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DEPARTMENT OF ENERGY

ABU DHABI ENERGY OUTLOOK 2050

REPORT (REVISION 1)
JULY 2023

REFLECTIONS ON ABU DHABI PATHWAYS TO NETZERO

Executive Summary

Introduction: The Abu Dhabi Department of Energy (DoE) has prepared the Abu Dhabi Energy Outlook 2050 (Outlook) following extensive consultation with **~15** relevant Emirate's stakeholders. **This Outlook should be seen as an enlightening document,** demonstrating a wide range of interventions that can be considered by decision makers to achieve the national NetZero target by 2050, **without providing prescriptive measures**. This report is also an **attempt to suggest what Abu Dhabi's transport, buildings, industry and power sectors might look like** under more ambitious policies aimed at achieving NetZero targets.

The Outlook covers all energy carriers and demand elements within the Emirate of Abu Dhabi, together with projections and assumptions around the policy intervention on the same as per the scenarios modelled in the **Integrated Energy Model (IEM)**, also known as **Energy Cube**.

Scenarios: Three **different but comparable scenarios** form the basis of the Outlook. One takes a ***business-as-usual*** **approach** while the other **two are geared towards achieving NetZero targets** by 2050. However, each scenario is influenced by two primary factors: **level of policy ambition** and **technology evolution assumptions**.

Energy Outlook scenarios' policy assumptions:

Scenarios	Scenario description	Main assumptions
1 Current Policies	1.1 Future **policy** fixed at what is **committed and approved currently**[1] 1.2 Gradual **improvement for mature technologies** 1.3 **Limited**/no take-up of **emerging technologies**/trends	**Power:** Moderate uptake of renewables **Industry:** NG[2] will be used for heating without CCUS technologies **Transport:** Economics define powertrain mix **Buildings:** Planned DSM[3] initiatives
2 NetZero NetZero by 2050	2.1 Introduction of **ambitious policies** to achieve NetZero targets by 2050, keeping in mind the **economic diversification agenda** 2.2 **Moderate level of technological development**, allowing for limited electrification, fuel switching and introduction of renewable energy sources 2.3 **Accelerated use of abatement technologies** to reduce emissions	**Power:** Significant use of NG with CCUS[4] **Industry:** Electrification, fuel switching, extensive use of CCUS technologies **Transport:** Electrification and fuel switching **Buildings:** Planned DSM initiatives
3 Technological Shift Paradigm NetZero by 2050	3.1 Introduction of **highly ambitious policies** to achieve NetZero targets by 2050 3.2 **Accelerated level of technological development**, allowing for greater electrification and fuel switching, aggressive deployment of renewable energy 3.3 **Moderate use of abatement technologies** to reduce emissions	**Power:** Aggressive uptake of RE[5] and nuclear **Industry:** Electrification, fuel switching, moderate use of CCUS technologies **Transport:** Electrification and fuel switching **Buildings:** Broader energy effic.[6] efforts

Note: 1) Scenario is based on current and under development policies as of 2022; 2) NG – Natural gas; 3) DSM – Demand-side management; 4) CCUS – Carbon capture utilization and storage; 5) RE– Renewable energy; 6) effic. – Efficiency
Source: Abu Dhabi Integrated Energy Model, Department of Energy - Abu Dhabi, 2022

Policies: Abu Dhabi has so far deployed **regulations/policies to accelerate the UAE's decarbonization**, such as "*Regulatory Policy for Clean Energy Certificates*", "*Public Policy on Low-Carbon Hydrogen*" (draft), "*Policy for Energy Production from Waste*", "*Regulatory Policy for Electric Vehicle Charging Infrastructure*", "*Clean Energy Strategic Target 2035 for Electricity Production in Abu Dhabi*", "*Abu Dhabi Demand-side Management (DSM) & Energy Rationalization Strategy 2030*" and others.

Nevertheless, **more ambitious energy policies will be required to achieve NetZero targets**. The Outlook proposes several potential Abu Dhabi policies to encourage and support decarbonization, such as **clean fuels vehicles deployment** policy for the transportation sector, **energy efficiency and electrification** policies for the buildings sector, **fuel switching** policy for the industrial sector, and **clean energy targets 2050** for the power sector.

The overarching goal of the policy framework developed by the DoE is to provide a **comprehensive, but not prescriptive direction** for how the NetZero objectives can be achieved. This framework is a **flexible and adaptable approach** and will need to be reviewed and adjusted as progress is made towards NetZero goals.

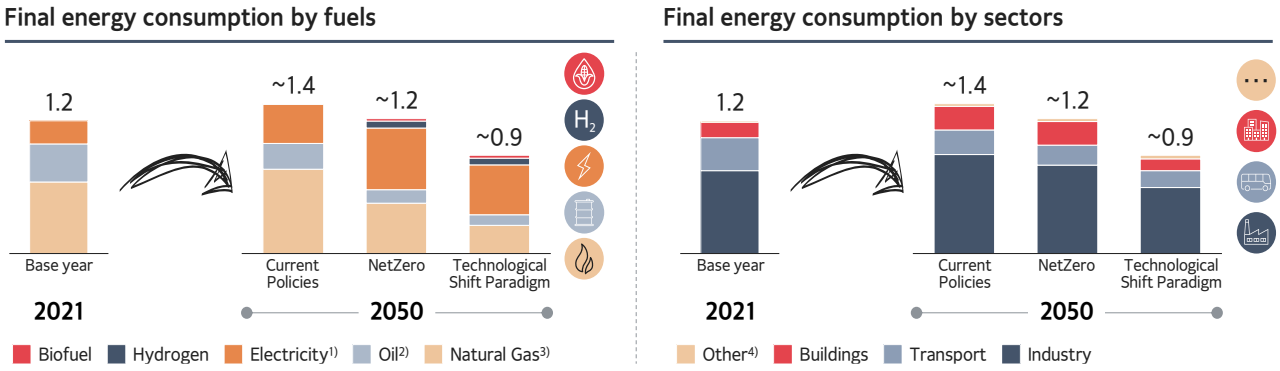
Outlook results: For modeling purposes, different **policy assumptions** and **levels of ambition** were adopted to trace what Abu Dhabi's sectors might look like in 2050. NetZero and Technology Shift Paradigm scenarios assume **gradual decarbonization of the demand and power sectors** to achieve NetZero targets by 2050. This could be done through **electrification, clean fuels** (e.g., hydrogen and biofuels), and **carbon capture, utilization and storage** (**CCUS**) technologies.

Changes in CO2 emissions by sector [% to 2021][1]:

	Power			Industry[2]			Transport			Buildings		
	2030	2040	2050	2030	2040	2050	2030	2040	2050	2030	2040	2050
Current Policies	-38%	-57%	-48%	-5%	-2%	2%	-29%	-53%	-70%	28%	33%	43%
NetZero	-41%	-95%	-100%	-16%	-64%	-100%	-30%	-71%	-100%	27%	-22%	-100%
Technological Shift Paradigm	-38%	-95%	-100%	-18%	-76%	-100%	-30%	-81%	-100%	20%	-52%	-100%

Note: 1) Based on the current design of the scenarios and modelled policy assumptions (subject to change based on the specific targets agreed in the policy elements); 2) Oil & gas sector is a part of industry
Source: Abu Dhabi Integrated Energy Model, Department of Energy – Abu Dhabi, 2022

Abu Dhabi final energy consumption [EJ]:



Note: 1) Includes all types of electricity generation, such as natural gas, solar PV, nuclear power and waste-to-energy; 2) Oil and petroleum products; 3) Excludes natural gas used for power generation; 4) Other includes district cooling and water treatment
Source: Abu Dhabi Integrated Energy Model, Department of Energy - Abu Dhabi, 2022

Sector analysis: Under the NetZero future, all demand sectors will **shift from being reliant on fossil fuel to a more diverse supply-side mix**.

Transportation: Gradual reduction of emissions from road transport will occur through the **increased use of clean-powered vehicles**, as well as a **shift to public transport**.

Buildings: New policies are expected to ensure that by 2050, the proportion of **liquefied petroleum gas** and **natural gas** used in buildings **will not exceed 1%** of the fuel mix.

Industry: **Electrification, energy efficiency** improvement, **CCUS technologies** and switching to **hydrogen** will play an important role in decarbonizing the industrial sector.

Power: The sector is expected to reduce emissions through the use of **renewable** energy, **nuclear power** and **natural gas with CCUS** technologies.

NetZero vision for transportation, buildings, industry and power sectors:

Source: Department of Energy - Abu Dhabi, 2022

Way forward: Further **cooperation with government entities and ministries** at the Emirate and national level is envisioned through performing and defining the position around individual policy targets to reach Emirate's NetZero goals. Setting the **Emirate's policy targets** can be done after performing detailed impact assessments and target setting efforts to ensure developing specific policies and regulations, as well as to facilitate discussions with the stakeholders.

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1. Purpose and Limitations

The Abu Dhabi Department of Energy (DoE) has prepared the Abu Dhabi Energy Outlook 2050 (Outlook) following extensive consultation with the relevant Emirate's stakeholders. **This Outlook should be seen as an enlightening document,** demonstrating a wide range of interventions that can be considered by decision makers to achieve the national NetZero target by 2050, **without providing any prescriptive measures**. This report is also an **attempt to suggest what Abu Dhabi's transport, buildings, industry and power sectors might look like** under more ambitious policies aimed at achieving NetZero targets.

The Outlook examines **three different pathways** for the Emirate's energy system by 2050, two of which consider the achievement of NetZero targets with different assumptions around the policy interventions and technology adoption. The pathways explored in this report are **not predictions –** the future is far too uncertain for that. Rather they consist of an educated simulation of hypothetical scenarios based on techno-economic and policy assumptions targeting Abu Dhabi's entire energy system, technology roadmap and investment opportunities that could result from pursing Abu Dhabi's NetZero goals.

Therefore, the findings of this document can only be considered as **guidance for decision makers, think tanks,** and anyone interested in energy and climate issues in the Emirate to consider meaningful long-term policies in support of Abu Dhabi's NetZero roadmap, as well as for consumers **to understand the implications** of different scenarios for future investment/consumption decisions.

This Outlook covers the major energy sectors of Abu Dhabi: transportation, buildings, industry and power[1]. **Water sector is not the focus** of this report and is considered in the broad sense. It will be detailed out separately in the Abu Dhabi Water Outlook 2050 works planned in near future. However, major aspects of the water system are covered from the supply side and demand side, including the outputs (e.g., water supply system cost) and decarbonization of the water system through deployment of efficient supply system and demand side management measures.

The Outlook should be considered subject to specific **modeling constraints**. Only energy-related emissions are considered in this version of the Abu Dhabi Integrated Energy Model (IEM). The emission impacts of the **agriculture, fishery** and **waste** sectors and the contribution of nature-based solutions such as **mangroves and wetlands** have not been explicitly modeled. On the same note, only **local aviation, maritime and road transport** activities were considered to estimate transport sector emissions.

The report provides information on IEM results up to 2050. These **results are estimates** and the reality may be different based on many factors: energy demand, technological development, fuel costs, market trends and others.

In order to maintain the quality and accuracy of this exercise and to continue to adequately inform policymakers, this Energy Outlook will be **periodically updated** to reflect technological changes, market evolution, policy priorities and United Arab Emirates (UAE) national NetZero outcomes, and latest Abu Dhabi's priorities.

[1] See Appendix 3 for details on the sub-sectors

2. Abu Dhabi's Current State of Play

Since the UAE founding in 1971, the Emirate of **Abu Dhabi** has quickly developed into an **industrialized economy** by leveraging its large natural resources. The rapid transformation combined with an arid climate meant that **energy intensity in Abu Dhabi is relatively high** (energy demand per capita in 2021 of ~430 gigajoules (GJ) vs ~170 GJ in the Organization for Economic Cooperation and Development (OECD)[2]).

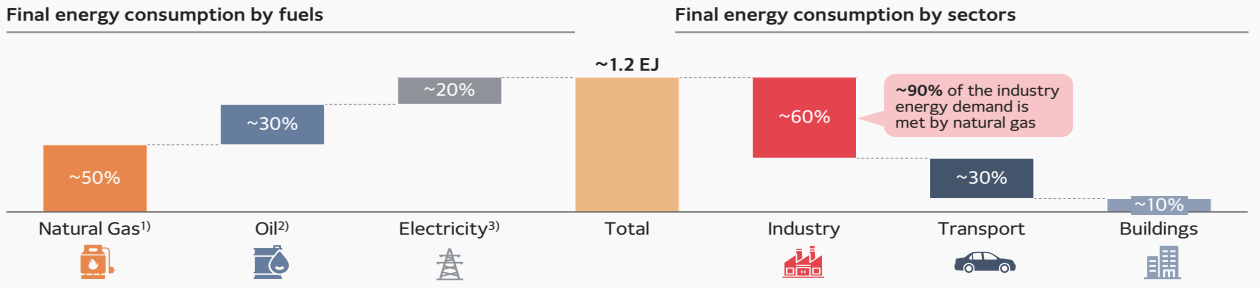
The **industrial sector** accounts for approximately 60%[3] of the total domestic energy demand, with the aluminum and oil & gas sectors representing the bulk of consumption. The **transportation sector** consumes about a third of the Emirate's energy demand, which comes from road transport, aviation and maritime activities. **Residential and non-residential buildings** in Abu Dhabi have a high level of electrification (~95%) and are responsible for only 10% of energy consumption.

During the past decade[4], the **Emirate has diversified its power generation mix** by developing significant clean energy facilities, including 5.6 gigawatt (GW) nuclear and ~3.4 GW solar, **which together today comprise over 30%**[5] of the total electricity generation capacity in Abu Dhabi**.** In November 2022, the DoE unveiled the "***Clean Energy Strategic Target 2035*** *for Electricity Production in Abu Dhabi*" regulatory framework, which is the first **legally binding** clean and renewable energy target in the Middle East for the electricity sector. Once realized, the framework will see **60%** of Abu Dhabi's power being generated from clean and renewable energy sources by 2035 and up to **75%**[6] reduction in the power sector's carbon emissions intensity (tons of carbon dioxide (CO_2) emitted per megawatt hour (MWh) produced).

Abu Dhabi has so far deployed **regulations/policies to accelerate the UAE's decarbonization**, such as "*Regulatory Policy for Clean Energy Certificates*", "*Public Policy on Low-Carbon Hydrogen*", "*Policy for Energy Production from Waste*", "*Regulatory Policy for Electric Vehicle Charging Infrastructure*", "*Energy Efficiency Policy for DoE offices*", "*Water Management in District Cooling Plants Policy"*, "*Recycled Water Policy*", and "*Demand Side Management and Energy Rationalization Strategy*".

