Executive Summary of the Net-Zero Greenhouse Gas Emissions Pathway for Israel's Energy Sector by 2050

Summary

This document presents a roadmap for carbon neutrality in Israel's energy sector by 2050, aiming to ensure a diverse, reliable, affordable, and clean energy system. The work is based on a model developed to achieve the neutrality target and outlines several policy measures to reach this objective. It draws on previous studies, international trends, particularly in decentralized and local energy-generation technologies, includes a detailed examination of Israel's unique characteristics and presents three main alternatives as well as significant policy steps necessary to meet the targets.

According to the IPCC (Intergovernmental Panel on Climate Change), international efforts to prevent the deterioration of global climate conditions require a 45% reduction in greenhouse gas emissions by 2030, compared to 2010 levels, and achieving net-zero emissions by 2050. Accordingly, many countries have committed to achieving net-zero emissions by 2050.

The climate change crisis emphasizes the need for resilience, energy independence, and the realization of geo-political and economic growth opportunities through resource diversification. These principles also underpin energy sector planning for security emergencies, such as those experienced during the "Iron Swords" war.

The increasing frequency of extreme weather events and international conflicts around the globe in which energy supply is disrupted, or prices are sharply increased and severely impact economies, suggests that in order to maintain a stable and continuous energy supply, along with stable prices, it is essential to diversify energy sources and ensure mutual backup across different technologies, including nuclear energy, hydrogen, and other complementary low-carbon technologies. This requirement highlights the importance of diversifying energy sources as part of Israel's overall strategy.

Furthermore, global trends suggest that developing Israeli technologies which will enable the transition to a clean energy economy, will leverage Israel's characteristics as a nation of innovation. Investment in R&D is expected to yield significant benefits in achieving Israel's carbon neutrality target and could help local industries adopt leading technologies, tailor them to Israel's unique characteristics, and ensure their widespread implementation. This, in turn, will help reduce emissions and enhance the global energy market while strengthening Israel's role as a global leader in this field. Therefore, investing and incentivizing the development of Israeli technologies as part of the national strategy will give Israel a significant advantage in leading specific sectors within this knowledge-intensive field and help it align with other advanced nations.

The globalization of the energy market, combined with Israel's geographical location, allows it to serve as an energy bridge between Europe and the Middle East, Asia, and Africa. This energy connection through Israel, linking continents, holds enormous geopolitical significance and offers substantial value to the economy, environment, security, and other areas.

Israel's strategy for carbon neutrality, aligned with global trends, will include a high percentage of energy from renewable sources, ensuring a stable and continuous supply, alongside local innovation, regional connectivity, and diversification of energy sources, including nuclear energy and hydrogen. These measures will drive both local and international growth.

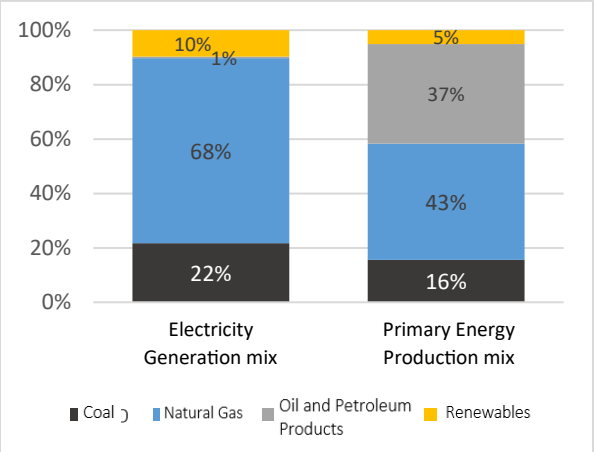
The Israeli Economy and the Model of Energy Demand and Usage

The examination of mitigation channels was conducted with reference to the following characteristics: the fact that solar energy is the almost sole source of renewable energy in Israel, Israel's current status as an energy island that is scarcely connected to energy grids in neighboring countries, the rapid increase in energy demand compared to other countries, Israel's high population density and the difficulty in allocating extensive areas for solar systems, as well as the presence of local natural gas reserves off the coast of Israel.

In 2022, approximately half of the energy in Israel was consumed as electricity, about a third as fuels and derivatives in the transportation and industrial sectors, and the remainder as natural gas for industry. The electricity sector was primarily based on natural gas (nearly 70% of production), while about 20% of electricity was generated from coal and about 10% from renewable energies, mainly solar energy. As detailed in this work, there is an ongoing trend towards the adoption of cleaner energy sources across the energy sector as a whole, with a particular emphasis on the electricity sector.

Israel's international commitment includes a target to reduce greenhouse gas emissions by 85% by the year 2050. Alongside this commitment, the Climate Law, which is currently in the legislative process, sets a national goal of achieving net-zero emissions by 2050. This document outlines three main approaches to meeting this target, all of which require proactive measures from both the government and the economy starting today.

Figure 1: The Energy Mix and Electricity Production in Israel in 2022



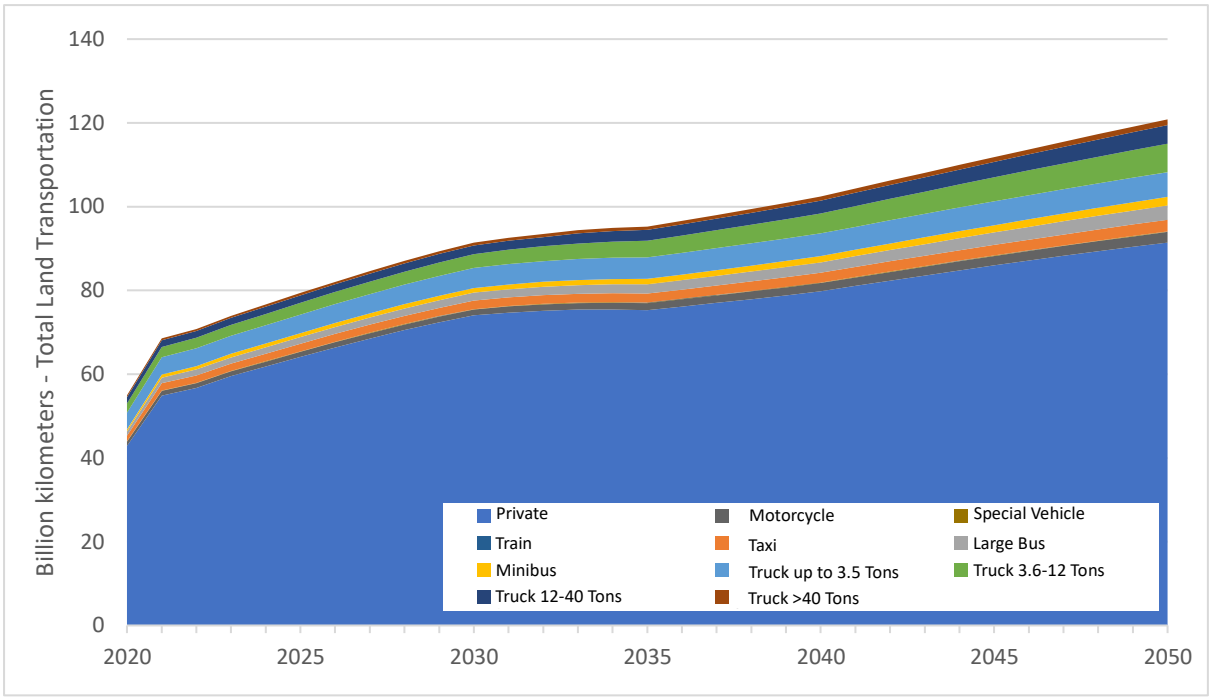
In order to make informed and data-driven decisions for developing a carbon-neutral energy sector, the Ministry of Energy and Infrastructure has developed a model to predict the **requirements** and implications of various decarbonization pathways. The model estimates the expected **demands** up to the year 2050, and even beyond, based on past trends and in consideration of policies published to date. The model addresses demand in the industrial, transportation, and building sectors.

