for example cost-reflective tariffs for the highest consumption blocks combined with net billing for prosumers, would make rooftop PV attractive for the households that consume most, while protecting low-income consumers.

7.7.3 Exercise: Wind Farm Appraisal

Appraise a 100 MW onshore wind farm near Adrar with CAPEX 1,250 USD/kW, capacity factor 35%, OPEX 35 USD/kW/yr, lifetime 25 years and WACC 9%. (a) Calculate the annual energy production. (b) Calculate the LCOE using the annuity formula. (c) Determine the minimum flat tariff for which NPV ≥ 0. (d) With 70% debt at 6.5% over 15 years, calculate the year-1 DSCR at that tariff and comment on bankability. Guidance answers are given in Appendix B.

Key Points of Chapter 7

- The LCOE is the constant price that equalises the present values of revenues and costs; it is the standard metric for comparing technologies.
- Renewable energy is capital-intensive: its LCOE is dominated by CAPEX and highly sensitive to the cost of capital.
- Costs follow learning curves: each doubling of cumulative PV capacity has lowered module prices by 20–35%.
- Project finance relies on an SPV and a set of contracts that allocate risks; lenders size debt on cash flows and require DSCR ≥ 1.25.

- NPV, IRR, payback and DSCR answer different questions and should be used together.
- Subsidised retail tariffs make self-generation unattractive and are a major barrier to rooftop PV in Algeria.
- Benban (Egypt) and Noor (Morocco) show how prepared sites, hard-currency contracts and DFI support make large projects bankable in North Africa.

Review Questions and Exercises — Chapter 7

1. Derive the simplified LCOE formula from the general formula, stating the assumptions required.
2. Calculate the capital recovery factor for r = 6%, 10% and 12% over 25 years. How does each affect the LCOE of Worked Example 7.1?
3. Explain the difference between project IRR and equity IRR. Why does leverage increase equity IRR, and what risk does it create?
4. Using Figure 7.2, estimate the module price that would be reached if cumulative capacity doubled again from 2023, with a learning rate of 25%.
5. For each risk in Table 7.4, explain why the indicated party is best placed to bear it.
6. Recompute Worked Example 7.2 for a household paying USD 0.06/kWh with net billing at USD 0.03/kWh for exports.
7. Compare the Noor and Benban projects in terms of technology, procurement model, tariff and financing.

General Conclusion

This module opened with global energy statistics and closed with the economics of a company that a graduate might one day create. The path between the two is the argument of the course: the energy transition is a socio-technical process, and its decisive bottlenecks are rarely located where an engineering curriculum expects to find them. Six conclusions follow from the seven chapters.

- Cost is no longer the obstacle. Utility-scale solar photovoltaics and onshore wind are today the cheapest sources of new electricity in most markets, following cost reductions of about 90% and 65% respectively since 2010 (IRENA, 2024a; Lazard, 2023). Any argument for renewable energy that rests solely on environmental duty now understates the case; the economic argument has become the stronger one.
- The binding constraint is institutional, not physical. Algeria possesses more than 2,000 GW of technical solar potential (CDER, 2022) and a target of 22 GW by 2030 (MEM, 2021), yet under 1 GW is installed. What is missing is not irradiation but bankable contracts, predictable tariffs, clear land tenure, faster permitting and available grid capacity (CREG, 2023). Investors consistently rank regulatory and policy risk above technology or resource risk (IRENA & CPI, 2023; REN21, 2023).
- Geopolitical power is being redistributed rather than abolished. The fossil era rewarded countries holding reserves; the clean energy era rewards countries holding renewable resources, manufacturing capacity and critical materials (IRENA, 2019a). Algeria is unusual in being well placed in both configurations — provided that hydrocarbon rents are used to finance the transition rather than to postpone it.
- The socioeconomic case is measurable and should be quantified. Renewable energy employed 16.2 million people worldwide in 2023 (IRENA & ILO, 2023); air pollution, largely from fossil combustion, is associated with approximately 7 million premature deaths each year (WHO, 2022); and access to energy underpins the majority of the Sustainable Development Goals (UN, 2015; World Bank, 2023a). These are the terms in which energy policy is publicly decided, and engineers able to quantify them take part in that decision.
- Projects are financed, not merely built. LCOE, NPV, IRR and DSCR form the vocabulary in which a project is judged by those who supply the capital (IRENA & CPI, 2023). A technically optimal design that yields a debt service coverage ratio below 1.25 will not be financed, and a project that is not financed does not exist.
- Law converts political intention into physical infrastructure. Feed-in tariffs, competitive auctions, net metering, portfolio standards and carbon pricing are the instruments through which commitments become megawatts (REN21, 2023; World Bank, 2023b). Each has documented strengths and characteristic failure modes; choosing among them is a policy decision with direct engineering consequences.