In 2023, the **UAE will host the United Nations Climate Change Conference of the Parties (COP 28**). During the UAE's presidency, the DoE will work closely with local, federal and global stakeholders to drive global efforts towards a cleaner future.

Figure 1: Abu Dhabi final energy consumption in 2021 [EJ]



Note: 1) Excludes natural gas used for power generation; 2) Oil and petroleum products; 3) Includes all types of electricity generation, such as natural gas, solar PV, nuclear power and waste-to-energy

Source: Abu Dhabi Integrated Energy Model, Department of Energy - Abu Dhabi, 2022

[2] Source of OECD data is "bp Statistical Review of World Energy 2022"

[3] Non-oil industrial sectors represent ~35% of total domestic energy demand

[4] The period from 2012 to 2022 is considered

[5] Includes the total capacity of Barakah Nuclear Plant and Al Dhafra PV Plant

[6] Compared to 2016 levels

3. NetZero Commitment

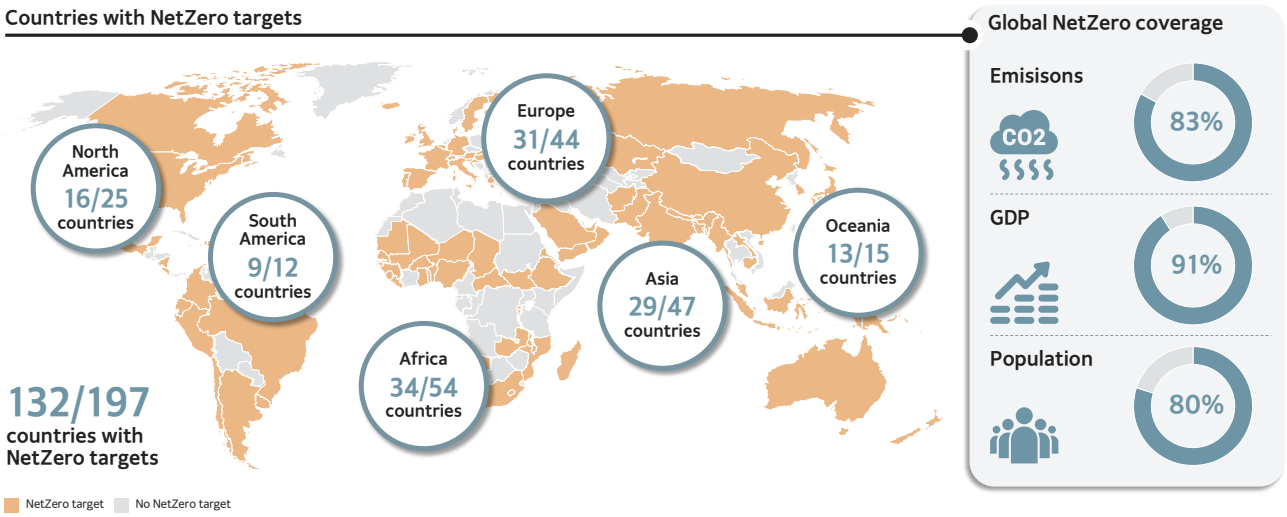
Achieving NetZero emissions is crucial in combating climate change and safeguarding the prosperity and wellbeing of future generations. In the last few years, interest in setting NetZero targets has increased exponentially. **In 2019, national NetZero pledges covered almost 16% of the global gross domestic product (GDP)**. Fast forward to 2022, NetZero coverage has increased sixfold to **encompass over 90% of the global economy**.

In October 2021, the **UAE became the first country in the Middle East and North Africa (MENA) region** to announce a national NetZero initiative **("NetZero by 2050 strategic initiative").** Furthermore, during COP 27, the UAE launched the **National NetZero by 2050 Pathway**, which defines the country's climate ambition with an emission reduction target of 100% by 2050, compared to 2019. The **UAE Governments Net Zero 2050 Charter** was signed in March 2023 by the governments of the seven emirates, which affirmed their commitment to contribute to achieving the national NetZero targets by 2050.

Abu Dhabi, which is the largest emirate in the federation (~60% of the country's energy consumption), will play a **leading role** in the UAE's transition to NetZero.

Attaining the NetZero status means that Abu Dhabi will balance the amount of greenhouse gas emissions it releases with the amount it removes, rather than allowing a persistent accumulation of these emissions in the atmosphere and exacerbating the effects of climate change. In essence, the energy system of the Emirate will **transition towards low and emission-free technologies**, and any residual emissions will be neutralized by other means, such as the process of atmospheric removal and permanent storage.

Figure 2: Global NetZero commitments by 2022



Source: NetZero Tracker[7], 2022

[7] NetZero Tracker is a collaboration between four organizations: Oxford Net Zero, Energy and Climate Intelligence Unit, Data-Driven EnviroLab and NewClimate Institute

4. Introduction to Abu Dhabi's NetZero Outlook

Achieving **NetZero** emissions in Abu Dhabi by 2050 is undoubtedly an **ambitious goal**. It will require implementing policies well beyond anything seen to date in the Emirate (and globally). It will also require navigating significant complexity and uncertainty.

In March 2023, the **UAE Governments Net Zero 2050 Charter** was signed by all seven emirates, including the Emirate of Abu Dhabi. Through signing the charter, the governments of the seven emirates affirmed their commitment to contribute to achieving national NetZero targets by 2050.

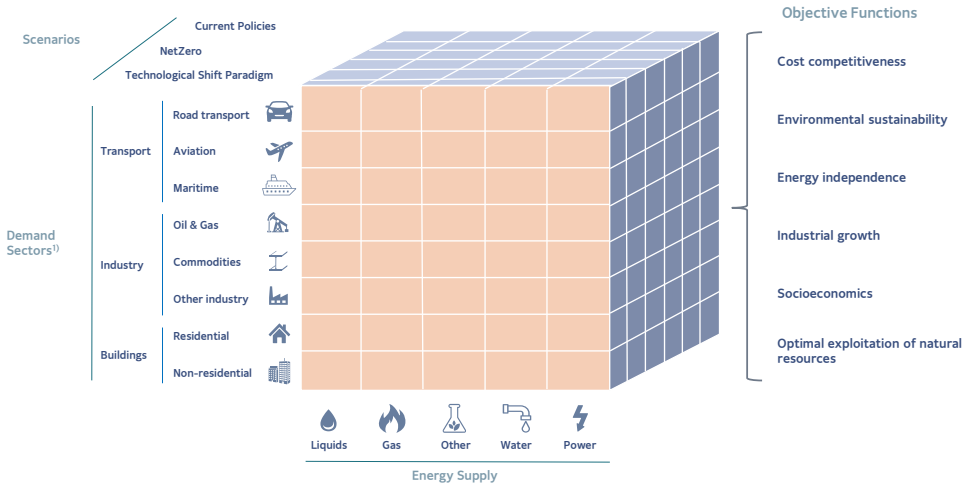
Accordingly, the DoE, being the energy sector regulator and policymaker, launches in 2023 the Abu Dhabi Energy Outlook 2050 report. It **explores how different policy scenarios can drive the achievement of our common goal for energy transition: NetZero**. The Outlook covers all energy carriers and demand elements within the Emirate of Abu Dhabi, together with projections and assumptions around the policy intervention on the same as per the scenarios modelled in the **IEM**, also known as **Energy Cube** (Figure 3).

The document intends to provide **vision** on the choices Abu Dhabi faces regarding energy use and its socioeconomic and environmental impacts **to national and federal public entities,** including policymakers and regulators, and **private businesses,** mainly energy companies (utilities, oil & gas and other), industrial players and financial investors.

The IEM was developed in 2019 by the DoE through extensive engagement with Abu Dhabi's energy stakeholders and evolved ever since with multiple capabilities and enhancements. It consists of **five distinctive modules** namely gas, liquids, power and water, demand, and output module[8], with a time horizon up to 2050.

For the purpose of this report, **NetZero pathways** are defined as credible, internally **consistent routes between current conditions and the future state**. The scenarios explored in this report are **not predictions or forecasts** - the future is far too uncertain for that. Rather they represent a comprehensive examination of a **range of potential outcomes, opportunities and trade-offs** that may arise from pursing Abu Dhabi's NetZero goals.

Figure 3: Energy Cube



Note: 1) See Appendix 3 for details on the sub-sectors

Source: Abu Dhabi Integrated Energy Model, Department of Energy - Abu Dhabi, 2022

[8] Output module includes socioeconomic module

5. Overview of Abu Dhabi's Energy Outlook Scenarios

Three **different but comparable scenarios** form the basis of the Outlook. One takes a ***business-as-usual*** **approach while the other two are geared toward achieving NetZero targets** by 2050. However, each scenario is largely influenced by two primary factors: level of ambition and technology evolution assumptions. These factors have a significant effect on sectorial transformation and socioeconomic implications.

The outlook for each approach depends on the collective impact of policy choices across six different key areas: **cost competitiveness, environmental sustainability, energy independence, industrial growth, optimal exploitation of natural resources and socioeconomic impacts**.

The three different scenarios are: **Current Policies**, **NetZero** and **Technological Shift Paradigm**. Rather than recommending any specific scenario, this report analyzes **available decarbonization options**. A unique set of policy assumptions regarding Abu Dhabi's energy system underpins each approach, as summarized in Figure 4.

Figure 4: Energy Outlook scenarios' policy assumptions

Scenarios	Scenario description	Main assumptions
1 Current Policies	1.1 Future **policy** fixed at what is **committed and approved currently**[1)] 1.2 Gradual **improvement for mature technologies** 1.3 **Limited**/no take-up of **emerging technologies**/trends	**Power:** Moderate uptake of renewables **Industry:** NG[2)] will be used for heating without CCUS technologies **Transport:** Economics define powertrain mix **Buildings:** Planned DSM[3)] initiatives
2 NetZero NetZero by 2050	2.1 Introduction of **ambitious policies** to achieve NetZero targets by 2050, keeping in mind the **economic diversification agenda** 2.2 **Moderate level of technological development**, allowing for limited electrification, fuel switching and introduction of renewable energy sources 2.3 **Accelerated use of abatement technologies** to reduce emissions	**Power:** Significant use of NG with CCUS[4)] **Industry:** Electrification, fuel switching, extensive use of CCUS technologies **Transport:** Electrification and fuel switching **Buildings:** Planned DSM initiatives
3 Technological Shift Paradigm NetZero by 2050	3.1 Introduction of **highly ambitious policies** to achieve NetZero targets by 2050 3.2 **Accelerated level of technological development**, allowing for greater electrification and fuel switching, aggressive deployment of renewable energy 3.3 **Moderate use of abatement technologies** to reduce emissions	**Power:** Aggressive uptake of RE[5)] and nuclear **Industry:** Electrification, fuel switching, moderate use of CCUS technologies **Transport:** Electrification and fuel switching **Buildings:** Broader energy effic.[6)] efforts

Note: 1) Scenario is based on current and under development policies as of 2022; 2) NG – Natural gas; 3) DSM – Demand-side management; 4) CCUS – Carbon capture utilization and storage; 5) RE– Renewable energy; 6) effic. – Efficiency
Source: Abu Dhabi Integrated Energy Model, Department of Energy - Abu Dhabi, 2022

1. The **Current Policies scenario** captures Abu Dhabi's current trajectory based on committed Government plans and policies. Under the Current Policies scenario, Abu Dhabi deploys decarbonization technologies following a **least-cost approach** allowing for a natural transition towards a cleaner energy system **without fully addressing the gap to reach the NetZero targets by 2050**.

However, the topic of climate change is important for the UAE and the Emirate of Abu Dhabi, which has already put a lot of effort into the energy transition by developing relevant policies and analytical tools. This work will be continued to achieve the NetZero targets by 2050. The NetZero and Technology Shift Paradigm scenarios represent potential ways to achieve this goal.

2. **NetZero is an energy transition scenario that** envisions the Emirate introducing **more ambitious measures and policies** than the Current Policies scenario to achieve NetZero emissions by 2050. These policy decisions are based on **tradeoffs** between Abu Dhabi's **sustainable development goals** and **economic diversification agenda**. Moderate level of technology development is

assumed under the NetZero scenario leading to the limited fuel switching and electrification initiatives.

3. The **Technological Shift Paradigm scenario** will require even **more ambitious policies** to encourage the decarbonization of the Emirate and achieve NetZero targets. However, compared to the NetZero scenario, a **higher level of technological development** is expected, allowing for greater electrification, fuel switching, aggressive deployment of renewable energy, and expanded energy efficiency reforms, leading to a complete overhaul of Abu Dhabi's energy system (including economy).

6. Policy Framework to Achieve NetZero

6.1. Current policies

Since its establishment, the DoE has recognized that energy is central to economic growth and social development. **Sustainability and environmental protection** are considered by the DoE as key objectives while ensuring **reliable and safe energy supply**. In light of these goals, the DoE has outlined its policy development process in three phases (short, medium, long term). Since 2019, the **IEM** has been used as a tool to assess the impact of policy measures.

Recent DoE's policy production covers key areas, like **electric vehicle charging infrastructure** for the transportation sector, **district cooling** regulation for the building sector and **captive generation**[9] for the industrial sector (Table 1). In the power sector, two policies have recently been developed to ensure transition to cleaner sources: "***Clean Energy Strategic Target 2035***" and "***Policy for Energy Production from Waste***".

In addition, the DoE has several policies that span multiple sectors, such as "***Demand Side Management and Energy Rationalization Strategy***", "***Public Policy on Low-Carbon Hydrogen***" and "***Regulatory Policy for Clean Energy Certificates***". These policies are a solid starting point for future fuel transition, energy efficiency and electrification initiatives.