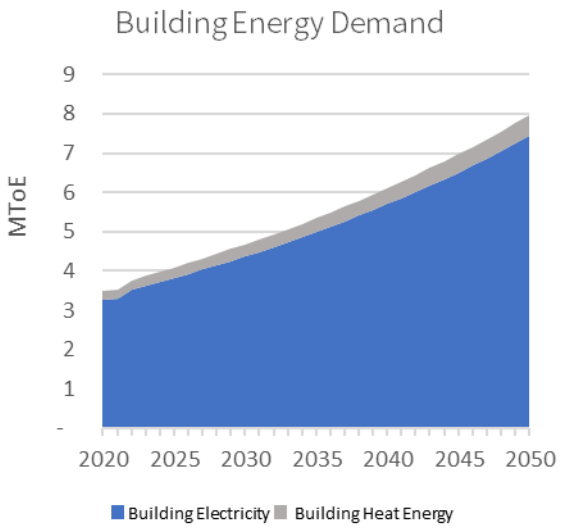
The current energy sector is based on approximately 40% fuels for transportation and industry (Figure 1) and 60% electricity. The majority of the electricity (68%) is generated from natural gas, about 22% from coal, and around 10% from renewable energy (mostly solar). It is important to note that more than half of the primary energy sources (37% fuels and 16% coal) are currently imported.

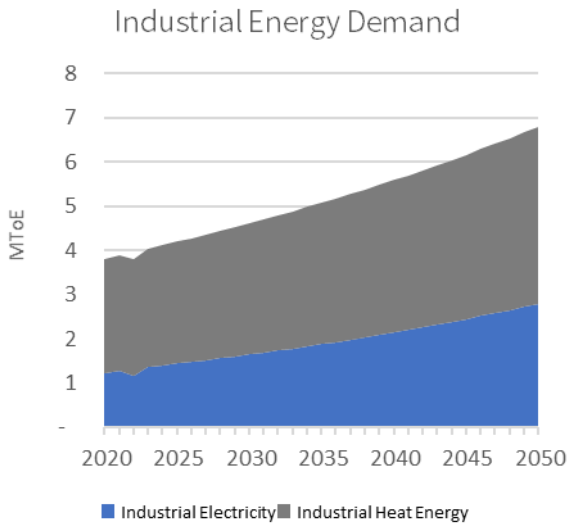
The model starts from the current state and forecasts future developments. It first considers the increase in energy demand due to population growth and economic expansion up to the year 2050, and examines the various sectors in the economy to enable a transition in the energy mix from fossil fuels to clean alternatives. Given the uncertainty regarding future trends, the demand analysis is conducted under three scenarios—high, central, and low.

Below is a summary of the model's forecast for total energy demand across various energy sources up to the year 2050 under the central scenario:

Figure 2: Energy Consumption Trends in the Market 2020-2050 Across Different Sectors[1]





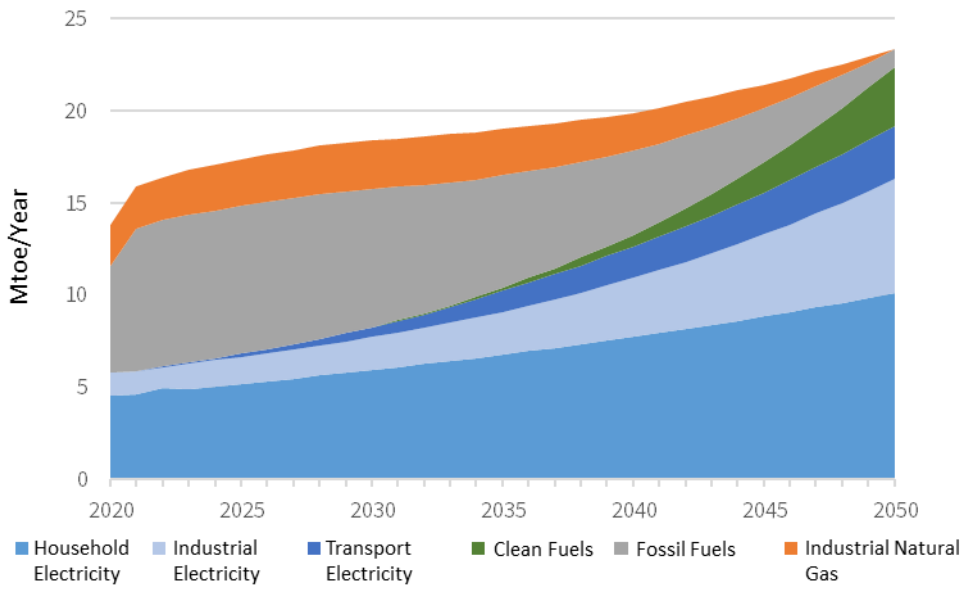


1 Forecast by the Ministry of Energy and Infrastructure.

As demonstrated in Figure 2, the expected demand for transport activity across various land transportation sectors is led by the demand in private transport; however, starting from 2030, with the electrification of most heavy rail lines, the introduction of the metro, and the operation of light rail networks, the share of trains in electricity demand will significantly increase. The bottom graphs show the continuous rise in energy demand in the industrial and building sectors, detailed in terms of electricity and heat. As the transition to a net-zero emissions economy progresses, most of the heat component will shift to electricity use, with a small portion likely to shift towards hydrogen.

Following the demand calculations, methods were examined to meet these demands in net-zero emissions scenarios. The model examined the electricity, fuel, and natural gas markets, as well as future components such as hydrogen, synthetic fuels, and biofuels, alongside the carbon dioxide emissions that will require management. The net-zero scenarios explored a combination of technologies that will enable the achievement of net-zero emissions goals: enhancing energy efficiency; transitioning industry from polluting fossil fuels to clean alternatives such as electricity and hydrogen; electrifying land transportation; using clean fuels for aviation and shipping (including hydrogen, biofuels, and synthetic fuels); replacing the use of fuels and LPG in the building sector with electricity.

Figure 3: Key Trends in Energy Sources in the Market 2020-2050 [2]



In Figure 3, the key emerging trends in the demand for various energy sources can be observed: The demand for fuels and natural gas is expected to decrease due to the shift towards clean energy sources in transportation, industry, and the electricity market. However, this demand will not drop to zero by 2050. The growth rate of electricity demand will accelerate, incorporating segments of demand that have shifted from fossil fuels in industry and transportation. Additionally, the hydrogen and clean fuels

[2] Forecast by the Ministry of Energy and Infrastructure.

sectors – both biological and synthetic – are expected to develop as alternatives to fossil fuels. According to the model, by 2050, electricity demand is expected to increase to approximately 19.2 MToE per year (around 220 TWh) – more than three times the current electricity demand.

Key Emission Reduction Technologies

To achieve net-zero greenhouse gas emissions in Israel, a review of the key existing technologies at various stages of maturity was conducted. From these, five main technologies were selected that could enable carbon neutrality in the economy. The implications and consequences of using each technology to achieve full carbon neutrality were examined, including factors such as: the amount of land required for solar systems, the amount of natural gas needed, the amount of carbon dioxide that would be captured and require treatment and storage, the amount of water needed to operate the various facilities, and more.

The five technologies examined are:

1. **Renewable Energy and "Green" Hydrogen:** In Israel, the main and almost exclusive source of renewable energy is solar power. Integrating high percentages of solar energy into the electricity grid is challenging. For example, there is a need for seasonal storage to store excess electricity from the spring for use in the following winter. One solution to this is green hydrogen (hydrogen produced from water using electricity), which is not yet viable on a large scale, but is important for local production on infrastructure close to end-users. In addition to the challenge of seasonal storage, vast areas are required for the installation of solar panels, and there will be a need for massive reinforcement of the electricity transmission network, which will impact open spaces and the landscapes of the country. To fully meet Israel's energy needs from solar energy, maximum electrification of energy consumers, the use of green hydrogen for heavy transport and heat consumers in industry where electrification is technically complex, and seasonal storage will be required.
2. **Natural Gas Combined with Carbon Capture Technologies:** Extensive use of natural gas with carbon capture (mainly to complement solar energy-based electricity production in winter and at night, as well as for heat consumers in heavy industry) will necessitate significant development of efficient and cost-effective carbon capture technologies, as well as the establishment of national infrastructure for carbon transport and storage sites through underground compression, or its use in a way that does not release it into the atmosphere. All of these are based on technologies that have not yet been tested on a large scale, are still expensive, require space and national infrastructure development, and will require complex planning procedures for implementation. Moreover, the use of such technologies will require sufficient reserves or the import of natural gas for the local market, even beyond the horizon of 2050.
3. **"Blue" Hydrogen:** Hydrogen produced from natural gas, with the carbon captured and stored or used, preventing its release into the atmosphere. The use of blue hydrogen requires the establishment of large-scale hydrogen production systems, including carbon capture, ~~transport~~, and storage systems, as well as the deployment of infrastructure for hydrogen transport or the adaptation of the existing natural gas network for hydrogen transport, and the conversion of electricity generation and industrial systems to hydrogen use. It should be noted that there are still no large-scale blue hydrogen production demonstration facilities in the world to rely on, and that in this case, natural gas reserves will also be needed beyond 2050.