Several questions remain genuinely open and should be treated as such rather than as settled doctrine. Whether Algeria can reform energy subsidies — of the order of USD 12 billion per year, close to 5% of GDP (IMF, 2023) — without imposing unacceptable social costs is uncertain, and the sequencing

of such a reform is contested. Whether green hydrogen exports to Europe will materialise at the scale currently discussed depends on European demand, transport economics and competition from other suppliers, none of which can be forecast confidently today. Whether local content requirements will build a genuine Algerian manufacturing base or simply raise project costs is an empirical question that the coming decade will answer. Students should approach confident predictions with scepticism, including those contained in the scenarios reproduced in this document.

The graduate of this module occupies a particular professional position. Few economists can size a power plant; few engineers can read a power purchase agreement. The professionals who actually move projects from concept to commissioning are generally those who can do both, and who can explain a technical constraint to a regulator and a regulatory constraint to a technical team. That interface role — rather than any specialised sub-discipline — is where the shortage of skills is most acute in Algeria and across North Africa, and it is the position this course has been designed to prepare students to occupy.

Finally, the data assembled in this support will age. Costs will continue to fall, targets will be revised, laws will be amended and new actors will emerge. The analytical framework should outlast the numbers: identify the resource, identify the actors, identify the rules, identify the money, and identify who gains and who loses. Applied consistently, that framework will remain useful long after the figures in these tables have been superseded.

Appendix A – Key Formulas and Reference Values

This appendix collects the formulas and reference values used throughout the course. It may be used as a revision sheet; students should nonetheless be able to explain the meaning and assumptions of each formula, not merely apply it.

Quantity	Formula	Notes
Annual energy of a plant	$E = P \times CF \times 8{,}760$ h	P in MW gives E in MWh
Capacity factor	$CF = E / (P \times 8{,}760)$	Solar 15–35%, wind 25–50%
Specific yield	$Y = E / P$ (kWh/kWp)	Algeria: ≈ 1,500–2,100 kWh/kWp
Present value	$PV = CF_t / (1 + r)^t$	r = discount rate, t = year
Net present value	$NPV = -CAPEX + \Sigma\, CF_t / (1 + r)^t$	Accept if NPV > 0
Internal rate of return	IRR such that NPV = 0	Compare with WACC
Capital recovery factor	$CRF = r / [1 - (1 + r)^{(-n)}]$	r = 8%, n = 25 → 0.0937
LCOE (general)	$\Sigma\,(Costs_t /(1+r)^t) / \Sigma\,(E_t /(1+r)^t)$	USD/MWh
LCOE (simplified)	$(CAPEX \times CRF + OPEX) / E$	Constant annual E and OPEX
Debt annuity	$A = D \times i / [1 - (1 + i)^{(-n)}]$	D = debt, i = interest rate
DSCR	CFADS / debt service	Lenders require ≥ 1.25–1.35
WACC	$E/V \times r_e + D/V \times r_d \times (1 - tax)$	Weighted cost of equity and debt
Learning curve	$C(x) = C_0 \times (x / x_0)^{(-b)}$; $LR = 1 - 2^{(-b)}$	x = cumulative capacity
Gas for power	V (bcm) ≈ E (TWh) × 3.6 / (η × 36)	η = plant efficiency
CO_2 avoided	$\Delta CO_2 = E \times (EF_{displaced} - EF_{RE})$	EF in tCO_2/MWh