Table 1: Abu Dhabi's policies and regulations supporting decarbonization (Current and under development as of 2022)

Sector	Policies and Regulations	Purpose	Owner
1. Transport	**1.1 Regulatory Policy for Electric Vehicle Charging Infrastructure**[1)]	Sets out fundamental principles for ownership, installation and management of EVSE[2)], the electricity supply to EVSE and pricing mechanism to end customers	Abu Dhabi Department of Energy
	1.2 ITC Livability Transport KPIs[3)]	Encourages shift to increased use of public transport over private cars and taxi **8.4%** - Public transport mode share in 2030 **14.4%** - Public transport mode share in 2040	Integrated Transport Centre
	1.3 Abu Dhabi Transportation Mobility Management Strategy	Encourages a change of attitude and behavior towards greater use of sustainable modes of transport	Department of Municipalities and Transport
	1.4 Surface Transport Master Plan	Presents measures to deliver a world class, sustainable transport system that supports Abu Dhabi's economic, social and cultural and environmental goals	Department of Municipalities and Transport
	1.5 Low Emission Vehicle Policy	Encourages the use of low emission vehicles in the Emirate	Department of Municipalities and Transport
2. Buildings	**2.1 District Cooling Applicability Regulation**	Intends to optimize energy infrastructure and encourages the adoption of more efficient cooling systems in areas where it is feasible. Specifically, it intends to increase the penetration of DC[4)] in the Emirate	Abu Dhabi Department of Energy

[9] Regulatory framework under development

	2.2 Energy and Water Efficiency Policy for Government Buildings	Presents a commitment to embedding a culture of energy and water efficiency within the government buildings in the Emirate of Abu Dhabi	Abu Dhabi Department of Energy
	2.3 Water Management in District Cooling Plants	Regulates the mechanism of identifying potential sources of water that can be used by district cooling providers	Abu Dhabi Department of Energy
3. Industry	**3.1 Policy Framework for licensing and regulating Captive Generation**	Clarifies criteria for setting up captive generation, such as ownership, fuel type, cost to the consumer for grid support, compensation for grid support by the consumer, etc.	Abu Dhabi Department of Energy
	3.2 Abu Dhabi Industrial Strategy 2031	Presents Abu Dhabi's industrial strategy by 2031, which is underpinned by six transformational programs that drive growth and innovation, boost skills, strengthen the ecosystem for local manufacturers, and advance the transition to a circular economy	Abu Dhabi Department of Economic Development
	3.3 Energy Tariff Incentive Program	Supports the private industrial sector by offering preferential gas and electricity rates, one of the aims of which is to improve energy efficiency in the Emirate of Abu Dhabi	Industrial Development Bureau
	3.4 Industrial Sustainability Program	Implements sustainability guidelines and practices in the Abu Dhabi industrial sector	Industrial Development Bureau
	3.5 Regulatory Mechanism for Implementing Circular Economy	Envisages appropriate laws and policies to kick-start and institutionalize the Circular Economy Program in the Emirate of Abu Dhabi	Industrial Development Bureau
	3.6 Green Products Procurement and Manufacturing	Encourages the production and procurement of green products, ensures market competitiveness through incentives and price privileges	Industrial Development Bureau
4. Power	**4.1 Clean Energy Strategic Target 2035**	Adapts the Emirate's regulatory framework to enable Abu Dhabi to meet the UAE's decarbonization goal **60%** - Share of electricity production to be generated from clean sources by 2035	Abu Dhabi Department of Energy
	4.2 Energy Production from Waste (EFW)	Sets out the principles for the allocation mechanism for Energy Production from Waste cost recovery	Abu Dhabi Department of Energy
5. Water	**5.1 Water Tankering Policy**	Sets out the regulatory principles for drinking water, non-drinking water and wastewater services through tankers	Abu Dhabi Department of Energy
	5.2 Recycled Water Policy	Facilitates the maximum utilization of recycled water in the Emirate of Abu Dhabi	Abu Dhabi Department of Energy
	5.3 Abu Dhabi Ground Water Policy	Ensures the sustainability of usable groundwater resources	Several owners[5)]

6. Cross-cutting[6]	**6.1 Abu Dhabi Demand-side Management (DSM) & Energy Rationalization Strategy 2030**[7]	Intends to slow the growth of energy consumption and balance supply and demand **22%** - Reduction of electricity consumption by 2030[8] **32%** - Reduction of water consumption by 2030[8]	Abu Dhabi Department of Energy
	6.2 Regulatory Policy for Clean Energy Certificates	Sets out implementation regulations for developing a clean energy certificate scheme in the Emirate	Abu Dhabi Department of Energy
	6.3 Abu Dhabi Low-Carbon Hydrogen draft public consultation of policy	Adopts a clear and robust framework to enable a low-carbon hydrogen economy in Abu Dhabi	Abu Dhabi Department of Energy
	6.4 Thermal Energy Storage	Promotes the expansion of DC plants with thermal energy storage	Abu Dhabi Department of Energy
	6.5 Abu Dhabi Climate Change Strategy	Promotes greater resilience in key sectors and makes adaptation to climate change part and parcel of government entities' plans	Environment Agency – Abu Dhabi

Note: 1) Policy focuses on infrastructure for transportation sector with related initiatives for the power sector; 2) Electric Vehicle Supply Equipment; 3) Key Performance Indicator; 4) DC – District Cooling; 5) Abu Dhabi Department of Energy, Environment Agency – Abu Dhabi, Abu Dhabi Agriculture and Food Safety Authority; 6) Policies that cover more than one sector; 7) Strategy includes 9 programs (building regulations, standards & labels, demand response, street lighting, building retrofits, rebates & behavioral change, efficient water use / reuse, district cooling, energy storage); 8) Against 2013

Source: Department of Energy - Abu Dhabi, 2022

6.2. Future policies

The overarching goal of the policy framework developed by the DoE is to provide **a view on the regulatory development necessary to achieve the NetZero** targets discussed in this report. It is important to note that this framework is by definition a flexible and adaptable approach and will need **to be reviewed and adjusted as progress is made towards NetZero goals**. Nonetheless, it provides a **comprehensive, but not prescriptive direction for how the NetZero objectives can be achieved**.

6.2.1 Transportation

Three policies are expected to contribute to NetZero targets in the Emirate's transportation sector: clean fuels vehicles deployment policy, public transit policy, and clean fuel policy for maritime and aviation (Table 2).

Table 2: Abu Dhabi's potential policies for NetZero (Transportation sector)

Policies and Regulations	Description
Clean fuels vehicles deployment policy support	Promotes the use of **electric and hydrogen vehicles** through **economic & fiscal incentives and mandates** (e.g., ban on sale of vehicles with internal combustion engine from 2040 or requirements to purchase clean fuel vehicles for public fleets)
Public transit policy	Supports the development of public transport **infrastructure** (e.g., rail infrastructure, transportation control system), as well as **incentives for the use of public transport** (including improved inter-modality and economic incentives)
Clean fuel policy for maritime and aviation	Enables clean market development for aviation and maritime sectors (including **biofuels, hydrogen-based fuels, and electrification**)

Source: Department of Energy - Abu Dhabi, 2022

Clean fuels vehicles deployment policy is expected together with a broad set of measures that support the development of clean vehicles in the Emirate, including electric and hydrogen-powered passenger cars, light-duty vehicles, buses and trucks. These measures may include infrastructure, economic and tax incentives, and restrictions on the sale of conventional vehicles. With this policy, the share of clean vehicles in the total fleet could exceed 55% by 2050.

The shift of passenger and freight traffic to public transport will be supported by various policies and plans (including **public transit policy)** and will have a significant impact on the average distance travelled by road transport, which is expected to decrease by 36-44% from 2021 to 2050. This policy can cover infrastructure development plans (including rail transport) as well as economic measures.

Emissions from international aviation and maritime activities are outside the scope of the Emirate and this Outlook[10]. However, decarbonization of these sectors is crucial to achieve NetZero's global commitments, which will create demand for new fuels as well as new types of aircraft and ships. A **clean fuel for maritime and aviation** policy is expected to help develop the local market to meet future demand from airlines and shipping companies coming to Abu Dhabi. This will lead to a 17% share of electricity in the fuel mix of maritime transport and a 50% share of biofuels, hydrogen and electricity in the fuel mix of aviation by 2050.

For modeling purposes, different assumptions and levels of ambition were adopted to trace what Abu Dhabi's transportation sector might look like in 2050, covering **key policy elements** such as: powertrain mix diversification, average distance travelled, and use of clean fuel for maritime and aviation (Table 3).

Table 3: Key policy assumptions and ambitions by scenarios (Transportation sector)

Policy elements	**Target:** Current Policies	**Target:** NetZero	**Target:** Technological Shift Paradigm
Powertrain mix diversification	Clean[1)] vehicles share in the total fleet in 2050: **26%**	Clean vehicles share in the total fleet in 2050: **57%**	Clean vehicles share in the total fleet in 2050: **59%**
Average distance travelled per vehicle	Decrease in average distance travelled by **36%** from 2021 to 2050	Decrease in average distance travelled by **36%** from 2021 to 2050	Decrease in average distance travelled by **44%** from 2021 to 2050
Clean fuel for maritime[2)]	Electricity will account for **<1%** of the fuel mix in 2050	Electricity will account for **17%** of the fuel mix in 2050	Electricity will account for **17%** of the fuel mix in 2050
Clean fuel for aviation[2)]	Biofuels, hydrogen, and electricity will account for **<1%** of the fuel mix in 2050	Biofuels, hydrogen, and electricity will account for **50%** of the fuel mix in 2050	Biofuels, hydrogen, and electricity will account for **51%** of the fuel mix in 2050

Note: 1) Including electric and hydrogen light-duty vehicles, buses and trucks; 2) Outlook only considers decarbonization of the local aviation and maritime sectors, which is the reason for the similar target assumptions for the whole sector (international and local) in both NetZero scenarios

Source: Abu Dhabi Integrated Energy Model, Department of Energy - Abu Dhabi, 2022

[10] Only local aviation, maritime and road transport activities were considered to estimate transportation sector emissions

6.2.2 Buildings

Two types of policies are expected to contribute to NetZero targets in the Emirate's buildings sector: energy efficiency and electrification policies, and efficient cooling policy (Table 4).

Table 4: Abu Dhabi's potential policies for NetZero (Buildings sector)

Policies and Regulations	Description
Energy efficiency and electrification policies	Implements broader energy efficiency efforts through **new building standards and retrofit programs** (DSM strategy could be updated with **accelerated timelines and targets**), as well as increasing the level of electrification rates
Efficient cooling policy	Increases penetration of efficient cooling by retrofitting buildings to **district cooling** through mandates and price regulation

Source: Department of Energy – Abu Dhabi, 2022

Energy efficiency improvements in the building sector will be supported by more ambitious **Demand-side management (DSM)** programs focused on the use of new technologies, building retrofits, and consumption rationalization, which could be supported with considerations on tariff reforms for various customer categories. This could lead to a **40-45% improvement in energy efficiency**[11] between 2021 and 2050. This is, in addition to the electrification policies, which will lead to increasing the electrification rates to over 99% of total buildings energy consumption.

Policy promoting **more energy-efficient cooling solutions** is expected in the future which can significantly increase district cooling penetration rate from 11% in 2021 to 30% in 2030.

For modeling purposes, different assumptions and levels of ambition were adopted to trace what Abu Dhabi's buildings sector might look like in 2050, covering **key policy elements** such as: energy efficiency, fuel switching, and district cooling penetration (Table 5).

Table 5: Key policy assumptions and ambitions by scenarios (Buildings sector)

Policy elements	**Target:** Current Policies	**Target:** NetZero	**Target:** Technological Shift Paradigm
Energy efficiency	Energy efficiency improvements in the sector: **~40%** between 2021 and 2050	Energy efficiency improvements in the sector: **~40%** between 2021 and 2050	Energy efficiency improvements in the sector: **~45%** between 2021 and 2050
Fuel switching	LPG[1)] and NG[2)] will account for **5%** of the fuel mix in 2050	LPG and NG will account for **<1%** of the fuel mix in 2050	LPG and NG will account for **<1%** of the fuel mix in 2050
District cooling penetration	District cooling penetration will be maintained at the same level: **11%** in 2050	District cooling penetration will be maintained at the same level: **11%** in 2050	District cooling penetration will be increased: **30%** in 2050

Note: 1) Liquefied petroleum gas; 2) Natural gas
Source: Abu Dhabi Integrated Energy Model, Department of Energy – Abu Dhabi, 2022

[11] Energy efficiency improvement is based on cumulative efficiency gains from several programs targeting various services and energy use in buildings

6.2.3 Industry

Four policies are expected to contribute to NetZero targets in the Emirate's industrial sector: fuel switching policy, energy efficiency policy for industrial processes, industrial power supply policy and industrial development policy (Table 6). In addition, the development of appropriate policies to support the deployment of CCUS technologies in the industrial sector is envisaged (see Section 6.2.6 "Cross-cutting" for more details).

Table 6: Abu Dhabi's potential policies for NetZero (Industrial sector)

Policies and Regulations	Description
Fuel switching policy	Encourages use of **alternative fuels** or **electrification** for industrial assets
Energy efficiency policy for industrial processes	Intends to improve the **energy efficiency of industrial processes** through standards, mandates, DSM programs and offtake agreements (e.g., mandate for clinker reduction in the cement industry, flare reduction in the oil and gas sector)
Industrial power supply policy	Promotes **decarbonization of industrial electricity demand** (e.g., by integrating industrial electricity demand into the grid)
Industrial development policy	**Supports industrial growth through economic and tax incentives**, given the potential increase in production costs with clean fuels and decarbonization technologies

Source: Department of Energy – Abu Dhabi, 2022

Decarbonization of the industrial sector will require the use of cleaner fuels, such as hydrogen, as well as electrification, which can be facilitated by a **fuel switching policy**. Such policy could include mandates that encourage local businesses to switch from fossil fuels, while ensuring the economic stability of their operations through subsidies and other economic initiatives. This policy could aim to significantly change the share of electricity in the industrial sector's fuel mix from 13% in 2021 to 36%-48% in 2050, with hydrogen share of 7-8%.

Energy efficiency improvement could be the first step toward decarbonizing the industrial sector, supported by **energy efficiency policy for industrial processes**. Such policy could include a mandate for clinker reduction in the cement industry, flare reduction in the oil and gas sector, direct reduction of iron ore using scrap in the steel production, and other energy efficiency initiatives. In addition, it may be necessary to target the full integration of industrial electricity demand into the grid through an **industrial power supply policy** (including iron and steel and aluminum industries).

The competitiveness and financial stability of local companies and wider industrial sector should be considered while setting the relevant policies. Responsible government entities can design an **industrial development policy** to support industrial players. Such a policy could ensure that industrial production in Abu Dhabi continues to grow (e.g., up to 22-26 Megaton (Mt) of commodities[12] production by 2050, compared to 16 Mt in 2021).

For modeling purposes, different assumptions and levels of ambition were adopted to trace what Abu Dhabi's industrial sector might look like in 2050, covering **key policy elements** such as: heat fuel switching, energy efficiency and intensity, self-generation mix and industrial development (Table 7).