4. **Nuclear Energy and "Red" Hydrogen:** New technologies for nuclear power reactors are currently being developed worldwide – specifically modular reactors (SMRs) and Generation IV reactors. These reactors are currently in development and pilot stages and are expected to be more efficient, cost-effective, and safer than existing reactors. Establishing a nuclear power reactor in Israel would require addressing technological, regulatory, and policy issues. Should a decision be made to pursue nuclear power, broader aspects of the issues will be examined, including a public discussion. Due to land constraints and safety distances from the population, it will be possible to establish a limited nuclear capacity in Israel that would supply only about 15-20% of the demand. Therefore, additional solar, hydrogen, or natural gas production with carbon capture will be required. It is challenging to integrate solar energy, which is inherently intermittent, with nuclear energy, which generates constant power. To bridge these gaps, energy storage will be necessary.

   Additionally, nuclear fusion technology, which is based on different principles from nuclear power reactors, could be utilized. This technology does not produce fissile material, and therefore, it may bypass the complex policy issues associated with nuclear technology. However, despite this technology being safer and cleaner, it is still in the early stages of development, so it is unclear whether it can be implemented in Israel by 2050.

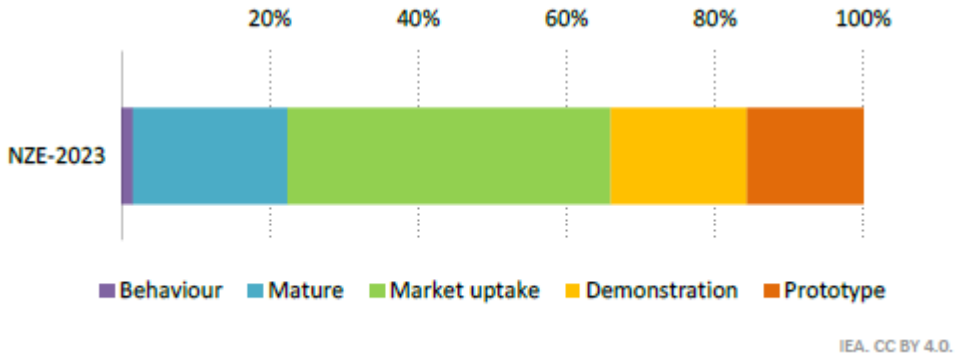
5. **Energy Import and Regional and International Connectivity:** With global progress towards the transition to renewable energies and new energy technologies, the importance of building regional energy connections is increasing. Establishing infrastructure for the import of electricity and hydrogen and the transfer of energy between different regions can foster economic, political, and technological cooperation that benefits all involved countries. Israel's unique geographical location, which connects continents and has historically served as a central crossroads for the passage of goods and cultures, offers significant advantages. Maximizing these advantages can position Israel as a bridge between the Middle East and Europe. Establishing energy connections with Middle Eastern and European countries could aid in the development and strengthening of political and economic ties between these nations and Israel. This trend, combined with Israel's unique location, opens a window of opportunity for Israel to advance regional and international connectivity, which will significantly contribute to ensuring energy import infrastructure and sources. Energy imports could include electricity, hydrogen, or other clean fuels. Israel is already working towards connectivity, for example, by connecting the Israeli electricity grid to the European grid and purchasing electricity from renewable sources, or by direct connection to renewable energy facilities in neighboring countries. At the same time, Israel’s role and position in the future global market, which is expected to develop for the transport of hydrogen and other clean fuels such as ammonia, methanol, and renewable energy-based fuels for aviation and shipping, must be examined. The need for energy imports necessitates an examination of various opportunities for regional and international connectivity while creating a clear strategy and vision for connectivity, alongside identifying the challenges involved and ensuring that these challenges are addressed.

   In addition to the emission-reduction technologies described above, there are several complementary technologies for achieving total net-zero emissions. For infrastructure that cannot be converted to clean sources by 2050, such as heavy trucks or airplanes, synthetic and biological fuels can be used – fuels for which production requires the capture of greenhouse gases from the atmosphere in the same amount that is emitted during their use, and therefore are considered to have net-zero emissions. For components of the energy sector which will

keep emitting greenhouse gases, such as power plants with carbon capture that do not achieve 100% capture of emissions, carbon removal tools from the atmosphere will be needed. These tools use chemical or biological technologies to capture carbon dioxide from the atmosphere and sequester it in the ground or the deep ocean.

In an investment analysis conducted by the IEA[3], it was found that a significant share of the technologies required to achieve Net-zero emissions by 2050 have not yet been developed and some are yet to be known (see Figure 4 below). Therefore, global investments in clean energy sectors are increasing rapidly. To meet global targets for 2030, the rate of investment will need to double or more. This presents a significant potential market, where Israel's unique advantages could position it favorably for developing solutions, provided that both government and private sector investments in clean energy R&D are significantly increased.

Figure 4: Technologies Required for Net-Zero Emissions by 2050 According to Readiness Level[4]



[3] *World Energy Investment 2023*, IEA

[4] *Net Zero Roadmap, 2023 Update*, IEA 2023.

Below is a table summarizing the key issues and comparing the main technologies examined for achieving net-zero emissions:

Table 1: Comparison of Key Emission Reduction Technologies

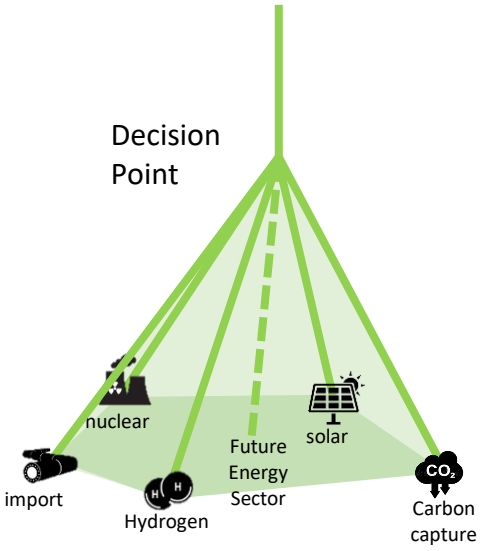
	Energy Import and Turning Israel into an Energy Bridge	Nuclear Energy and "Red" Hydrogen	"Blue" Hydrogen	Natural Gas with Carbon Capture	Renewable Energy and "Green" Hydrogen
Technology Maturity	There are projects in development. More projects are needed	Exists, in process of improvement and upgrading	In development	In development	**Exists, except for seasonal storage. Low efficiency**
Land and Planning Issues	Fuel reception and storage sites	Locating areas and establishing a network for the sites	Requires production areas and transmission infrastructure	Requires the identification of storage sites and the development of a CO2 pipeline network	**Very high land requirement, up to 1.5 million dunams**
Natural Gas Requirement	None	None	High	High	**None**
Additional Infrastructure	reception infrastructures, storage tanks, and distribution infrastructure	Deployment of a network for power plants, protection	Hydrogen production sites, nationwide hydrogen and CO2 pipeline networks, and CO2 storage sites	Nationwide CO2 pipeline network and storage sites	**Deployment of an extensive electricity and storage network**
Additional Issues	Energy security, development of clean fuel markets	Technological, regulatory, and policy issues	Natural gas consumption relative to reserves	Natural gas consumption relative to reserves	**Seasonal storage**

Model Conclusions and Integrated Scenarios

Through the analysis of the model results for the five key emission reduction technologies, it was found that each technology faces significant challenges for full implementation. When using renewable energy, there is a technical difficulty in approaching 100% solar energy usage in the economy, along with the challenging requirement to meet the suitable land requirement. Regarding the use of natural gas with carbon capture or blue hydrogen, significant amounts of natural gas will be needed until 2050 and beyond, and there is uncertainty about the ability to capture and store CO2 globally and particularly in Israel. For nuclear energy, it appears that there are technological, regulatory, and policy issues that need to be addressed. Concerning energy imports, to maintain Israel's energy security and independence, it is essential to limit reliance on high levels of imported energy. **Therefore, it is clear that a single technology cannot be relied upon to achieve carbon neutrality**. Any comprehensive future solution must be based on a **combination of several technologies** to meet the economy's needs at all times.