Table A.1 — Key Formulas Used in the Course (Source: own compilation)

Indicator	Value	Source
Population (2023)	≈ 45–46 million	World Bank Open Data
Electricity generation	≈ 81 TWh/yr	Sonelgaz, 2023
Installed capacity	≈ 26 GW	Sonelgaz, 2023
Share of gas in generation	≈ 97%	CREG, 2023
Renewable target 2030	22 GW; 27% of generation	MEM, 2021
Solar irradiation	1,800–2,700 kWh/m²/yr	CDER, 2022
Gas reserves	≈ 2.4 trillion m³	Energy Institute, 2023
Gas exports	≈ 52–55 bcm/yr	Sonatrach, 2023
Emission factor of gas-fired power	≈ 0.45–0.55 tCO_2/MWh	IPCC, 2014 (lifecycle 0.49)
Energy subsidies	≈ USD 12 billion/yr (≈ 5% of GDP)	IMF, 2023

Table A.2 — Reference Values for Algeria Used in This Course (Source: compiled from Tables 2.1–2.4 and the sources cited therein; values rounded)

Appendix B – Guidance Answers to Selected Exercises

The answers below are deliberately brief. They indicate the expected reasoning and orders of magnitude; in an examination, students are expected to justify each step and to discuss the assumptions.

Chapter 1, Exercise 3 — Gas exports in other units

55 bcm × 36 PJ/bcm ≈ 1,980 PJ ≈ **2.0 EJ**; 55 × 0.9 ≈ **50 Mtoe**; 2.0 EJ × 277.8 TWh/EJ ≈ **550 TWh** of heat — almost seven times Algeria's annual electricity generation.

Chapter 1, Exercise 5 — Solar plant and gas equivalent

E = 1,000 MW × 0.22 × 8,760 h = 1,927 GWh ≈ **1.93 TWh**. Gas needed in a CCGT at 55%: 1.93 × 3.6 / 0.55 = 12.6 PJ, i.e. 12.6 / 36 ≈ **0.35 bcm per year**.

Chapter 2, Exercise 4 — Gas saved, variant

At $\eta = 50\%$, gas per TWh = 3.6 / (0.5 × 36) = 0.20 bcm; 35 TWh → 7.0 bcm. At USD 10/MMBtu, 1 bcm ≈ 35.7 million MMBtu ≈ USD 357 million, so 7.0 bcm ≈ **USD 2.5 billion per year**. The higher efficiency reduces the volume saved, but the higher price compensates: the order of magnitude is robust.

Chapter 2, Exercise 6 — Network losses

Losses fall from 0.13 × 81 = 10.5 TWh to 0.08 × 81 = 6.5 TWh: about **4 TWh saved per year**, equivalent to the output of roughly 2 GW of solar PV, or about 1 bcm of gas.

Chapter 6, Exercise 1 — Permanent PV jobs

13,575 MW × 0.4 jobs/MW ≈ **5,400 permanent O&M jobs**, to be compared with 115,000–165,000 construction job-years.

Chapter 6, Exercise 3 — CSP water use

Wet cooling at about 3,000 L/MWh: 350,000 MWh × 3 m³/MWh ≈ **1.05 million m³ per year**. Dry cooling at about 350 L/MWh: ≈ 0.12 million m³ per year, i.e. almost 90% less, at the cost of a few points of efficiency.

Chapter 7, Exercise 2 — Capital recovery factors

CRF(6%, 25) = 0.0782; CRF(10%, 25) = 0.1102; CRF(12%, 25) = 0.1275. With the full LCOE formula of Worked Example 7.1, the LCOE becomes about 36.7, 48.7 and 55.1 USD/MWh respectively.