[12] Commodities include iron and steel, cement and aluminum industries

Table 7: Key policy assumptions and ambitions by scenarios (Industrial sector)

Policy elements	**Target:** Current Policies	**Target:** NetZero	**Target:** Technological Shift Paradigm
Heat fuel switching	Electricity share will increase from 8% in 2021 to **13%** in 2050	Electricity share will increase from 8% in 2021 to **36%** in 2050	Electricity share will increase from 8% in 2021 to **48%** in 2050
Energy intensity[1)]	Decrease in energy intensity by **17%** between 2021 and 2050	Decrease in energy intensity by **54%** between 2021 and 2050	Decrease in energy intensity by **59%** between 2021 and 2050
Self-generation mix	**Constrained** self-generation in aluminum, iron & steel and oil & gas industries	**Full integration** of iron & steel and aluminum electricity demand in the grid[2)]	**Full integration** of iron & steel and aluminum electricity demand in the grid[2)]
Industrial development	Commodities[3)] production growth from 16 Mt in 2021 to **22 Mt** in 2050	Commodities production growth from 16 Mt in 2021 to **26 Mt** in 2050	Commodities production growth from 16 Mt in 2021 to **22 Mt** in 2050

Note: 1) Based on the commodities sector energy consumption per ton of output; 2) Instead of fossil fuel-based cogeneration; 3) Commodities sector includes iron and steel, cement and aluminum industries
Source: Abu Dhabi Integrated Energy Model, Department of Energy - Abu Dhabi, 2022

6.2.4 Power

Three policies are expected to contribute to NetZero targets in the Emirate's power sector: clean energy targets, grid flexibility policy, and electricity market reform policy (Table 8).

Table 8: Abu Dhabi's potential policies for NetZero (Power sector)

Policies and Regulations	Description
Clean energy targets	Defines **clean energy (electricity) target for Abu Dhabi in 2050** and adapts **power sector regulatory framework** to enable the Emirate to meet the UAE's decarbonization target
Grid flexibility policy	Introduces programs to ensure a **stable supply of clean energy** (e.g., development of power and cooling storage systems, grid infrastructure additions, power tariffs methodology update)
Electricity market reform policy	Suggests a **new electricity market structure** to facilitate and foster the energy transition

Source: Department of Energy – Abu Dhabi, 2022

Clean energy targets and electricity market reform policies are expected to be introduced to facilitate the transition to cleaner energy sources such as renewables with battery storage, nuclear power and natural gas with Carbon Capture Utilization and Storage (CCUS). With these policies, the Emirate can target a generation mix of 96-99% to be produced from clean sources with solar photovoltaic (PV) share of 16–29%.

Grid flexibility policy will be a critical document for ensuring a stable energy supply. This policy can include programs covering power and cooling storages, as well as an update to the tariff methodology.

For modeling purposes, different assumptions and levels of ambition were adopted to trace what Abu Dhabi's power sector might look like in 2050, covering **key policy elements** such as: clean energy strategy, solar & storage penetration and nuclear capacity (Table 9).

Table 9: Key policy assumptions and ambitions by scenarios (Power sector)

Policy elements	**Target:** Current Policies	**Target:** NetZero	**Target:** Technological Shift Paradigm
Clean energy strategy	**58%** of electricity produced from clean sources by 2050	**96%**[1)] of electricity produced from clean sources by 2050	**99%**[1)] of electricity produced from clean sources by 2050
Solar & storage penetration	Generate **~26% (41 TWh**[2)]**)** of power through solar technologies in 2050	Generate **~16% (41 TWh)** of power through solar technologies in 2050	Generate **~29% (61 TWh)** of power through solar technologies in 2050
Nuclear capacity[3)]	**No increase** in nuclear capacity (**5.6 GW**[4)] in 2050)	**No increase** in nuclear capacity (**5.6 GW** in 2050)	**~50% increase** in nuclear capacity through SMRs[5)] (**8.3 GW** in 2050)

Note: 1) The remaining 1-4% of electricity is expected to be produced by new clean technologies (e.g., waste-to-energy, additional gas with CCUS technologies, additional renewables, additional nuclear, Direct Air Capture (DAC)); 2) TWh – Terawatt Hour; 3) After the commissioning of all units of Barakah NPP; 4) GW – Gigawatt; 5) Small modular reactors
Source: Abu Dhabi Integrated Energy Model, Department of Energy – Abu Dhabi, 2022

6.2.5 Gas & liquids

Two policies are expected to contribute to NetZero targets in the Emirate's gas and liquids sector: gas supply strategy and gas market pricing strategy (Table 10). These policies will be necessary to promote demand sectors decarbonization while ensuring security of supply.

For modeling purposes, different assumptions and levels of ambition were adopted to trace what Abu Dhabi's gas & liquids sector might look like in 2050 covering **key policy elements** highlighted earlier (Table 11).

Table 10: Abu Dhabi's potential policies for NetZero (Gas & liquids)

Policies and Regulations	Description
Gas supply strategy	Provides a vision for **natural gas supplies beyond 2032**
Gas market pricing policy	Sets a **new pricing framework for natural gas supplies** based on market prices to drive further efficiency gains and electrifications measures

Source: Department of Energy - Abu Dhabi, 2022

Table 11: Key policy assumptions and ambitions by scenarios (Gas & liquids)

Policy elements	**Target:** Current Policies	**Target:** NetZero	**Target:** Technological Shift Paradigm
Gas supply strategy	**0%** of import in natural gas consumption in 2050	**0%** of import in natural gas consumption in 2050	**~57%**[1)] of import in natural gas consumption in 2050
Gas pricing strategy	**Regulated** cost plus pricing[2)] for all consuming sectors	**Regulated** cost plus pricing[2)] for all consuming sectors	**Market**-based pricing for some sectors

Note: 1) Increase of natural gas imports in absolute terms by ~80% compared to 2021; 2) A pricing method in which a fixed percentage is added to the cost required to produce one unit of product
Source: Abu Dhabi Integrated Energy Model, Department of Energy – Abu Dhabi, 2022

6.2.6 Cross-cutting

Four cross-cutting policies are expected to contribute to NetZero targets in Abu Dhabi: demand side management strategy, low-carbon hydrogen policy, carbon market/ pricing policy and carbon capture, utilization and storage policy (Table 12).

Table 12: Abu Dhabi's potential policies for NetZero (Cross-cutting)

Policies and Regulations	Description
Demand side management strategy	Promotes initiatives and technologies that accelerate **energy efficiency improvements across all sectors** with measures that have the greatest energy-saving potential
Low-carbon hydrogen policy	Promotes use of **low-carbon hydrogen** in **existing** (refining, petrochemicals) and **new sectors** (transportation, industry) through mandates and subsidies
Carbon market/pricing policy	Sets the structure of the carbon market in the Emirate, including **carbon pricing scheme**
Carbon capture, utilization and storage policy (CCUS)	Encourages **use of CCUS technologies by different sectors** through subsidies and mandates

Source: Department of Energy - Abu Dhabi, 2022

Demand-side management strategy is a comprehensive regulation supporting energy efficiency improvements in Abu Dhabi, involving several program owners and stakeholders. A broader range of programs with more ambitious targets could be considered to realize the potential for energy savings in different sectors (e.g., buildings and industry).

Low-carbon hydrogen policy will be updated as the market develops to support low-carbon production and hydrogen use in existing (refining, petrochemical) and new demand sectors (transportation, industry). With this policy update, hydrogen supply could exceed 100 petajoule (PJ) by 2050.

Introduction of **carbon pricing** design through **carbon market/ pricing policy** will provide an economic signal to emitters and create demand for clean technology investments. Carbon price of more than 700 United Arab Emirates Dirham (AED) per ton of CO_2 is expected by 2050, as well as the carbon off-setting considerations, in order to achieve NetZero targets.

Carbon capture, utilization and storage policy will promote the use of CCUS technologies in the hard-to-abate sectors such as power and industry. This is expected to result in 24 to 69 Mt of CO_2 being captured in 2050, enabled through opening further use cases and sectors based on carbon utilization.

For modeling purposes, different assumptions and levels of ambition were adopted, covering **key policy elements** such as: hydrogen supply, carbon pricing and offsetting, and CCUS (Table 13).

Table 13: Key policy assumptions and ambitions by scenarios (Cross-cutting)

Policy elements	**Target:** Current Policies	**Target:** NetZero	**Target:** Technological Shift Paradigm
Hydrogen supply	**56 PJ**[1)] of low-carbon hydrogen supply in 2050	**118 PJ** of low-carbon hydrogen supply in 2050	**116 PJ** of low-carbon hydrogen supply in 2050
Carbon pricing and offset	**No carbon price**	Carbon price: **734 AED**[2)] / ton CO_2 by 2050	Carbon price: **734 AED** / ton CO_2 by 2050
Carbon capture, utilization and storage	**5 Mt**[3)] of CO_2 emissions captured in 2050	**69 Mt** of CO_2 emissions captured in 2050	**24 Mt** of CO_2 emissions captured in 2050

Note: 1) Petajoule; 2) United Arab Emirates Dirham; 3) Megaton
Source: Abu Dhabi Integrated Energy Model, Department of Energy - Abu Dhabi, 2022

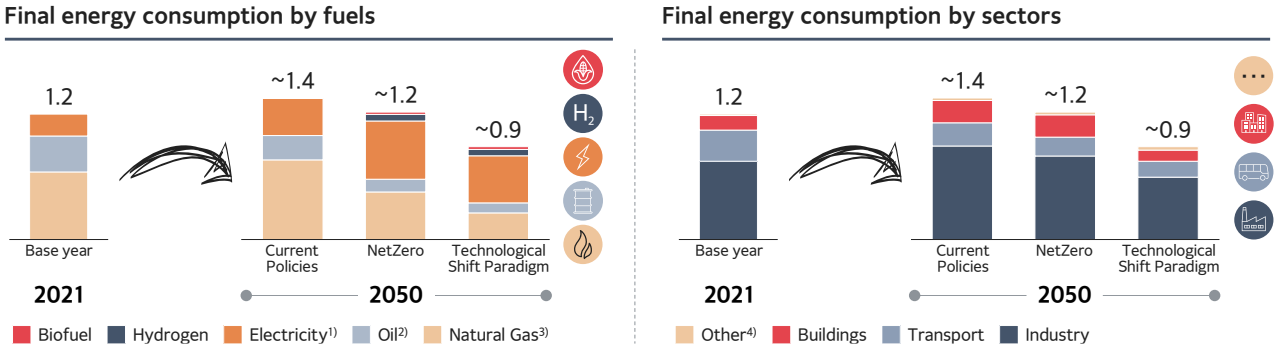
7. Outcome of Abu Dhabi's Energy Outlook

7.1. Key changes in the energy system

Energy demand in Abu Dhabi under the Current Policies scenario will grow to **~1.4 exajoule (EJ) in 2050**. The introduction of **more ambitious policies could reduce the energy demand growth rate** and lead to 0.9-1.2 EJ of total energy consumption in the Emirate, depending on technological development evolution.

Natural gas will remain the most important source of supply, accounting for about 55%[113] of Abu Dhabi's total demand in 2050 under the Current Policies scenario; electricity will cover less than 30%. However, achieving NetZero goals will require higher rates of electrification, rise of **alternative fuel switching** in both industry and transportation and adoption of **CCUS technologies.**

Figure 5: Abu Dhabi final energy consumption [EJ]



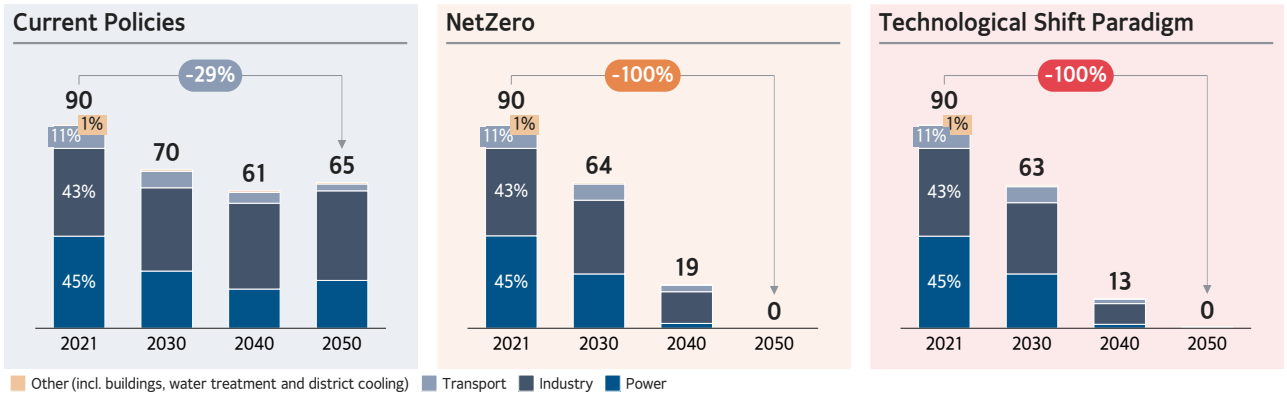
Note: 1) Includes all types of electricity generation, such as natural gas, solar PV, nuclear power and waste-to-energy; 2) Oil and petroleum products; 3) Excludes natural gas used for power generation; 4) Other includes district cooling and water treatment

Source: Abu Dhabi Integrated Energy Model, Department of Energy - Abu Dhabi, 2022

7.2. Compliance with NetZero targets

The Current Policies are expected to have a noticeable impact on total CO_2 emissions in Abu Dhabi: **they will decrease by ~30% from 2021 to 2050**. Nonetheless, given a high share of fossil fuels in the total final consumption fuel mix, Current Policies projections imply the need for a greater long-term change to reach decarbonization targets. More ambitious policies will be needed to achieve NetZero by 2050; **cost and pace** will depend on **technological developments and policy goals**.