Additionally, energy security-of-supply considerations also necessitate the diversification of energy sources. Extreme events could impair the supply capability of any single technology, making it essential to integrate multiple technologies to provide mutual backup in times of crisis. However, most technologies require dedicated, complex, and costly national infrastructure. Consequently, the integration of multiple technologies comes with a significant cost due to the necessity of developing multiple infrastructures. Therefore, it is important to balance the benefits of integrating new and diverse technologies against the costs of establishing or adapting existing or planned infrastructure for these technologies.

Figure 5: The Future Operational Scope for Achieving Net-Zero Emissions.



In Figure 5, the limited operational scope between the technologies described is presented. The future framework will operate within this scope and will integrate multiple technologies to maximize the advantages inherent in each. Therefore, the key question in the coming years will be **determining the optimal combination of future technologies that achieves the most effective balance** between the diverse demands of the energy sector.

In this light, **three integrated scenarios were examined**, aiming to maximize the benefits of combining new technologies without massive investment in supporting infrastructure. The scenarios were built around three key technologies—**solar energy, carbon capture, and nuclear energy**—combined with imports and complementary technologies in all scenarios, while considering Israel's unique constraints. The different scenarios depend on several assumptions regarding future technological developments. The likelihood of a scenario being realized increases if these developments are achieved. Conversely, if these developments are delayed or not achieved at all, the feasibility of the scenario decreases, and the likelihood of selecting it accordingly diminishes. The choice of the technological mix in each scenario was based on the likelihood of realization according to the current technological potential, alongside a recommendation for periodic review.

Below is a brief description of the scenarios that were examined:

The "Yellow" Scenario: This scenario integrates a relatively high percentage of solar energy, supplemented by gas turbines equipped with carbon capture and supported by energy imports. In this scenario, approximately 64% of the energy in the market (77% of electricity generation) would come from solar systems, around 14% from natural-gas-fired generation equipped with carbon capture that would operate during periods of solar energy shortages, and about 22% from imports. The imports would include clean electricity to support solar generation during shortages, as well as hydrogen for use in industry and heavy transportation. This scenario relies on the assumption that advancements in solar and battery storage technology will lower costs and increase efficiency, enabling the production of the same amount of electricity from a smaller area. It also assumes that technical solutions will be developed to integrate a high percentage of solar energy into the grid, and that further efforts will be made to realize renewable energy potential, such as creating renewable energy facilities combined with agriculture (agrivoltaics) and in marine areas. Despite the high levels of renewable energy, this scenario avoids the need for seasonal electricity storage and provides backup for the solar systems using imported electricity and natural gas turbines with carbon capture. The scenario also assumes that clean fuels (synthetic and biological) will be imported to meet the needs of the aviation, shipping, and heavy transport sectors.

An alternative to the yellow scenario includes allocating some of the solar-generated electricity to produce green hydrogen for local use, especially for various hydrogen projects targeting industrial and transportation applications (such as Hydrogen Valleys). According to current technologies, producing green hydrogen requires converting electricity generated from renewable energy into hydrogen, and sometimes reconverting it back into electricity for use. These conversions result in energy losses, which would require a significant additional area for the installation of more solar systems. This scenario utilizes excess solar production as green hydrogen. As technological advancements are made and the efficiency of green hydrogen production improves, a broader integration of green hydrogen may become strategically advantageous.

The "Blue" Scenario: The blue scenario also relies on solar energy, but to a lesser extent, covering approximately 45% of total energy demand (56% of electricity generation). Additionally, around 30% of the energy demand would be met by natural gas, which would be used to produce blue hydrogen. This process would involve capturing the CO2 emissions generated and either storing it or using it as an industrial raw material. To diversify energy sources and enhance supply security, this scenario also includes about 25% imports of energy products such as electricity and synthetic fuels. Significant infrastructure investments will be required in this scenario, which will only be justified if technological developments improve the efficiency and cost-effectiveness of hydrogen production and utilization processes, as well as CO2 capture and storage. Blue hydrogen technologies are in their early stages, making it difficult to draw conclusions about their ability and the implications for wide-scale deployment as a central energy source. Additionally, hydrogen production facilities, CO2 capture systems, and the national transmission infrastructure will require extensive lands, necessitating the identification of suitable locations, regulatory planning, and bearing the costs of land acquisition. Another issue is the source of natural gas—as long as Israel has local natural gas reserves, hydrogen production costs will be relatively low. However, if natural gas needs to be imported, whether through pipelines from neighboring countries or as LNG on the global market, costs are likely to rise, and risks will increase.

A variant of the blue scenario is based on the direct use of natural gas with carbon capture. This variant has both advantages and disadvantages. On the one hand, using natural gas with carbon capture reduces the efficiency of turbines, requiring an increase in the installed capacity needed to produce

the same amount of energy. On the other hand, the cost of blue hydrogen is currently higher than that of natural gas and carbon capture. Additionally, although CO2 capture technology has been under development for many years, its commercial maturity has not yet been proven. From a system-wide perspective, blue hydrogen has the advantage of requiring fewer CO2 sources, necessitating less extensive CO2 transport infrastructure compared to capturing carbon from power plants and factories spread across the country. It is also unclear whether it is feasible and what the implications would be for establishing carbon capture facilities at every plant and power station in the country. Therefore, the blue scenario is based on blue hydrogen, although, in basic calculations, using natural gas currently appears to be cheaper.

The "Red" Scenario: The red scenario involves electricity generation from nuclear energy. The use of nuclear energy in Israel would be combined with significant electrification of the transportation and industrial sectors and the use of renewable energies to meet approximately 55% of the energy demand. Starting in 2030, carbon capture measures will be implemented for the remaining natural gas consumers in the electricity and industrial sectors, or a transition to blue hydrogen will take place. Simultaneously, the development of energy import channels is necessary—connecting the Israeli electricity grid to the European grid and neighboring countries, importing clean fuels via ships, and importing clean hydrogen from neighboring countries through pipelines to complete the energy mix and enhance energy diversity.

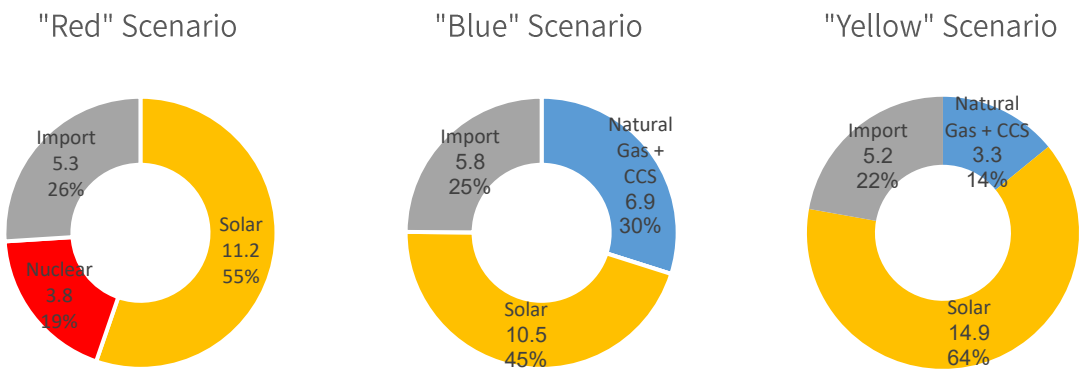
It is assumed that by 2050, several nuclear power plants (NPPs) will be operational—either two large plants or several small plants. Thus, by 2050, Israel's energy mix is expected to be net-zero emissions, consisting of approximately 55% renewable sources, about 20% nuclear energy and red hydrogen, and around 26% imported energy products. This scenario depends on several processes, such as technological developments in modular reactors that would make them more accessible, affordable, and reliable; addressing policy issues; completing a techno-economic cost/benefit analysis to determine the feasibility of establishing NPPs in Israel is feasible; and conducting a deep public discussion that examines all aspects of using this technology in Israel and supports its implementation. It should be noted that as nuclear fusion technologies, which are safer and cleaner, are developed, similar use of these technologies may also become possible.

Summary Of Scenarios

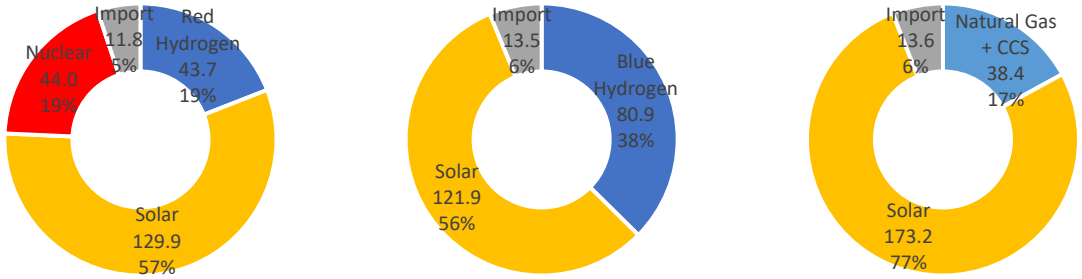
Below is a diagram and table summarizing the scenarios examined. It is important to distinguish between the quantities of energy produced and the installed capacities. For example, in the red scenario, nuclear power constitutes approximately 5% of the total installed capacity, but generates almost 20% of the electricity, due to its high capacity factor[5].