Chapter 7, Exercise 4 — Learning curve

With a 25% learning rate, one further doubling reduces the price by 25%: from about 0.15 USD/W to about **0.11 USD/W**. The calculation assumes that the historical relationship continues and ignores raw-material price shocks.

Chapter 7, Exercise 6 — Rooftop PV, variant

Self-consumed 2,800 kWh × 0.06 = USD 168; exported 1,850 kWh × 0.03 = USD 55.5; total ≈ USD 224 per year; simple payback ≈ 2,700 / 224 ≈ **12 years** — viable over a 25-year life but unattractive to most households.

Section 7.7.3 — Wind farm appraisal

(a) E = 100 × 0.35 × 8,760 = **306,600 MWh/yr**. (b) CAPEX = USD 125 million; CRF(9%, 25) = 0.1018; annualised CAPEX = USD 12.73 million; OPEX = USD 3.5 million; LCOE = 16.23×10^6 / 306,600 ≈ **52.9 USD/MWh**. (c) With constant output, the break-even flat tariff equals the LCOE, ≈ 53 USD/MWh. (d) Debt = USD 87.5 million; annuity at 6.5% over 15 years = USD 9.31 million; CFADS = $306{,}600 \times 52.9 - 3.5 \times 10^6 \approx$ USD 12.7 million; DSCR ≈ **1.37** — bankable, but with limited margin; lenders would test it against a P90 production scenario.

Glossary of Key Terms

Term	Definition
Capacity Factor (CF)	The ratio of actual energy output to the maximum possible output if a plant operated at full capacity continuously. Solar PV: 15–35%; Wind: 25–50%.
CAPEX	Capital Expenditure: the upfront cost of building an RE project (land, equipment, civil works, grid connection).
Capital Recovery Factor (CRF)	Factor that converts an initial investment into an equivalent constant annual payment over n years at discount rate r: CRF = r / [1 − (1 + r)^(−n)].
Carbon Budget	The total amount of CO_2 that can be emitted globally while still limiting warming to a specific temperature target (e.g., 1.5°C).
Carbon Credits / Offsets	Certificates representing one tonne of CO_2 equivalent avoided or removed from the atmosphere; can be sold on voluntary or compliance carbon markets.
CBAM	Carbon Border Adjustment Mechanism: EU instrument requiring importers of carbon-intensive goods (steel, aluminium, cement, fertilisers, hydrogen, electricity) to pay for embedded emissions.
CCGT	Combined Cycle Gas Turbine: a highly efficient gas power plant using both gas and steam turbines.
CDER	Centre de Développement des Energies Renouvelables: Algeria's national RE research centre, based in Algiers.
CDM	Clean Development Mechanism: Kyoto Protocol instrument allowing developed countries to fund RE/efficiency projects in developing countries and claim carbon credits.
COD	Commercial Operation Date: the date on which a project begins commercial electricity production.
CREG	Commission de Régulation de l'Electricité et du Gaz: Algeria's energy sector regulator.
Critical Minerals	Minerals essential to clean-energy technologies (lithium, cobalt, nickel, rare earths, copper, graphite) whose supply is geographically concentrated.