Figure 6: Abu Dhabi total CO_2 emissions [Mt]



Source: Abu Dhabi Integrated Energy Model, Department of Energy – Abu Dhabi, 2022

[13] Excluding natural gas used for power generation

Figure 7: Changes in CO_2 emissions by sector [% to 2021][1)]

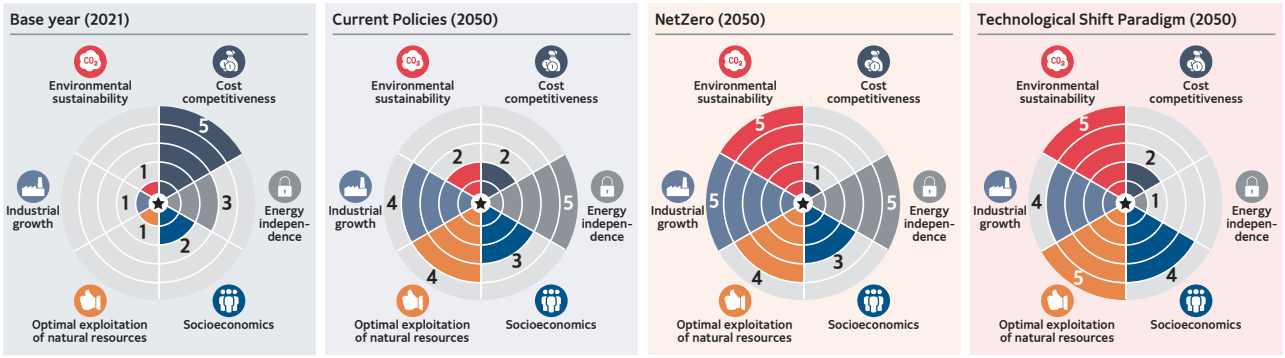
	Power			Industry[2)]			Transport			Buildings		
	2030	2040	2050	2030	2040	2050	2030	2040	2050	2030	2040	2050
Current Policies	-38%	-57%	-48%	-5%	-2%	2%	-29%	-53%	-70%	28%	33%	43%
NetZero	-41%	-95%	-100%	-16%	-64%	-100%	-30%	-71%	-100%	27%	-22%	-100%
Technological Shift Paradigm	-38%	-95%	-100%	-18%	-76%	-100%	-30%	-81%	-100%	20%	-52%	-100%

Note: 1) Based on the current design of the scenarios and modelled policy assumptions (subject to change based on the specific targets agreed in the policy elements); 2) Oil & gas sector is a part of industry
Source: Abu Dhabi Integrated Energy Model, Department of Energy – Abu Dhabi, 2022

7.3. Impact of energy transition on Abu Dhabi

Development of the Emirate's energy system will have a direct impact on Abu Dhabi, which was assessed through six comparable key outcome indicators, including **environmental sustainability, cost competitiveness, energy independence, optimal exploitation of natural resources, industrial growth** and **socioeconomics** (Figure 8).

Figure 8: Impact of the Outlook's scenarios on the Emirate's six key indicators[14]



Source: Abu Dhabi Integrated Energy Model, Department of Energy – Abu Dhabi, 2022

1. Environmental sustainability: By 2050, the Emirate's energy system under the NetZero and Technological Shift Paradigm pathways will meet the NetZero targets through the introduction of more ambitious policies and use of new technologies. This complete decarbonization will take place in all sectors, including industry, buildings, transportation and power (and water).

2. Cost competitiveness: Introduction of new technologies will have a direct impact on Emirate's energy system cost, which will be monitored by regulators to keep costs competitive. **Average unitary energy production costs** are expected to **increase by 160% from 2021 to 2050** due to the Emirate's plans to decarbonize under the **Current Policy** scenario (Figure 9). These costs are associated with annual cost and investments made in the primary supply demand of crude oil, natural gas, biofuels, hydrogen, and other abatement technologies, as well as electricity generation.

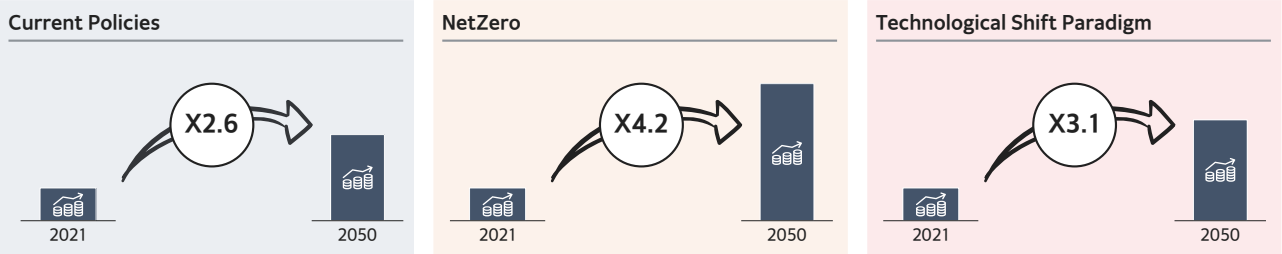
Achievement of **NetZero** targets will require greater adoption of new and more expensive technologies, which will increase costs by **320%** from 2021 to 2050. The main increase in costs is expected in the

[14] See Appendix 4 for methodology details

power generation sector, which will require significant investments in natural gas-fired facilities with CCUS, as well as investments in additional renewable energy capacity.

The **Technological Shift Paradigm** scenario assumes a higher rate of technology development than the NetZero scenario, which is expected to have a positive impact on costs with an increase of **210%**[15] **from 2021 to 2050**.

Figure 9: Average unitary energy production cost[16]



Source: Abu Dhabi Integrated Energy Model, Department of Energy – Abu Dhabi, 2022

3. Energy independence: Security of supply is undoubtedly the cornerstone of the Emirates' energy system and will be maintained in all scenarios. The gas supply policy assumptions in the Current Policies and NetZero scenarios aim to achieve energy independence with the **elimination of all gas imports by 2032**. On the other hand, the Technological Shift Paradigm pathway assumes a softer approach to gas import in order to mitigate the increase in the system cost, while reducing a footprint of the Abu Dhabi supply system (share of import in natural gas consumption is expected to reach 57% in 2050, with natural gas imports increasing by 80% in absolute terms compared to 2021).

4. Optimal exploitation of natural resources: In 2050, natural resources such as crude oil, natural gas and groundwater will be more efficiently exploited through electrification, fuel switching and energy efficiency initiatives. These initiatives will help to achieve a **~15-25% reduction in domestic oil and gas demand by 2050** under the Current Policies and NetZero scenarios, with natural gas consumption fully met by local natural gas production. Lower oil and gas consumption is expected under the Technological Shift Paradigm scenario due to a more diverse generation mix in the power sector with a smaller share of natural gas with CCUS.

5. Industrial growth: Abu Dhabi's Industrial Production Index (IPI) is expected to double from pre-pandemic levels, with the main growth foreseen in non-oil industries. Under the Current Policies and Technological Shift Paradigm scenarios, **production in the commodities**[17] **sector will grow by about 40% by 2050**. The commodities sector production will see an even higher growth of **~60%** in the NetZero scenario driven by more proactive industry support.

6. Socioeconomics: The socioeconomic factor will be carefully considered to ensure sustainable economic growth while promoting social prosperity. All scenarios assume a growing **population (~X2.1), labor supply (~X1.5), GDP (~X1.8), foreign direct investments (~X3.6)** as well as **improvement of public health index** from 2021 to 2050.

[15] Cost increases in line with the Current Policy scenario, driven by the adoption of more expensive technologies, but significantly lower energy demand under more stringent and ambitious energy efficiency policy assumptions

[16] Energy production cost excluding transportation and storage and put in unitary terms (AED/TJ), which shall not similar to the levelized cost of energy

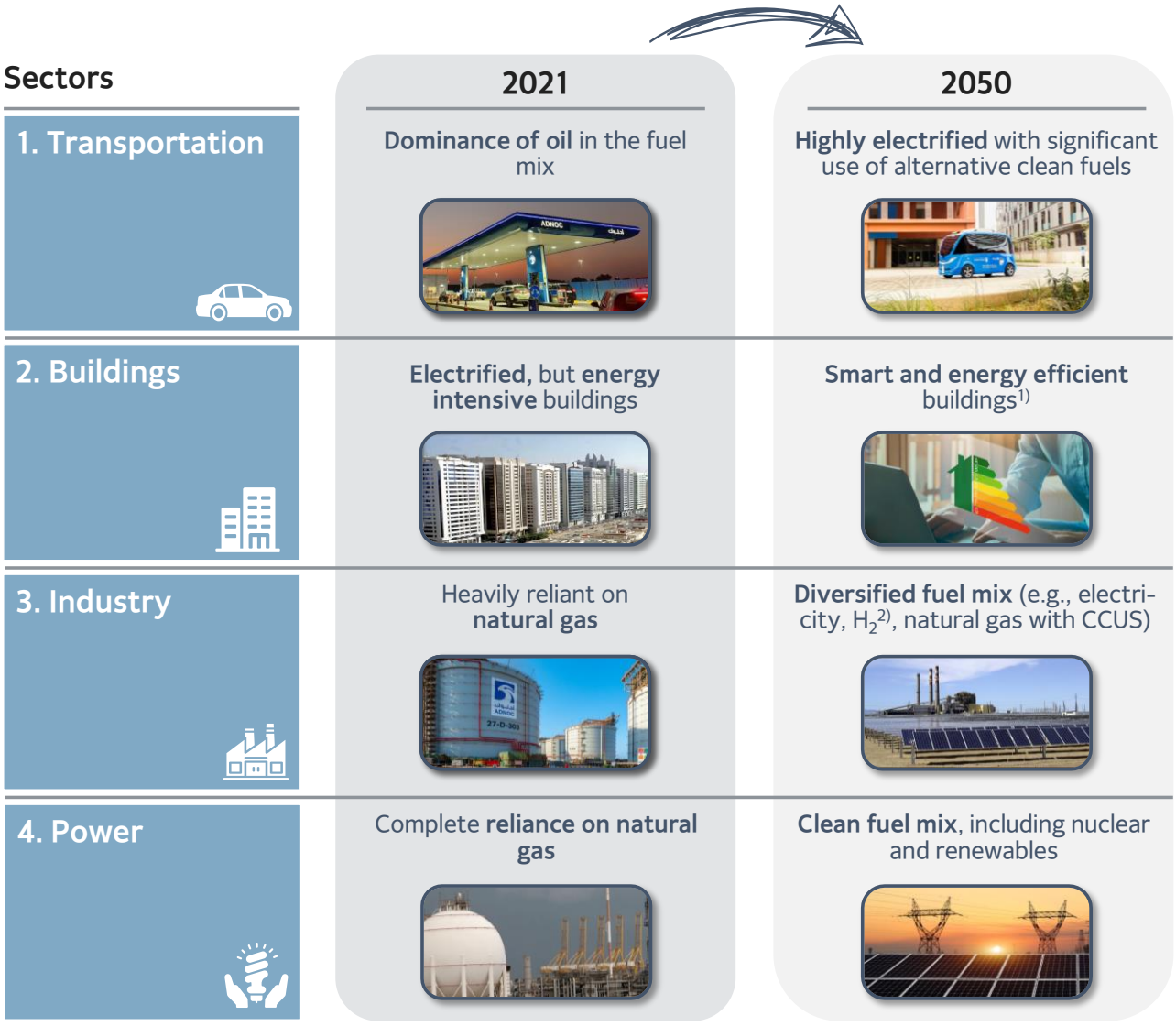
[17] Commodities sector includes iron and steel, cement and aluminum industries

8. Abu Dhabi's NetZero Implications

Under the NetZero future, **all demand sectors will shift from being reliant on fossil fuel to a more diverse supply-side mix**. Therefore, both activities and energy use patterns will vary significantly from one sector to another.

However, the adoption of new technologies and solutions in Abu Dhabi's sectors will depend on the degree of **maturity of these technologies** and **policy targets**.

Figure 10: NetZero vision for transportation, buildings, industry and power sectors[18] [19]



Note: 1) Still relatively energy intensive; 2) Hydrogen
Source: Department of Energy – Abu Dhabi, 2022

[18] Oil & gas sector is a part of industry

[19] Water sector is not the focus of this report and will be discussed separately in the Abu Dhabi Water Outlook 2050

8.1. Transportation

NetZero vision

Profound changes in transportation sector activities will enable the Emirate to position itself as a **regional powerhouse for sustainable mobility**.

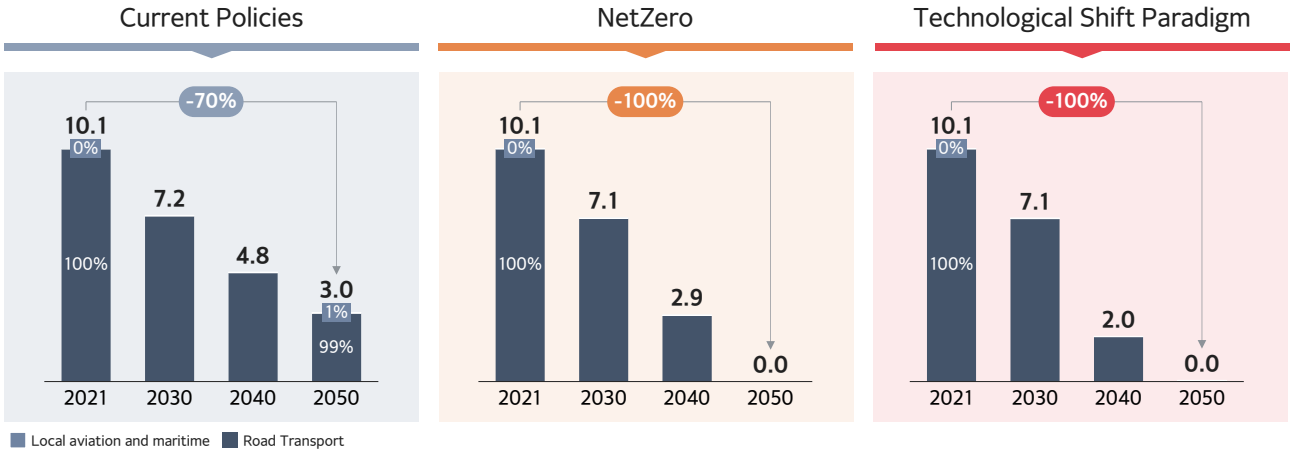
Abu Dhabi has an opportunity to become a **regional hub** for synthetic fuel production, including biofuels and hydrogen-based fuels. This will come because of **investments in key mobility technologies** (e.g., Hydrogen Refueling Stations), enabling Abu Dhabi to realize optimal incremental cost and achieve scale in production.

On another front, Abu Dhabi could become a **regional home to key companies across the vehicle system** including original equipment manufacturers (OEMs), producers and infrastructure operators, who will seek to utilize Abu Dhabi as a launching pad for innovative technologies and initiatives in the region.

Scenario results

Compliance with NetZero targets

Figure 11: Transportation sector CO2 emissions [Mt][20]



Source: Abu Dhabi Integrated Energy Model, Department of Energy - Abu Dhabi, 2022

Emissions from transport sector in the Current Policies scenario are expected to decrease **by about 70% between 2021 and 2050**, reaching about 3 Mt of CO_2 emissions in 2050 (Figure 11). The introduction of new policies focused on decarbonization could significantly accelerate this reduction to **NetZero emissions by 2050**. The rate of emission reductions will depend on the level of **policy ambition** and the **rate of technology development**.