Figure 6: Summary of scenarios

Energy sources according to the three scenarios



Electricity generation sources according to the three scenarios



[5] The Capacity Factor describes the percentage of time, on an annual average, that a production unit is operational. Thus, solar energy, which operates for approximately 5 effective hours per day, has a Capacity Factor of 20%, while a nuclear power plant, on the other hand, has a Capacity Factor of 95%.

Table 2: Summary of the energy mix and installed capacities in the combined scenarios.

Aspect	"Red" Scenario	"Blue" Scenario	"Yellow" Scenario
Solar Energy	Approximately 80GW, which is about 600-700 thousand dunams (mostly in dual-use).	Approximately 75GW, which is about 550-650 thousand dunams (mostly in dual-use).	Approximately 108GW, which is about 800-900 thousand dunams (mostly in dual-use).
Storage	Approximately 50GW for 4 hours	Approximately 34GW for 4 hours	Approximately 70GW for 4 hours
Power Plants	22GW Hydrogen-Fueled Turbines	29GW Hydrogen-Fueled Turbines	22GW Natural gas Turbines with carbon capture.
Estimation of Electricity Generation Systems Cost **LCOE**	96.5 $/MWh	105.6 $/MWh	91.5 $/MWh
Use of Natural Gas	None.	Approximately 18.9 BCM of natural gas in 2050 for the production of blue hydrogen.	Approximately 7.6 BCM of natural gas in 2050 for gas turbines with carbon capture.
Use of Hydrogen	Approximately 3.4 million tons of hydrogen per year. Out of this, about 850,000 tons are allocated for industry, transportation, and the production of clean fuels.	Approximately 5.5 million tons of hydrogen per year. Out of this, about 790,000 tons are allocated for industry, transportation, and the production of clean fuels.	Approximately 600,000 tons of hydrogen per year for the transportation and industrial sectors, as well as for the production of clean fuels.
Local Hydrogen Production	Approximately 2.7 million tons of red hydrogen per year.	Approximately 4.7 million tons of blue hydrogen per year.	Local production of green hydrogen on a small scale.

Aspect	"Red" Scenario	"Blue" Scenario	"Yellow" Scenario
Carbon Capture	None	Approximately 34 million tons per year.	Approximately 16 million tons per year.
Carbon Removal	Approximately 2.8 million tons per year in 2050, at a cost of about 1.0 billion NIS per year.	Approximately 3.8 million tons per year in 2050, at a cost of about 1.4 billion NIS per year.	Approximately 3.2 million tons per year in 2050, at a cost of about 1.2 billion NIS per year.
Hydrogen or Other Fuels Import	Approximately 700,000 tons of hydrogen, 1.3 million tons of clean fuels, and 1.1 million tons of fossil fuels.	Approximately 810,000 tons of hydrogen, 1.7 million tons of clean fuels, and 1.1 million tons of fossil fuels.	Approximately 600,000 tons of hydrogen, 1.7 million tons of clean fuels, and 1.1 million tons of fossil fuels.
National Infrastructure	Expansion of the electrical transmission segment from reactor sites, red hydrogen production facilities in the reactor area, infrastructure for hydrogen transmission to the national grid, clean fuel reception facilities at seaports, and distribution of fuels to power stations and consumers nationwide.	Expansion of the national transmission network, blue hydrogen production facilities, a national hydrogen transmission network, and a national network for carbon capture and storage. Clean fuel reception facilities at seaports and distribution of fuels to power stations and consumers nationwide.	Expansion of the national electricity transmission network, national hydrogen transmission network, clean fuel reception facilities at seaports, and distribution of fuels to power stations and consumers nationwide.

Figure 7: Percentage of Solar Energy Out of Total Electricity Production Across Different Scenarios

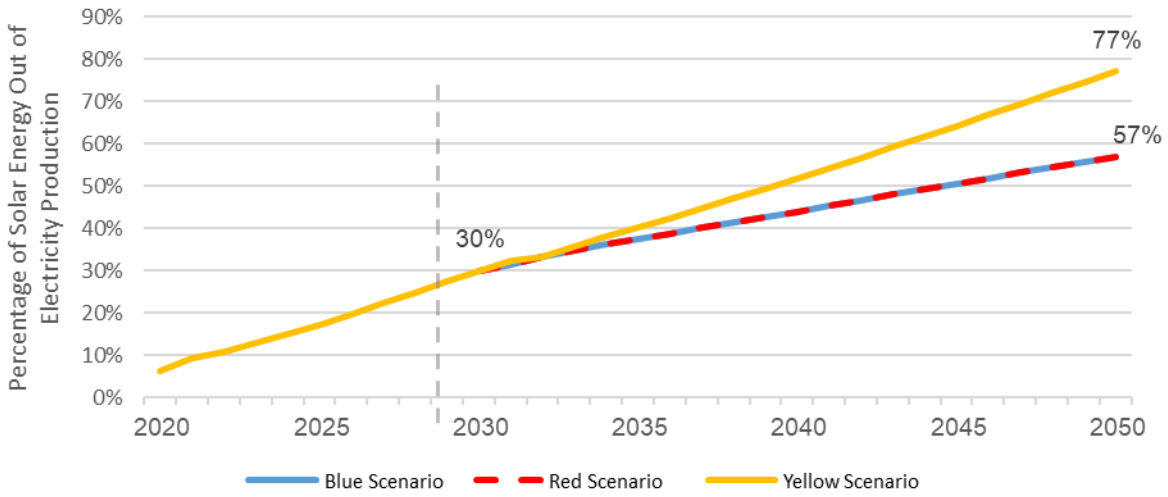


Figure 7 shows the percentage of renewable energy out of total electricity production across different scenarios. The share of renewable energies is expected to be higher in 2050, ranging from 57% in the blue and red scenarios to 77% in the yellow scenario.

Figure 8: Natural Gas Consumption for Electricity Production Across Different Scenarios