Term	Definition
CSP	Concentrated Solar Power: uses mirrors or lenses to concentrate sunlight, generating heat that drives a turbine. Unlike PV, CSP can include thermal storage.
DSCR	Debt Service Coverage Ratio: cash flow available to service debt divided by total debt service. Lenders typically require DSCR ≥ 1.25.
Duck Curve	Shape of the net load in a power system with high solar penetration: low at midday, rising steeply in the evening.
EJ	Exajoule: 10^18 joules. A unit of energy. 1 EJ ≈ 278 TWh of electricity.
EPC	Engineering, Procurement and Construction: a type of contract where one company designs, procures equipment for, and builds the project at a fixed price.
ETS	Emissions Trading System: a market mechanism where entities must hold permits for each tonne of CO_2 they emit; permits can be bought and sold.
FIT	Feed-in Tariff: a guaranteed above-market price paid to RE generators for electricity supplied to the grid.
Green Bond	A debt instrument (bond) whose proceeds are exclusively used to finance green or climate-related projects.
Green Hydrogen	Hydrogen produced by electrolysis of water using renewable electricity. Has near-zero lifecycle GHG emissions.
GW / GWh	Gigawatt (power) / Gigawatt-hour (energy). 1 GW = 1,000 MW = 1,000,000 kW.
IPP	Independent Power Producer: a private company that owns and operates electricity generating plants.
IRENA	International Renewable Energy Agency: intergovernmental organisation (Abu Dhabi, 2009) promoting worldwide adoption of RE.
IRR	Internal Rate of Return: the discount rate that makes the Net Present Value (NPV) of a project equal to zero.
Just Transition	Principle that the costs and benefits of moving away from fossil fuels should be shared fairly, protecting affected workers and communities.

Term	Definition
LCOE	Levelized Cost of Energy: the lifetime average cost of generating one unit of electricity (USD/MWh), accounting for all costs and discounted to present value.
Learning Rate	Percentage reduction in unit cost of a technology for each doubling of its cumulative production (Wright's law).
MW / MWh	Megawatt (power) / Megawatt-hour (energy). 1 MW = 1,000 kW; 1 MWh = 1 MW delivered for 1 hour.
NDC	Nationally Determined Contribution: each country's climate action plan submitted to the UNFCCC under the Paris Agreement.
Net Load	Electricity demand minus variable renewable generation; the load that must be met by dispatchable plants or storage.
Net Metering	A billing mechanism allowing RE self-generators to feed excess electricity to the grid and receive a credit against their electricity bill.
NPV	Net Present Value: the present value of all future cash flows of a project, minus the initial investment.
OPEX	Operating Expenditure: the ongoing costs of running an RE project (maintenance, insurance, land lease, salaries).
P50 / P90	Energy yield probability estimates: P50 = 50% probability of exceeding this energy output; P90 = 90% probability (conservative estimate).
PNREE	Programme National des Energies Renouvelables et de l'Efficacité Energétique: Algeria's national RE and energy efficiency programme targeting 22 GW by 2030.
PPA	Power Purchase Agreement: a long-term contract between an RE generator and an off-taker (utility or corporate) specifying the price and volume of electricity to be sold.
REIPPPP	South Africa's Renewable Energy Independent Power Producer Procurement Programme: a competitive auction programme that has procured over 6 GW of RE since 2011.
RPS	Renewable Portfolio Standard: a regulation requiring utilities to source a defined percentage of their electricity from renewable sources.

Term	Definition
Sonatrach	Société Nationale pour la Recherche, la Production, le Transport, la Transformation et la Commercialisation des Hydrocarbures: Algeria's state-owned oil and gas company.
Sonelgaz	Société Nationale de l'Electricité et du Gaz: Algeria's state electricity utility, responsible for generation, transmission, and distribution.
Special Purpose Vehicle (SPV)	Company created solely to own and operate a project, so that lenders have recourse only to the project's assets and cash flows.
Stranded Assets	Investments that lose their economic value before the end of their expected life, e.g. fossil reserves made unburnable by climate policy.
TES	Thermal Energy Storage: molten salt tanks used in CSP plants to store heat and generate electricity after sunset.
TWh	Terawatt-hour: 10^12 watt-hours. 1 TWh = 1,000 GWh. Algeria generates approximately 81 TWh of electricity per year.
Unbundling	Separation of the generation, transmission, system operation and distribution functions of an electricity utility into distinct entities.
WACC	Weighted Average Cost of Capital: the average rate of return required by all investors (debt and equity) in a project or company.

Bibliography & Further Reading

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