Energy supply and demand

Road transport in Current Policies scenario will see a reduction in energy demand of 65% by 2050 driven by the **increased use of clean-powered vehicles** and a **decrease in the average distance travelled.** This decrease will be supported by the government plans to develop **public transportation** (including a rail network for passengers and freight). However, achieving NetZero targets will require more ambitious policies, such as **restrictions on the sale of cars with internal combustion engines (ICE) from 2045.** These measures, together with a shift toward

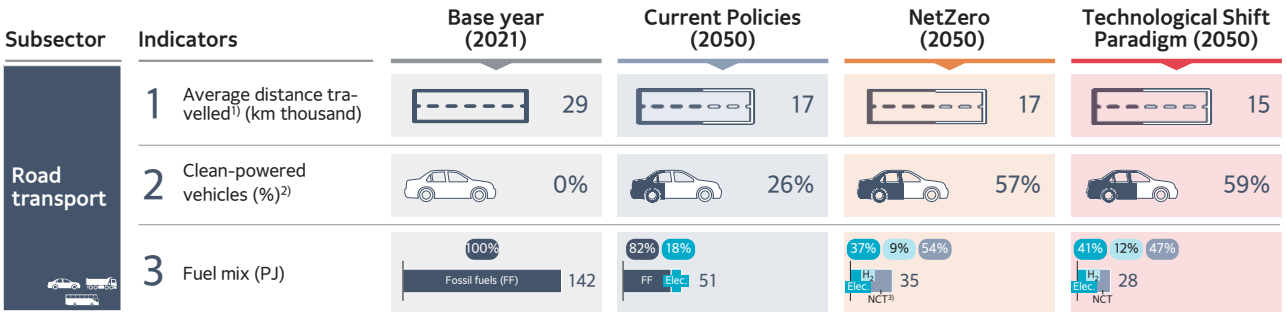
[20] Transportation sector limits the scope of the emissions to local aviation and maritime (excluding international aviation and maritime activities)

clean-powered public transport, will reduce energy demand in road transportation by 75% from 2021 to 2050 in the **NetZero scenario**. Accelerated development of electric, hydrogen and other clean-fuel vehicles under the **Technological Shift Paradigm** scenario is expected to enable an energy transition with a sooner restriction on the sale of internal combustion engines (starting in 2040) and even lower energy consumption in 2050.

Energy demand in the **international aviation sector** is expected to increase by more than 25% by 2050 under the **Current Policies** scenario due to the growth in the sector but will remain 100% dependent on traditional aviation fuels. **New policies** under the **NetZero and Technological Shift Paradigm** scenarios are expected to have a significant impact on energy efficiency, resulting in an **18% reduction of total energy consumption** in 2050 compared to the Current Policies pathway. Fuel switching initiatives under both NetZero pathways will lead to a new fuel mix with a **30% share of biofuels, a ~10% share of hydrogen and a 10% share of electricity in 2050**.

Energy consumption in the **maritime** sector will decrease slightly by 2050 under the **Current Policies** scenario, despite an expected increase in goods imports. This decline will be driven by the expected transition from heavy fuel oil (HFO) to more efficient fuels, including liquefied natural gas (LNG). However, **further energy efficiency initiatives**, such as the promotion of electric ships, will be needed to achieve the NetZero targets. The **NetZero** and **Technological Shift Paradigm** scenarios assume that the share of electricity in the fuel mix will be ~17% in 2050, with a greater reduction in energy consumption by 2050 (40% compared to 2021) in the Technological Shift Paradigm scenario driven by accelerated technological development.

Figure 12: Transportation sector outlook 2050



Note: 1) Weighted average distance travelled per vehicle, depending on the size of the fleet (incl. light-duty vehicles, buses and trucks); 2) Including electric and hydrogen light-duty vehicles, buses and trucks; 3) NCT – New clean technologies (e.g., biofuels/e-fuels, additional hydrogen, additional electrification)

Source: Abu Dhabi Integrated Energy Model, Department of Energy - Abu Dhabi, 2022

8.2. Buildings

NetZero vision

Under the NetZero future, Abu Dhabi's landscape will continue to **boast some of the world's most innovative and modern buildings**. Nonetheless, developments in the sector will enable the Emirate to position itself as a **global champion of sustainable buildings**.

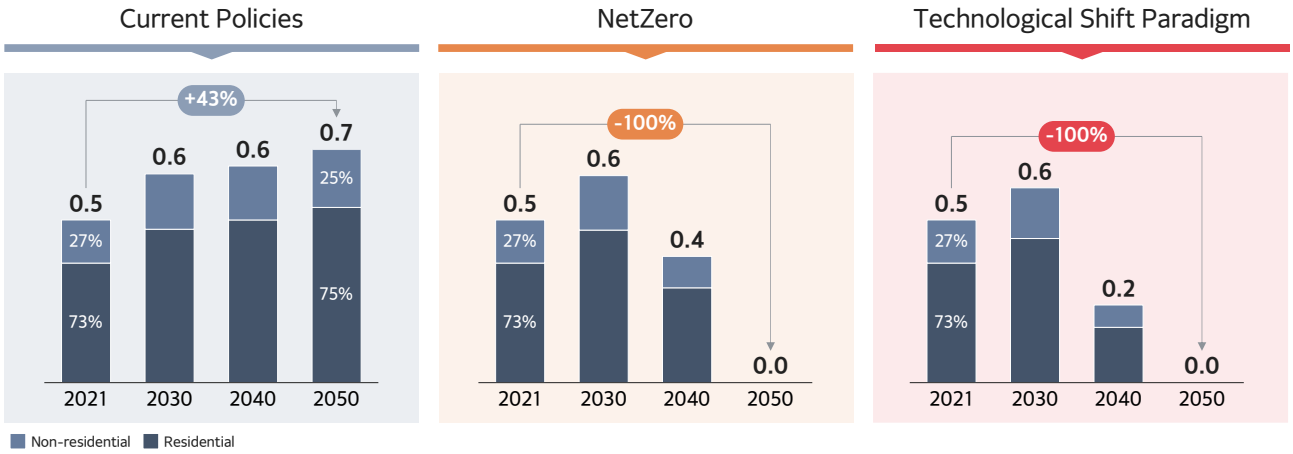
Deployment of **DSM initiatives** will foster an ecosystem for energy-efficiency players, including contractors, financiers and technology providers. As a result, Abu Dhabi emerges as **a regional hub for energy-efficiency providers**.

Proliferation of low-emitting and architecturally innovative buildings across the Emirate's real estate sector will position it as **a destination for sustainable tourism.**

Scenario results

Compliance with NetZero targets

Figure 13: Buildings sector CO_2 emissions [Mt]



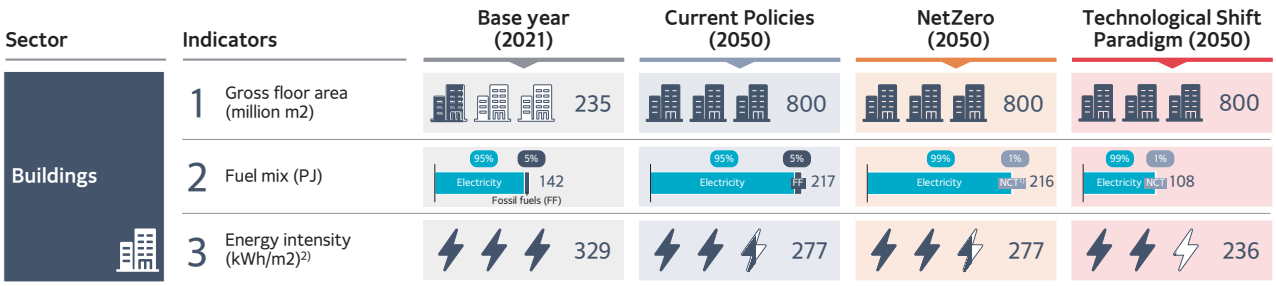
Source: Abu Dhabi Integrated Energy Model, Department of Energy - Abu Dhabi, 2022

Unlike other demand sectors, the building sector will benefit from having **lower CO_2 emissions at early stages** of the Outlook's horizon with **0.5 Mt** in 2021. These emissions are expected to increase by 2050 under the Current Policies pathway, driven by more than a threefold increase in the total building gross floor area (Figure 13). Achieving **NetZero targets** in the building sector will require broader energy efficiency efforts with **accelerated timelines and targets supported by policy and technology development**.

Energy supply and demand

The Abu Dhabi buildings sector is significantly electrified with a **95% share of electricity** in the fuel mix. The **Current Policies** pathway will not lead to fuel mix changes but will target buildings efficiency improvement. **New policies** under the **NetZero** and **Technological Shift Paradigm** scenarios are expected to ensure that by 2050, the proportion of liquefied petroleum gas and natural gas used in buildings will **not exceed 1% of the fuel mix**. Further advances in technology under the **Technological Shift Paradigm** scenario will result in much greater energy efficiency and a **~50% reduction in the overall energy consumption** by 2050 compared to the NetZero and Current Policies pathways.

Figure 14: Buildings sector outlook 2050



Note: 1) NCT - New clean technologies (e.g., biogas, hydrogen); 2) Weighted average based on total floorspace for residential and non-residential buildings

Source: Abu Dhabi Integrated Energy Model, Department of Energy - Abu Dhabi, 2022

8.3. Industry

NetZero vision

Despite fundamental changes in the energy use of the industrial sector, **Abu Dhabi's IPI is expected to double** from ~95 in 2021 to ~200 in 2050[21]. Therefore, Abu Dhabi industrial sector will transform as follows:

Incremental deployment of fuel switching along with carbon capture technologies will lead to **significant reductions in energy intensity** (**50-60%** from 2021 to 2050[22]). As a result, energy-intensive industries in Abu Dhabi, led by aluminum and steel, would emerge as global innovators in sustainable production.

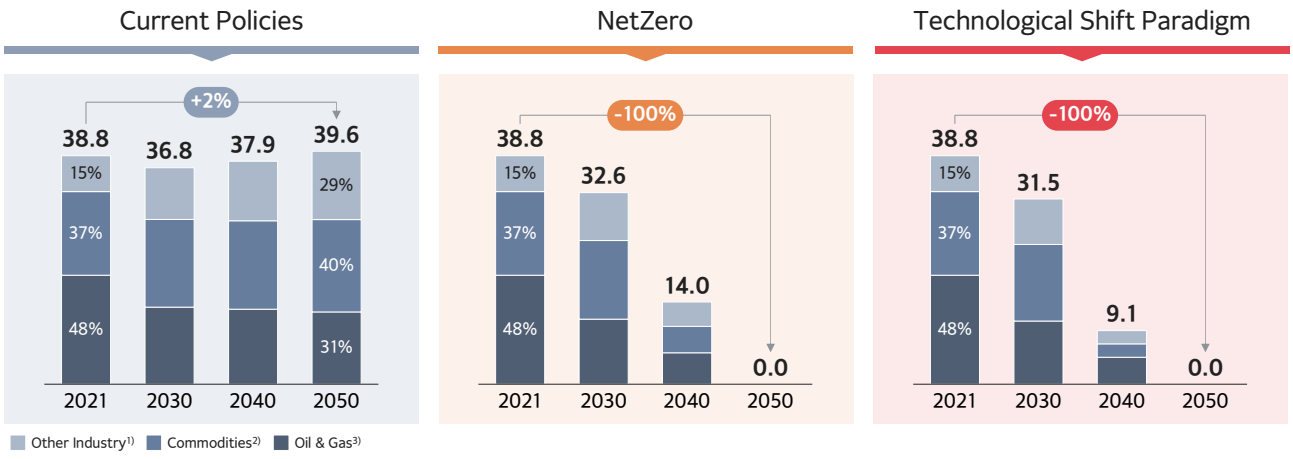
Investments in alternative fuel switching and electrification infrastructure will result in maintaining a **competitive energy system cost** in the industrial sector. Hence, **production levels of non-oil industrial sectors would increase by 40-60%[23].** Therefore, Abu Dhabi will dominate the regional markets of construction materials (subject to assumptions on favorable global market demand).

Unlike other demand sectors, emissions reduction pathways for industry are diverse and uncertain. On the one hand, it includes solutions that are more certain and tested such as **electrification.** On the other hand, it also relies on technologies that are either nascent or commercially uncertain such as **fuel switching to hydrogen and biofuels, application of CCUS technologies** and, in some instances, **changes to production processes or product mix**.

Scenario results

Compliance with NetZero targets

Figure 15: Industrial sector CO_2 emissions [Mt][24]



Note: 1) "Other industry" includes light industries (e.g., food processing, furniture); 2) "Commodities" includes iron & steel, cement, aluminum 3) "Oil & Gas" includes oil & gas production, petrochemicals and refining
Source: Abu Dhabi Integrated Energy Model, Department of Energy - Abu Dhabi, 2022

The current policies in place to **decarbonize the industrial sector will not be sufficient** if the sector continues to grow as a result of the Emirates' diversification agenda. Both NetZero projections suggest the development of more ambitious policies that promote **significant changes in the**

[21] Based on the IEM model results for both NetZero scenarios (2018 is used as base year for IPI calculation with a value of 100)
[22] Energy intensity is calculated as energy consumption per ton of commodities production (incl. iron and steel, cement, aluminum)
[23] Expected output growth for the commodities sector, including iron and steel, cement, aluminum
[24] Excluding emissions captured by CCUS technologies

energy consumption of the industrial sector leading to large-scale reductions in CO_2 emissions with **NetZero targets** being achieved by 2050 (Figure 15).

Carbon capture technologies are expected to be used in both energy-intensive and light industries in order to achieve NetZero targets. The total amount of CO_2 emissions captured in 2050 will be ~24 Mt under the NetZero scenario. Accelerated technology development under the Technological Shift Paradigm scenario will enable a higher rate of emissions reduction with more use of alternative fuels and lower amounts of captured CO_2 emissions (12 Mt in 2050).

The **carbon pricing regime** will be introduced in line with global decarbonization efforts in the NetZero and Technological Shift Paradigm scenarios and will encourage players in the industrial sector to invest in decarbonization technologies (including, CCUS) and switch to other fuels such as hydrogen.