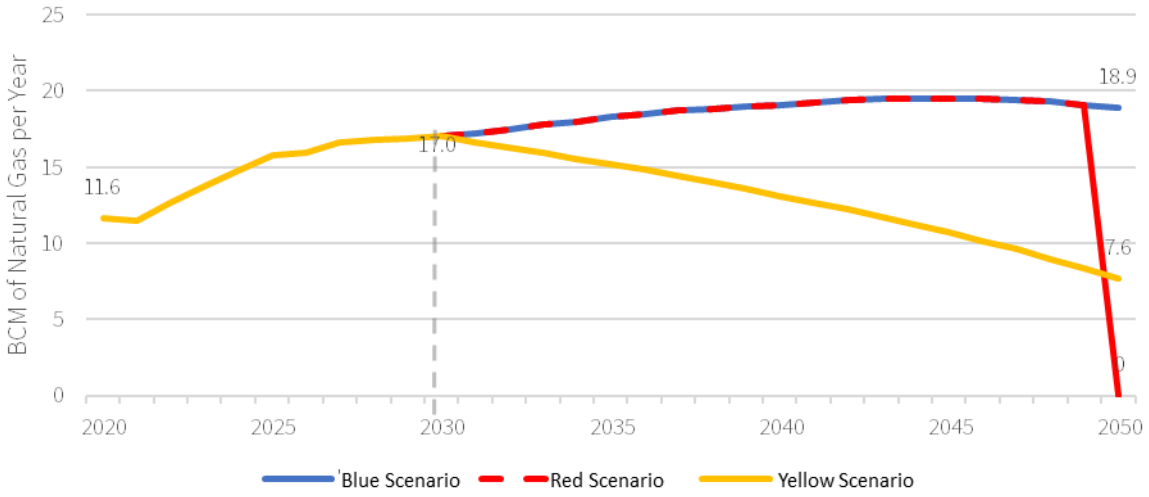


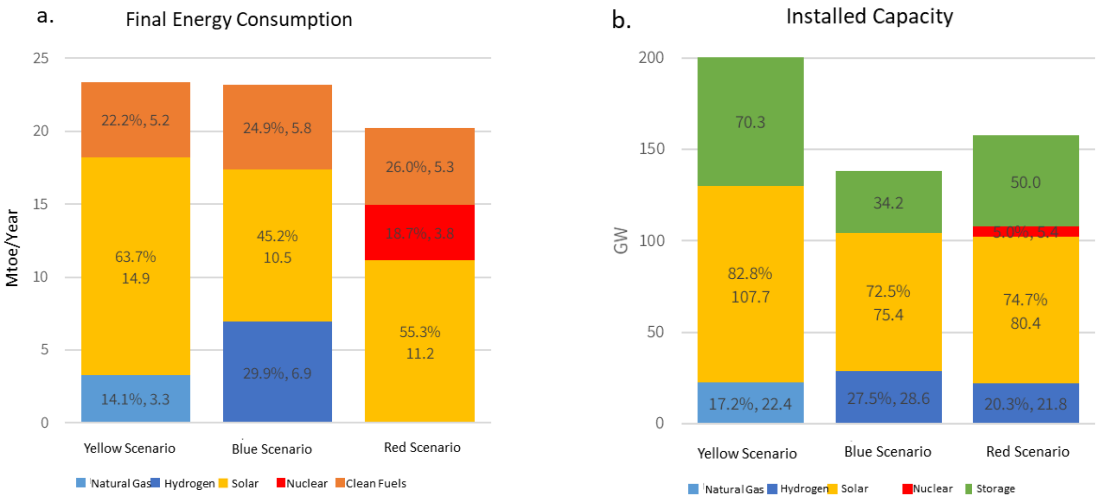
Figure 8 shows the annual natural gas consumption for electricity production across different scenarios. In the blue scenario, which involves the ongoing use of natural gas with its conversion to blue hydrogen, natural gas consumption is the highest, stabilizing at around 19 BCM per year (compared to approximately 13 BCM in 2023). In the yellow scenario, significant installation of solar systems is expected, but natural gas use with carbon capture will continue, leading to a consumption of about 7.6 BCM per year by 2050. In the red scenario, the demand for natural gas will decrease due to the installation of renewable energy systems, and by 2050, with the integration of nuclear reactors into the grid, natural gas consumption will drop to zero.

Economic Analysis – Estimated Production Costs

Due to technological uncertainty and rapid changes in the energy sector, it is currently challenging to estimate the economic costs of each scenario up to 2050. Despite this, calculations have been conducted to estimate the costs of electricity generation in the future scenarios as a basis for comparison. For this purpose, the Levelized Cost of Electricity (LCOE), a commonly accepted metric which represents the cost of production systems over their lifetimes and calculates the effective cost per kWh, was used. The LCOE allows for the calculation of the cost per kWh for different technologies and future scenarios, thereby enabling a comparison of the economic viability of these scenarios. However, **the estimated cost only refers to the direct establishment and operation of the electricity generation sector, without factoring in additional costs** such as the addition and construction of transmission lines, carbon capture and storage infrastructure, security costs, and more.

Cost estimates were based on the U.S. National Renewable Energy Laboratory (NREL) and its annual report, which assesses long-term technology costs-NREL Annual Technology Baseline[6]. For areas not covered by NREL, such as hydrogen, additional sources were used.

Figure 9: Comparison of Model Findings Across the Three Main Scenarios Examined



[6] https://atb.nrel.gov/

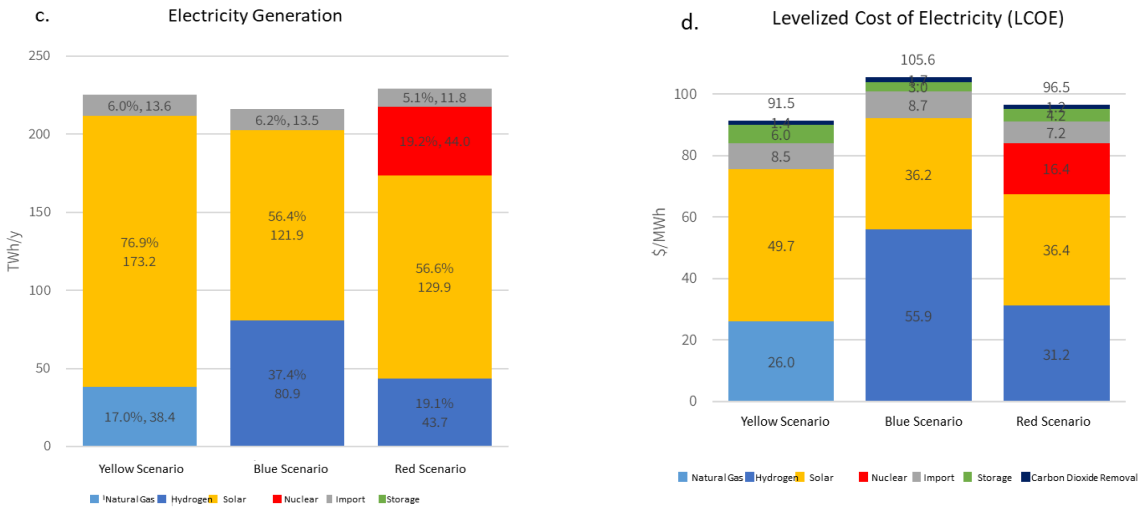


Figure 9 presents graphs comparing the three main alternatives for achieving net-zero emissions by 2050.

Graph A illustrates a comparison of energy sources for final consumption across the three scenarios. It is evident that the yellow and blue scenarios are similar, while the red scenario shows significantly lower values due to the production of red hydrogen, which utilizes heat from nuclear reactors and, therefore, requires relatively less electricity. **Graph B** depicts the installed capacity across different technologies. It is observed that in the red and blue scenarios, the solar capacity is similar due to reliance on other technologies—blue hydrogen and nuclear, respectively. However, in the yellow scenario, a significantly higher capacity is required, along with increased storage capacity, due to the heavy reliance on solar technology. **Graph C** illustrates the energy sources for electricity generation, which sums to a similar total across the different scenarios despite variations in the energy mix. **Graph D** presents the weighted cost per kWh, based on the economic assessment using the LCOE metric, showing that the overall cost for the yellow scenario appears to be the most favorable. It is important to note that these costs do not include certain necessary infrastructure components, such as network costs, carbon capture and storage systems, security and protection, among others. These additional costs could significantly impact the choice of the preferred scenario. Currently, there is insufficient data to accurately assess these costs, so they are not included in the current metric. As the technological outlook becomes clearer and infrastructure costs are better understood, further professional analysis will be required to refine the total costs across the different scenarios.

Key Insights

It is evident that achieving net-zero emissions by 2050 can be accomplished through various approaches; however, none of these approaches provide a "silver bullet" solution. Each pathway to net-zero consists of a combination of multiple solutions and technologies and requires comprehensive planning across several dimensions, which will be subject to periodic evaluation:

- **Energy Security:** Ensuring a continuous and reliable energy supply is a fundamental and essential condition for any scenario that is chosen. This includes assessing the diversity of production methods and sources, the decentralization of production means, and the capability to manage electricity consumption locally.
- **Demand Reduction and Management:** One of the most significant challenges in successfully transitioning to a net-zero energy system is the overall energy demand and the alignment between load matching. Energy efficiency processes are crucial, as are technological and behavioral changes that reduce energy demand, thereby minimizing the investments and infrastructure required for the transition to a clean energy system. Similarly, the more demand can be managed and aligned with supply, the less need there will be for storage and backup generation units to support the solar energy system.
- **No Single Technology:** The examination of available technologies for reducing and achieving net-zero emissions in the energy sector has demonstrated that no single technology can fully meet Israel's future needs under its unique constraints. Therefore, a combination of multiple technologies that complement each other will be necessary.
- **Technology Diversification:** The need for diversifying and integrating technologies across different scenarios arises primarily from energy security considerations, which necessitate a variety of energy sources to provide backup and prevent reliance on a single energy source. As the integration of a particular technology increases, the process becomes more challenging and costly. Therefore, the goal is to integrate multiple technologies in a way that maximizes benefits while balancing the investment required for the various infrastructures.
- **Carbon Removal:** It appears that it will not be possible to eliminate all emissions across all sectors, with approximately 5% of emissions likely to remain and be released into the atmosphere. To achieve full net-zero emissions, it will be necessary to employ carbon removal technologies, meaning the removal of 3-4 million tons of CO2 from the atmosphere annually.
- **Action Must Begin Now:** To achieve net-zero emissions by 2050, dramatic changes in the energy sector are required, both in energy production systems and in supporting infrastructure, such as the expansion of the national electricity grid and the establishment of carbon capture and storage facilities. Given that these involve innovative technologies and significant infrastructure, there are many steps that must be initiated now, even though the target year is two and a half decades away.
- **No-Regret Investments:** There are several solutions that will likely be necessary in any future scenario—maximizing the potential for solar energy production and storage, importing energy products, massive investments in the development of the electricity grid, and more. In these areas, significant action should be taken now, as they represent no-regret investments, meaning investments that will be required in any future scenario and will not be regretted. As noted, all these solutions demand substantial investments in energy infrastructure, necessitating a balance between the benefits of integrating multiple technologies and the associated costs of their adaptation and variety.
- **Land Requirement Challenge:** Extensive land areas will be required in any future scenario. The largest areas will be needed for solar systems, with a focus on maximizing dual-use applications. In the blue scenario, land will also be needed for carbon capture infrastructure and facilities for

converting natural gas to hydrogen. The red scenario will require safety buffer zones around power plants. Additionally, energy imports will necessitate land for reception, conversion, distribution, and transmission facilities.