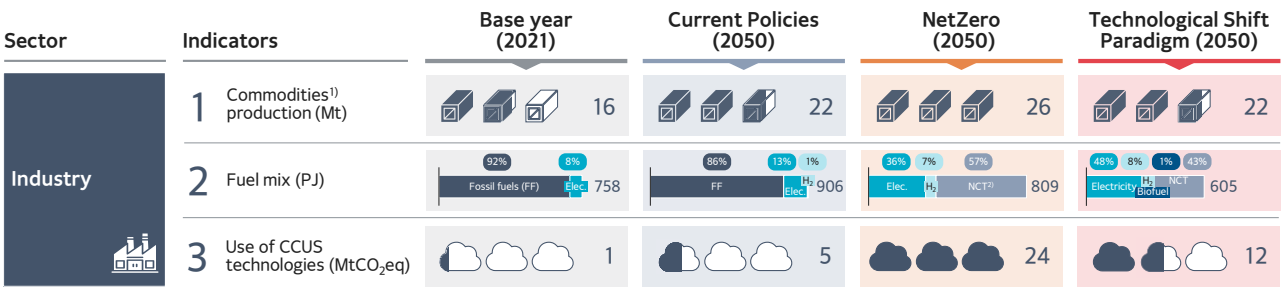
Energy supply and demand

Under the **Current Policies** scenario, production growth in the industrial sector will **increase the total energy consumption by ~20%**, with natural gas remaining as the main fuel. The level of electrification is expected to reach **13%** in 2050 (compared to 8% in 2021).

More **ambitious policies** will be required to decrease energy consumption and achieve higher rates of electrification and fuel switching. This will enable to decrease the total energy consumption by additional **~100 PJ in 2050** and reach just an over **35% share of electrification under the NetZero scenario**. Switching to **low-carbon hydrogen** will contribute to decarbonizing some industries (e.g., iron and steel), reaching over **7% of the total fuel mix**.

Further development of **technologies** under the **Technological Shift Paradigm** scenario will allow achieving higher energy efficiency in the sector, with a reduction of total energy consumption by approximately **300 PJ in 2050** compared to the Current Policies pathway. There will be a higher reduction of fossil fuels with CCUS in the sector's fuel mix, which will be compensated by a **48% share of electrification** and a further shift to **hydrogen** and **biofuels**, which will account for **~10% of total supply by 2050**.

Figure 16: Industrial sector outlook 2050

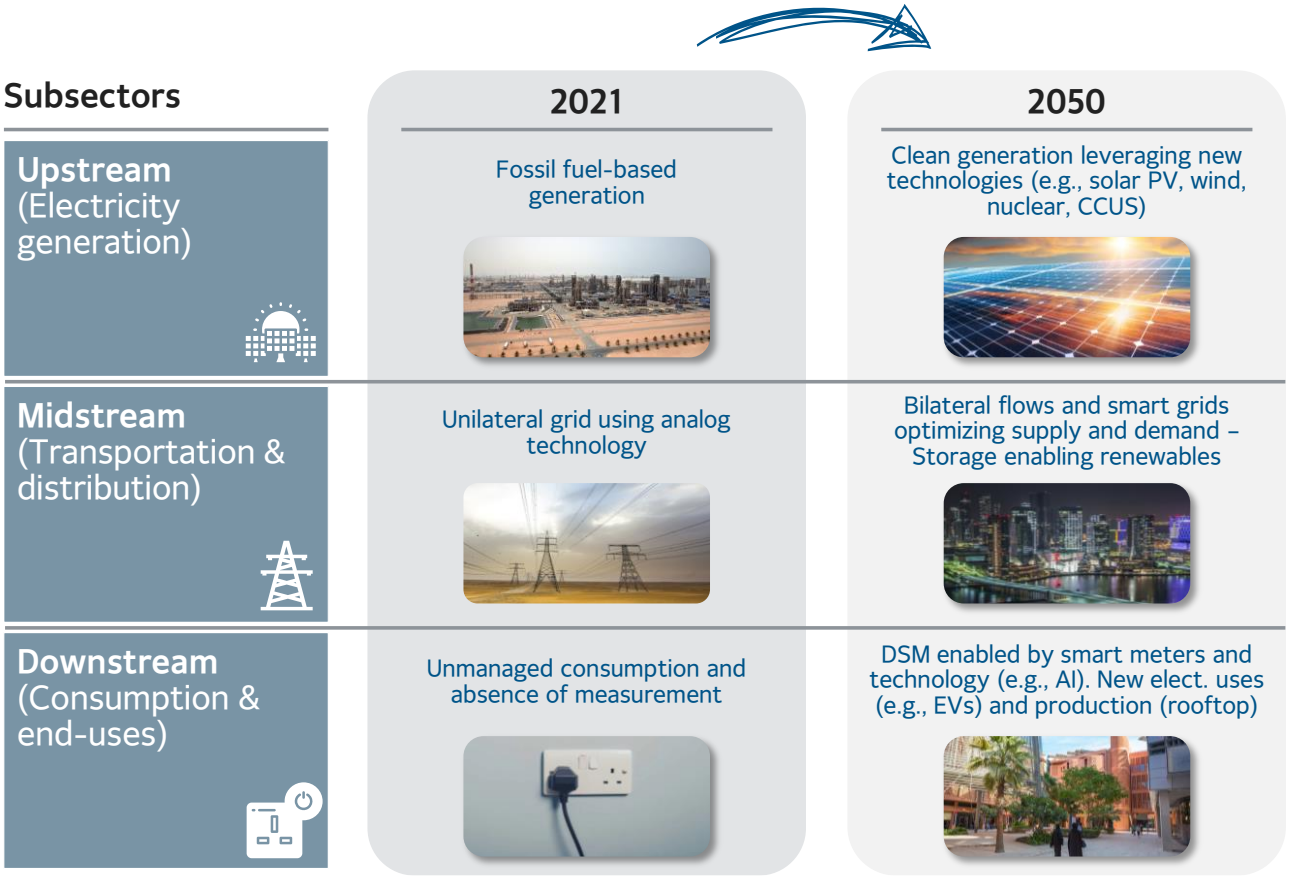


Note: 1) Commodities include iron & steel, cement, aluminum; 2) NCT - New clean technologies (e.g., use of CCUS technologies, additional biofuel, additional hydrogen, additional electrification)
Source: Abu Dhabi Integrated Energy Model, Department of Energy - Abu Dhabi, 2022

8.4. Power

NetZero vision

Figure 17: Power sector vision 2050



Source: Department of Energy - Abu Dhabi, 2022

Power generation will become **clean**; nuclear, renewables and natural gas with CCUS will make up more than 95% of the primary generation fuel mix. It will also become the most dominant secondary energy source in the energy system, meeting approximately **40% of road transport** demand**, 35-50% of industrial** demand **and 99% of buildings** demand. As a result, the production of electricity will grow at an average annual rate of ~3% between 2021 and 2050.

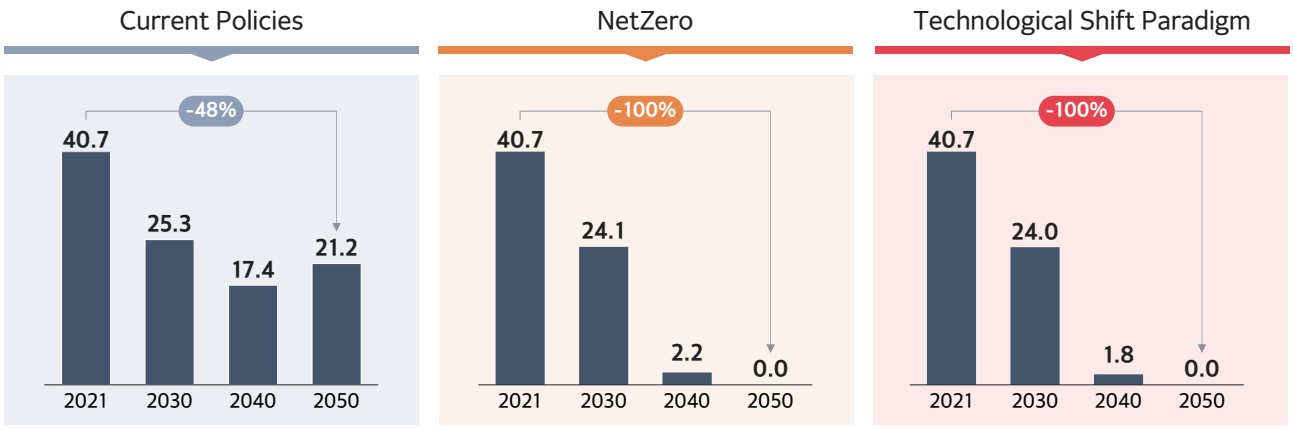
The results from the demand sectors point to a key insight, that is the critical role of electricity in enabling Abu Dhabi's transition to a cleaner energy system. In other words, **electricity will comprise a significant share of the supply mix in all Emirate's demand sectors**. Therefore, it is not an exaggeration to state that decarbonization of the power sector will shape the future of Abu Dhabi's energy system.

Decarbonization of the power sector will require the development of technologies such as CCUS and energy storage. **CCUS technologies** will be used to decarbonize power generation from combined cycle plants. **Battery systems** will be needed to store excess renewable energy produced during favorable weather conditions, which can then be used during peak demand.

Scenario results

Compliance with NetZero targets

Figure 18: Power sector CO_2 emissions [Mt]



Source: Abu Dhabi Integrated Energy Model, Department of Energy - Abu Dhabi, 2022

In 2021, **natural gas** accounted for nearly **90% of electricity generation and 100% of related CO_2 emissions** in the power sector. However, Abu Dhabi's current clean energy policy calls for 60% of electricity to be generated from clean sources by 2035. Following this pathway, an almost **50% reduction in total emissions could be achieved** by 2050, despite an expected increase in demand of about 60% from 2021 to 2050. Achieving **NetZero targets** in the power sector will require more **ambitious clean energy policies and technologies**.

Energy supply and demand

Power generation will increase significantly under the **Current Policies** pathway **from ~95 terawatt hour (TWh) in 2021 to 152 TWh in 2050** due to plans to electrify demand sectors. More **ambitious decarbonization policies**, adapted for transportation, industry and buildings, would require a much larger increase in power supply: the expected annual power generation will be **251 TWh in 2050** in the NetZero scenario. Further **technology development** under the Technological Shift Paradigm scenario is expected to allow higher efficiency and switch to cleaner fuels within the demand sector, reducing electricity demand to **205 TWh in 2050** compared to NetZero scenario.

The power generation mix will be completely overhauled by 2050. Co-generation will be completely phased out by 2042, and **cleaner sources will account for ~60% of the generation mix** under the **Current Policies**, while the rest will be from conventional gas-based generation.

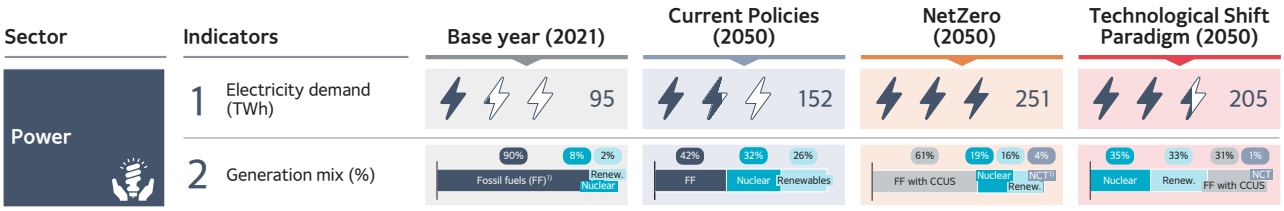
More ambitious policies, such as the Clean Energy Strategic Target 2050, are expected under the **NetZero scenario** in order to reduce the emitting power generation sources further. The power system will become cleaner with a share of nuclear power at 19%, renewables at 16% (including battery storage) and significant use of gas-based abatement technologies to maintain system operability (share of natural gas with CCUS in the total generation mix will be close to 60%).

Accelerated technology development under the **Technological Shift Paradigm scenario** will allow the Emirate to have a more diverse clean technologies compared to the NetZero scenario, with a higher share of nuclear energy (35%) and renewable energy[25] (33%), while natural gas with

[25] Including battery storage

CCUS will account for about 31% in the generation mix. Moreover, wind power is expected to be integrated in the 2030s and will potentially reach ~7 TWh of power generation by 2050.

Figure 19: Power sector outlook 2050



Note: 1) NCT - New clean technologies (e.g., waste-to-energy, additional gas with CCUS technologies, additional renewables, additional nuclear, Direct Air Capture (DAC))

Source: Abu Dhabi Integrated Energy Model, Department of Energy - Abu Dhabi, 2022

9. Challenges on the Path to NetZero

Abu Dhabi could face several challenges that affect how its transition journey evolves. Some of these are within the Emirate's control, such as **Research & Development and investment in human capital**, while others are beyond its control, including **global markets' supply of key technologies**.

Access to key technologies (e.g., electrolysis, storage) is vital to the development of scalable decarbonization. Uncertainties regarding disruptions of supply chains and global market supply dynamics are two key factors that could affect the Emirate's ability to secure such technologies. In response, the relevant policymakers could consider establishing policies and measures that will enable and incentivize the **localizing production of certain technologies** to take advantage of opportunities to become a regional supplier.

Building an operating energy system that is NetZero is complex; it requires a special know-how that is still in development even in the most advanced economies. This know-how should facilitate the **introduction of decarbonization technologies, which are currently in the early stages of development** and have not been put into mass production. Abu Dhabi, while having a wealth of know-how in many areas, could further **invest in education** to strengthen local human capital capabilities and **deepen international collaboration** in key **research and development** areas in general, and particularly the decarbonization technologies and policy making areas.

Several **infrastructure projects** could accelerate the decarbonization of local players and attract new companies to the Emirate. The development of **backbone infrastructure** such as hydrogen and CO_2 pipelines or CCUS hubs could accelerate the decarbonization of the industrial and power sectors. Moreover, **hydrogen valleys** are already proposed by the DoE in its Low-carbon Hydrogen policy and focus on an economically competitive way to produce and consume hydrogen.

The use of climate-neutral technologies is currently costly compared to the traditional use of fossil fuels. This may require the introduction of several initiatives to **bridge the cost gap**, such as **carbon pricing, end-use sector targets** and other support mechanisms (e.g., **fiscal, economic and financial**).

Figure 20: Barriers and enablers on the path to NetZero

Barriers	Key enablers		
1 Access to key technologies	**1.1 Manufacturing localization** to capture opportunities to become a regional supplier	**1.2 Government incentives** to promote cost-competitive clean energy technologies	**1.3 Regulatory framework** to encourage the development of clean energy technology projects
	1.4 Partnerships with leading companies and organizations to bring new technologies to the market	**1.5 Public-Private Partnerships** to attract private investments and accelerate the deployment of clean technologies	
2 Human capital	**2.1 Qualified local workforce development** to have access to human capital with the required skillset	**2.2 Communities and local organizations** involvement to promote the transition to clean energy regionally	**2.3 Inter-country working groups** to partner with international experts with the required skillset
3 Research and Development (R&D)	**3.1 Government funding and tax incentives** to promote an R&D ecosystem for clean energy technologies	**3.2 Governments, industry, and academia** collaboration to advance on R&D for clean energy technologies	**3.3 Intellectual property protection policies** to ensure R&D efforts can be commercialized and scaled
4 Infrastructure	**4.1** Development of **backbone infrastructure** (e.g., H_2 pipelines, CO_2 pipelines, CCUS-hubs)	**4.2** Development of **hydrogen valleys** with production and demand sectors located in the same area	**4.3 Development of other infrastructure** (e.g., public transport, seaports, clean power facilities, etc.)
5 Cost gap for clean solutions	**5.1** Definition of **carbon pricing** (carbon market, regulated pricing, etc.)	**5.2 Fiscal, economic and financial** support for clean energy projects	**5.3** Introduction of **end-use sector targets** in line with NetZero

Source: Department of Energy - Abu Dhabi, 2022

10. Way Forward

In the past five decades, Abu Dhabi's economic growth was significantly supported by fossil fuels usage. An orderly and predictable **transition to a NetZero energy system is possible**. Nonetheless, it is prone to various challenges and opportunities. The Abu Dhabi Energy Outlook 2050 compares the Current Policies scenario with the two potential pathways of how Abu Dhabi's decarbonization transition could unfold in the long term.

The Emirate, and DoE in particular, have already developed many policies to promote decarbonization. However, **more ambitious energy policies will be required to have a cleaner energy mix in the Emirate**, led by massive deployment of renewable and wider clean energy technologies. This will also entail significant electrification, fuel switching and efficiency improvement in demand sectors such as industry, buildings and transportation. **The speed of technology development is difficult to predict** for such a long period, but its advancement will allow Abu Dhabi to achieve an even cleaner and more diverse energy mix by 2050. However, several measures can be put in place to allow materialization and **acceleration** of technology development through the policy making processes in the Emirate (and globally).

NetZero pathways will allow Abu Dhabi to achieve NetZero targets by 2050, which will improve **resilience of its economy**, conserve **natural resources, cement its reputation** as a global innovator in energy markets, make its **economy more competitive** (green products at competitive prices) and demonstrate its **commitment to a cleaner world**. In addition, decarbonization will have a positive impact on **air quality** and **public health** in the Emirate of Abu Dhabi.

The Outlook should be seen as the DoE's **reflection on Abu Dhabi's pathways to contribute to achieving national NetZero targets.** This document could be positioned as a **key input to the Emirate's energy transition policies debate.**

Further **cooperation with government entities and ministries** at the Emirate and national level is envisioned through performing and defining the position around individual policy targets to reach Emirate's NetZero goals. Setting the **Emirate's policy targets** can be done after performing detailed impact assessments and target setting efforts to ensure developing the specific policies and regulations, as well as to facilitate discussions with public and private companies.

Appendix 1: Glossary

Table 14: List of abbreviations

Abbreviation	Full name
AI	Artificial Intelligence
AED	United Arab Emirates Dirham
CCUS	Carbon Capture, Utilization and Storage
CO_2	Carbon Dioxide
COP 27	27th Session of the Conference of Parties
COP 28	28th Session of the Conference of Parties
DC	District Cooling
DoE	Abu Dhabi Department of Energy
DSM	Demand-side Management
EFW	Energy Production from Waste
EJ	Exajoule
EV	Electric Vehicle
EVSE	Electric Vehicle Supply Equipment
FDI	Foreign Direct Investment
GDP	Gross Domestic Product
GJ	Gigajoule
GW	Gigawatt
HFO	Heavy Fuel Oil
ICE	Internal Combustion Engine
IEM	Integrated Energy Model
IPI	Industrial Production Index
KPI	Key Performance Indicator
LNG	Liquefied Natural Gas
m^2	Square Meter
MENA	Middle East and North Africa
Mt	Megaton
MWh	Megawatt Hour
NCT	New Clean Technologies
NG	Natural Gas
OECD	Organization for Economic Co-operation and Development
OEM	Original Equipment Manufacturer
PJ	Petajoule
PV	Photovoltaics
R&D	Research and Development
RE	Renewable Energy
SMR	Small Modular Rectors
TWh	Terawatt Hour
UAE	United Arab Emirates

Appendix 2: List of Definitions

Alternative fuels: Fuels that are produced from renewable or sustainable sources (e.g., hydrogen, biofuels, natural gas with CCUS).

Aviation fuels: Petroleum-based fuels used to power the aircraft (e.g., kerosene-type fuel).

Biofuels: Fuels derived from biological sources, such as plants and animals (includes bioethanol, biodiesel, biogas, etc.).

Carbon capture, utilization and storage (CCUS): The process of capturing carbon dioxide emissions from fuel combustion, industrial processes or directly from the atmosphere. Captured CO_2 emissions can be stored in underground geological formations, onshore or offshore, or used as an input or feedstock in manufacturing.

Carbon market: System of trading and pricing carbon emissions, which is designed to reduce emissions and encourage the development of low-carbon technologies.

Carbon pricing: Setting of a price for carbon emissions through a carbon tax (USD per CO_2 emitted).

Clean energy: Energy produced from sources that have minimal environmental impact, such as renewables, hydrogen, natural gas with CCUS.

Cross-cutting: Cover more than one sector (e.g., buildings and industry together).

Decarbonization: Process of reducing or eliminating carbon emissions.

Demand sectors: Include transportation, buildings and industry sectors in Abu Dhabi.

Economic diversification: Reduction of Abu Dhabi's economic dependence on the Oil & Gas sector by developing other sectors, such as iron & steel, cement, aluminum, tourism and others.

Electricity from clean sources: Electricity generated from nuclear, solar, low-carbon hydrogen, thermal generation with fossil fuels and carbon capture, utilization, and storage (CCUS), wind, geothermal, tidal energy, hydropower, biomass, landfill gas, sewage treatment plant gas and biogases.

Electrification: Use of electricity instead of other energy sources (e.g., natural gas, crude oil).

Energy demand: Amount of energy consumed in Abu Dhabi (e.g., by transportation, buildings, industry sectors).

Energy efficiency: Amount of energy required for a particular activity.

Energy mix: Combination of different sources of energy used in the Emirate of Abu Dhabi (e.g., natural gas, oil, electricity, hydrogen, etc.).

Energy production: Process of generating energy from natural sources, such as coal, oil, natural gas, solar, wind, wastes and nuclear power. The energy produced can be used directly or converted into other forms of energy, such as electricity or heat.

Energy supply: Amount of energy available for use in Abu Dhabi (e.g., energy from natural gas, crude oil, electricity).

Energy system: Abu Dhabi's energy system that includes all the elements necessary to produce, deliver, and use energy, such as power plants, transmission/distribution lines, storage and end-use facilities.

Energy transition: Shift from fossil-based systems of energy production and consumption (incl. natural gas and oil) to clean energy sources (e.g., renewables, hydrogen, natural gas with CCUS, etc.).

Fossil fuels: Include natural gas and crude oil.

Fuel mix: Different types of energy sources used in Abu Dhabi (e.g., natural gas, crude oil, electricity).

Fuel mix diversification: Reduction of Abu Dhabi's energy dependence on the fossil fuels through the use of renewable energy sources and alternative fuels.

Greenhouse gases (GHGs) - Gases that trap heat in the atmosphere, including carbon dioxide (CO_2) which is the primary greenhouse gas emitted through human activities and other gases such as: Methane (CH_4), Nitrous Oxide (N_2O).

Horizon: Time period over which a forecast is made: 2022-2050.

Integrated Energy Model / Energy Cube: Energy Model that captures the whole value chain of the energy sector within the Emirate of Abu Dhabi and provides perspectives into the future up to the year 2050.

Low and emission-free technologies: Technologies that have a low environmental impact and produce little or no emissions (e.g., solar PV, CCUS, clean hydrogen facilities).

Low-carbon hydrogen: Hydrogen whose production process per kilogram of hydrogen produced emits a limited quantity of carbon dioxide that is less than or equal to an agreed threshold. It includes, among other technologies, hydrogen produced from Electricity from Clean Sources, biomass, waste, and fossil fuels with CCUS.

Modeling: Use of Integrated Energy Model to simulate and analyze the Abu Dhabi's energy sector.

Modules: Energy Cube consists of five modules: gas, liquids, electricity and water, demand, output.

Gas module

Module of the Energy Cube determines domestic gas balance (yearly and monthly), linked to power and domestic demand, generates the optimum cost curve, provides marginal cost, total cost of supply and the supply mix.

Liquids module:

Module includes crude oil and natural gas and determines the total available liquids supply for export and for domestic consumption.

Demand module

Module provides the energy and feedstock domestic demand projections through bottom-up assessment for different subsectors covered under four main sectors: transport, buildings and industry.

Power and water module

Module includes three sectors: power generation, water production, and district cooling. The IEM considers electricity generation from fossil fuels, nuclear power, solar PV and other renewable energy sources. The power sector is based on the "Gurobi' power solver and PLEXOS' simulation software, which optimizes capacity additions based on electricity demand and economic and other constraints and perspectives. The module provides total system generation cost, optimum capacity and generation mix among other key outputs. Water treatment energy use from fossil fuels and electricity is analyzed for three water sources: desalination, recycling and groundwater. Electric and gas chillers energy consumption is forecasted for the district cooling sector based on the penetration rate in residential and non-residential buildings.

Output module

Module generates probable future scenarios and trade-offs through comparable key output metrics, including industrial growth, optimal exploitation of natural sources, environmental sustainability, socioeconomics, cost competitiveness and energy independence.

Nascent technologies: Emerging technologies that aim to reduce or eliminate emissions (e.g., CCUS, hydrogen-based facilities).

NetZero: A situation in which the energy system of the Emirate will transition towards low and emission-free technologies, and any residual emissions will be neutralized by other means, such as the process of atmospheric removal and permanent storage.

Objective functions: Metrics in six areas used to access the impact of IEM scenarios (cost competitiveness, environmental sustainability, energy independence, industrial growth, optimal exploitation of natural resources and socioeconomic impacts).

Outlook: Abu Dhabi's energy sector vision by 2050.

Renewables: Includes bioenergy, geothermal, hydropower, solar PV, CSP, wind and marine (tide and wave) energy for electricity and heat generation.

Residential: Energy used by households including space heating and cooling, water heating, lighting, appliances, electronic devices and cooking.

Road transport: Includes all road vehicle types (passenger cars, two/three-wheelers, light commercial vehicles, buses and medium and heavy freight trucks).

Scenarios/ Pathways: Potential options for the evolution of Abu Dhabi's energy system.

Synthetic fuels: Include biofuels and hydrogen-based fuels.

Target: Specific goal or objective set to reduce carbon dioxide emissions by 2050.

Appendix 3: Overview of Sectors and Sub-sectors Included in the Analysis

The Outlook covers the four main energy-related sectors in Abu Dhabi, such as transportation, buildings, industry and power. Details of the sub-sectors are shown in Figure 21.

Figure 21: Overview of sectors and sub-sectors included in the analysis

Sectors	Sub - sectors
1. Transportation	**1.1 Road transport** (light duty vehicles, heavy duty vehicles – buses, heavy duty vehicles – trucks) **1.2 Aviation** (local aviation, international aviation) **1.3 Maritime** (local maritime, international maritime)
2. Buildings	**2.1 Residential** (appliances, cooking, lighting, space cooling, water heating) **2.2 Non-residential** (appliances, cooking, lighting, space cooling, water heating)
3. Industry	**3.1 Oil & Gas** (oil & gas production, petrochemicals, refining) **3.2 Commodities** (iron & steel, cement, aluminum) **3.3 Other industry** (agriculture & forestry, light industries (e.g., food processing, furniture))
4. Power	**4.1 Nuclear** (traditional nuclear, SMR) **4.2 Co-generation** **4.3 Gas-based facilities** (combined cycle gas turbine (CCGT), open-cycle gas turbine (OCGT), CCGT with CCUS) **4.4 Waste - Bioenergy** **4.5 Renewables** (solar, wind onshore)

Source: Abu Dhabi Integrated Energy Model, Department of Energy - Abu Dhabi, 2022

Appendix 4: Impact Assessment Methodology

Six impact areas were rated for Abu Dhabi on a five-point scale: environment sustainability, cost competitiveness, energy independence, optimal exploitation of natural resources, industrial growth and socioeconomics. Each scenario's KPIs were ranked based on the ranking criteria presented in Figure 22, with the best scenario receiving 5 points and the worst scenario receiving 1 point. The other scenarios received a score of 1 to 5, depending on their position between best and worst.

Figure 22: KPI and ranking criteria

Impact area	KPIs	Ranking criteria
1. Environmental sustainability	1.1) Total **CO_2 emissions**	1.1) Highest = 1, Lowest = 5
2. Cost competitiveness	2.1) Total **energy production cost**/ energy supply	2.1) Highest = 1, Lowest = 5
3. Energy independence	3.1) Share of **energy imported**	3.1) Highest = 1, Lowest = 5
4. Optimal exploitation of natural resources	4.1) **Crude oil** production 4.2) **Natural gas** production 4.3) **Hydrogen** production 4.4) **Groundwater supply**	4.1) Highest = 1, Lowest = 5 4.2) Highest = 1, Lowest = 5 4.3) Highest = 5, Lowest = 1 4.4) Highest = 1, Lowest = 5
5. Industrial growth	5.1) Industrial **output**	5.1) Highest = 5, Lowest = 1
6. Socioeconomics	6.1) **Demographics:** a. Population 6.2) **Labor market:** a. Earnings b. Labor supply c. Unemployment 6.3) **Health:** a. Public health index b. Deaths from emissions 6.4) **GDP:** a. Total GDP b. Non-oil GDP share 6.5) **Trade:** a. Export b. Import 6.6) **Investments:** a. Total fixed investment b. Foreign direct investment 6.7) **Fiscal:** a. Government revenue b. Government balance 6.8) **Prices:** a. Consumer price index b. Energy component of CPI 6.9) **Tariffs and subsidies:** a. Energy subsidies b. Water subsidies	6.1) a. Highest = 5, Lowest = 1 6.2) a. b. Highest = 5, Lowest = 1, c. Highest = 1, Lowest = 5 6.3) a. Highest = 5, Lowest = 1, b. Highest = 1, Lowest = 5 6.4) a. b. Highest = 5, Lowest = 1 6.5) a. Highest = 5, Lowest = 1, b. Highest = 1, Lowest = 5 6.6) a. b. Highest = 5, Lowest = 1 6.7) a. b. Highest = 5, Lowest = 1 6.8) a. b. Highest = 1, Lowest = 5 6.9) a. b. Highest = 1, Lowest = 5

Source: Abu Dhabi Integrated Energy Model, Department of Energy - Abu Dhabi, 2022

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