- **Enabling Regulation:** The various scenarios outlined in this study rely on emerging technologies that are currently under development and are expected to enter widespread commercial use in the coming years. To achieve the net-zero target by 2050, and considering the time required for regulatory development, statutory planning, engineering, and construction phases, it is essential to begin experimenting with these technologies now. Flexible regulation must be developed to allow for experimentation with new technologies, enabling their implementation and the assessment of their impact on Israel's environment and society before final regulations are fully established.
- **Renewable Energy is the Most Cost-Effective and Efficient:** Solar energy produces electricity directly at the lowest cost, but it is limited by the available land for solar installations and the challenges of integrating very high percentages into the grid (requiring significant storage capacity). Solar energy plays a central role in every scenario, but it must be supplemented by supporting technologies such as imports, nuclear power, or gas turbines with carbon capture.
- **Local Management of the Electricity Grid (Microgrid):** Decentralizing energy production sources closer to consumption centers, alongside the increasing digitization of grid components, enables local management of the electricity system at the community or regional level. Unlike the traditional electricity grid, where production is adjusted to meet demand, a grid focused on renewable energy benefits from aligning demand with production. Local management of the electricity grid (microgrid) allows this not only on a national scale but also at the local level. For example, non-essential consumers can be managed during peak hours, or signals can be sent to electric vehicles connected to charging stations to temporarily return energy to the grid. Additionally, the grid can be strategically managed during emergencies.
- **Energy Imports and Regional and International Connectivity:** In all future scenarios, the need for energy imports will be unavoidable. To ensure energy diversity, it will be essential to diversify both the origins of imports—by engaging multiple suppliers—and the technologies used for these imports. This could involve importing electricity through cables from neighboring countries, clean fuels via ships, and hydrogen and other fuels through pipelines. This need emphasizes the critical importance and urgency of establishing robust regional and international connectivity.
- **Maintaining the Domestic Natural Gas Industry:** In nearly all of the scenarios assessed, electricity generation will depend on natural gas with carbon capture or hydrogen produced from natural gas. Therefore, it is critical to preserve the domestic natural gas industry, which will remain a vital resource for Israel in the coming years. Additionally, it is important to ensure that the transmission infrastructure is aligned with future demands and that the power plants currently under construction are designed to incorporate future technologies aimed at reducing and ultimately eliminating greenhouse gas emissions.
- **Securing the Supply of Critical Minerals:** The extensive transition to a clean energy economy, such as the increased use of renewable energy, energy storage, and electric vehicles, necessitates a greater reliance on rare metals and minerals, including lithium, copper, and cobalt. As this trend is global, the demand for these materials is expected to rise substantially, potentially leading to shortages. It is imperative to safeguard Israel's access to critical minerals. This demand will be significantly shaped by geopolitical dynamics, likely driving both competition and the formation of new strategic alliances. The Ministry of Energy and Infrastructure is currently advancing efforts to map the anticipated challenges and opportunities, ensuring that Israel is adequately prepared.

- **Nuclear Power Plants:** Among the technologies mentioned is nuclear energy, which, although a well-established and commercially viable technology, is being considered in the context of modular reactors (SMRs) currently under development. In Israel, this technology is in the early stages of evaluation, but it appears to be a significant and important solution for 2050 and beyond.
- **Adaptation Alongside Mitigation:** The impacts of the climate crisis are already evident today. Therefore, in addition to taking actions to reduce and eliminate emissions, it is essential to address both current and anticipated climate changes. This includes ensuring that energy infrastructure is prepared for rising temperatures, significant decreases in precipitation, and an increase in the frequency of extreme weather events, such as heatwaves, sandstorms, rainstorms, and floods. Preparing the energy sector for extreme weather events will also enhance resilience to security crises and other challenges.
- **Ongoing Horizon Scanning:** Alongside the technologies reviewed in this document and their advancements, it is likely that new technologies will emerge over time that could complement or replace some of the current technologies. It is essential to continuously scan the technological horizon to identify these future technologies, support their integration and adaptation into the local energy sector, and promote research and development for addressing both local and global energy challenges. By developing and advancing groundbreaking technologies for emissions reduction, particularly through the establishment and implementation of a comprehensive R&D strategy for energy and climate, Israel can become a leading global player in this field and drive broader change.
- **Just Transition:** Ensuring a continuous energy supply requires attention to the most vulnerable segments of society, which may be adversely affected by the transition to a zero-emissions energy future. The concept of "Just Transition" addresses the potential risks associated with this shift and offers various policy tools to manage these challenges. This includes ensuring that energy prices remain affordable, safeguarding job security in industries that may decline, and exploring financial mechanisms to support the transition to clean energy for disadvantaged populations.

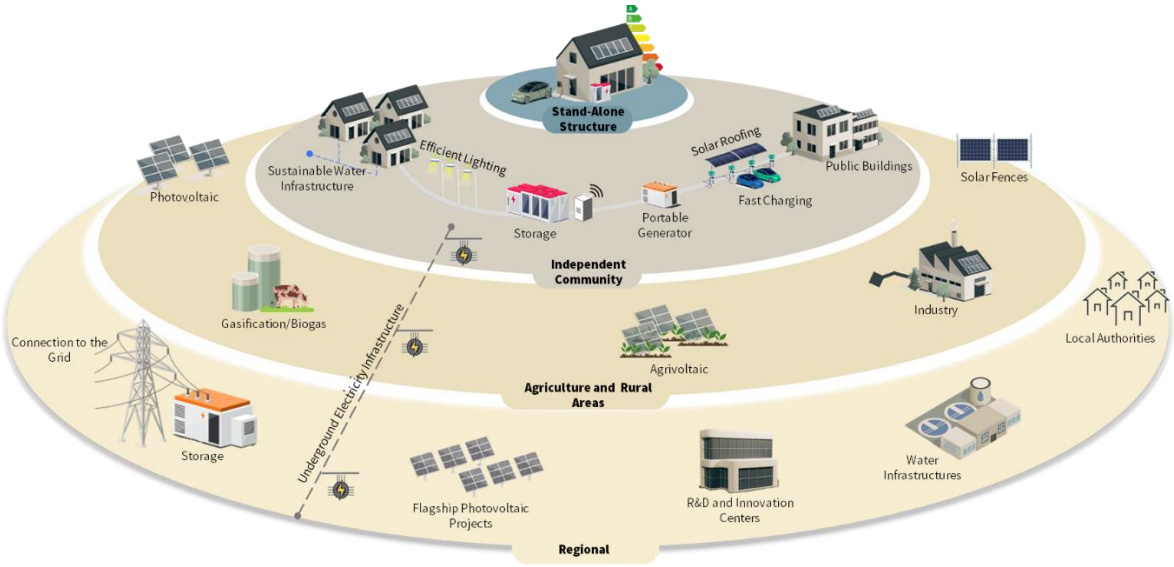
A significant portion of these insights is reflected in the Ministry of Energy and Infrastructure's plan for the rehabilitation and development of the Tekomah region (Gaza Envelope)[7]. The plan outlines a model for energy independence and resilience through the promotion of sustainable, decentralized, and net-zero emissions energy, coupled with accelerated climate innovation and economic development. Under this plan, buildings in the Tekomah region (both private and public) will be constructed to the highest energy efficiency standards, powered by renewable energy, and equipped with storage systems. Additionally, infrastructure for electric vehicle charging will be installed.

Furthermore, for each settlement in the region, electrical infrastructure will be embedded, efficient energy systems (such as smart municipal lighting) will be implemented, and energy management systems at the municipal level ("microgrid") will be established. In agricultural areas and adjacent lands, renewable energy and storage systems will be developed, including agro-voltaic dual-use systems. Regional treatment of agricultural waste for energy (gasification) will be promoted, regional water infrastructure will be upgraded, and a research and development center for energy innovation will be established.

[7] Multiyear Master Plan for the Rehabilitation of Energy and Water Infrastructure in the Tekomah Region, Ministry of Energy and Infrastructure 2024.

The implementation of this vision and plan will transform the Tekomah region into an energy, economic, and climate hub that can be independently managed both in emergencies and in routine situations, thereby serving as a model for the future energy sector.

Figure 10: General Framework for the Rehabilitation of the Tekomah Region Based on Energy Resilience and Independence. Ministry of Energy.



Policy Measures

To achieve the ambitious plan for achieving net-zero emissions, and in alignment with any chosen scenario, it is essential to initiate several processes now that will enable its implementation in the future, even if updates and changes occur based on future developments. There are numerous steps that will be relevant to any selected scenario and can, and should, be undertaken at this stage. These include:

1. **Establishing Renewable Energy Targets:** To meet the ambitious goal of achieving net-zero emissions by 2050, it is essential to set targets for renewable energy that go beyond the current 2030 goal. This includes defining specific targets for 2035 and establishing target ranges for 2040 and 2050. Such targets will provide clear benchmarks for the private sector and set an aspirational standard for government efforts, all within a framework that, along with complementary technologies, will facilitate the achievement of the net-zero emissions goal.

2. **Setting Energy Efficiency Targets for 2050 and Updating and Funding the National Energy Efficiency Program:** Energy efficiency will play a crucial role in all future scenarios and is vital for achieving net-zero emissions. Reducing energy demand will decrease the required investments for any chosen net-zero scenario. Furthermore, energy efficiency investments typically pay back within a few years, making them advantageous for consumers. It is essential to continue promoting energy efficiency through the implementation of the National Energy Efficiency Program and to develop and fund an extended program through 2050.

3. **Multi-Year Funded Program for R&D and Innovation in the Energy Sector, with a Focus on Electricity:** Israel is a global leader in R&D and technology, with some of the most advanced capabilities in the world[8]. Investments in energy technologies have not only generated substantial returns but also led to groundbreaking advancements with global significance[9]. Developing advanced energy technologies in Israel will facilitate rapid progress toward achieving net-zero emissions while ensuring energy security. Simultaneously, it will unlock new global markets that are hungry for technology. A significant investment in this area, including budgetary commitments and a long-term strategic framework, will enhance Israel's capacity to integrate innovative and tailored technological solutions into the local energy sector. It will also expand the existing ecosystem, positioning Israel as a global leader and contributing to the development of future energy industries, thereby playing a major role in both the national economy and global emissions reduction efforts.

4. **Significant Investment in Electrical Grid and Infrastructure:** Currently, Israel's electrical grid is operating at full capacity. Given Israel's unique characteristics, the demand for electricity continues to rise steadily, while solar generation capacity is expanding rapidly in peripheral areas. These trends are placing increasing strain on the transmission infrastructure, which will intensify as the proportion of solar energy in the grid grows and as transportation and industry electrification progresses. Therefore, it is crucial to invest in and prepare for the ongoing increase in demand from now.

5. **Advanced Management of the Electrical Grid:** Developing the grid is crucial for the future of the electricity sector, and its importance will increase as the share of renewable and

[8] From the Innovation Authority Report 2022

[9] For instance, see articles on Israeli technological advancements, and the Ministry of Science's data on Israeli discoveries and innovations that have impacted the world.

decentralized energy sources grows. The planning and construction of grid components are lengthy processes and can delay the connection and operation of new generation facilities. To accommodate large, intermittent, and multi-directional energy flows on the existing grid, advanced tools such as monitoring and control systems are essential for optimal grid utilization. Investment in research, development, and implementation of innovative technologies is necessary to address this national challenge effectively.

6. **Integrated Planning for the Energy Sector:** The analysis conducted highlights the complex interconnections among various sectors of the energy system and the central role of their mutual interactions. Therefore, it is essential to plan the entire energy sector with a holistic approach that incorporates the electricity generation, transmission, and distribution infrastructure, as well as energy efficiency processes. Additionally, emission reductions in other sectors, such as the shift to electric vehicles, can impact the energy system, necessitating the inclusion of future demand centers in the planning process.

7. **Regulatory Flexibility and Certainty:** All scenarios for achieving emission reductions involve the integration of diverse new technologies, such as carbon capture, hydrogen production and utilization, nuclear energy, and more. To provide certainty for the sector and facilitate optimal investments and preparations by the private market, it is essential to prepare the sector for the rapid adoption of new technologies with minimal bureaucratic hurdles.

8. **Enhancing Demand Management:** With the increasing digitization of network components and the expansion of remote control and monitoring capabilities, new methods for managing energy consumption in alignment with network needs are emerging. This advancement enables the temporary shutdown of non-essential consumers during peak times or allows electric vehicles connected to charging stations to either return energy to the grid or increase their consumption during periods of excess production. These strategies can be complemented by incentivizing behavioral changes that promote energy use during surplus production hours. Additionally, substantial investment in research and development is necessary to advance solutions that address these challenges. Demand-side management measures are generally more cost-effective than expanding production or storage capacities and improve the efficiency of network components.

9. **Promotion of Renewable Energy with Storage Integration:** All potential scenarios envision significant utilization of renewable energy, particularly solar energy. Consequently, Israel should aim to be a global leader in solar energy deployment, especially in dual-use applications. This involves evaluating the establishment of renewable energy infrastructure in maritime areas and exploring associated potentials and opportunities. Additionally, efforts should be intensified to support the development of renewable energy sources, expand agro-voltaic projects, advance legislative and regulatory reforms to accelerate the installation of rooftop solar systems, and incentivize energy storage installations. It is also essential to assess the adaptation of natural gas storage facilities and the necessary regulations for their potential conversion to hydrogen storage for seasonal energy storage.

10. **Electrification of Private, Public, and Commercial Transport:** Electric transportation is the most efficient in terms of energy use and plays a crucial role in reducing emissions. This is particularly relevant for Israel, where relatively short travel distances and driving habits align with the advantages of electric vehicles. While some land transportation, especially heavy trucks, may not transition to electric propulsion, efforts should focus on maximizing the electrification of transportation wherever feasible.

11. **Establishing Policy for Sustained Operation During Energy Supply Disruptions (Natural Gas, Fuels, Electricity):** As part of emergency preparedness for the energy sector, a comprehensive policy must be established to address long-term disruptions in one or more of the critical energy infrastructures.

12. **Regional and International Energy Connectivity:** Future scenarios will necessitate energy imports. Given that international agreements and infrastructure development for energy importation are time-consuming, immediate action is required to advance energy import projects to Israel through various channels (electricity, green hydrogen, and clean fuels). Connectivity with neighboring networks will enhance Israel's energy sources, add geopolitical value, and position Israel as an energy bridge connecting Europe with Asia and Africa. An integrated strategy and action plan should be formulated, ongoing international connectivity projects should be advanced, additional projects should be evaluated, and global energy market trends should be monitored.

13. **Advancing Hydrogen as a Clean Energy Source:** Implementation of the hydrogen strategy roadmap for Israel[10] requires completing necessary standardization processes and developing regulations for hydrogen pilot projects. Innovation hubs for hydrogen should be promoted to determine the extent of hydrogen use in Israel and update regulations accordingly. Additionally, preliminary assessments should be conducted on adapting natural gas infrastructure for hydrogen and identifying the implications of such conversions.

14. **Carbon Capture and Storage (CCS):** To meet the target year, a comprehensive sub-surface survey in Israel should be completed to identify suitable areas for carbon storage, estimate storage capacities, and determine injection rates. This includes evaluating all aspects of carbon capture and storage, advancing relevant technologies, and developing the necessary regulatory framework.

15. **Evaluating the Integration of Nuclear Energy into Israel's Energy Mix:** To explore the inclusion of nuclear energy in Israel’s energy mix, immediate action is needed to address technological, regulatory, and policy issues. This includes conducting inter-ministerial feasibility studies as a preliminary assessment for the establishment of a nuclear power plant in Israel.

[10] Hydrogen Strategy for Israel, Ministry of Energy and Infrastructure 2023.