המשרד להגנת הסביבה
الوزارة لحماية البيئة
Israel Ministry of Environmental Protection

Assessment Of Greenhouse Gas Emission Reduction Potential And Recommended National Target For Israel

FINAL REPORT
September 2015

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This analysis was performed by a joint team of expert consultants consisting of the Ministry of Environmental Protection, EcoTraders Ltd., and Ricardo Energy & Environment, for the Inter-ministerial Steering Committee for the Formulation of a National Greenhouse Gas Reduction Target. The team members are:

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EXECUTIVE SUMMARY

1 INTRODUCTION

This project was carried out by Ricardo Energy and Environment (UK) and EcoTraders Ltd (Israel) under the direction of the Israeli Ministry of Environmental Protection, in order to support the Inter-ministerial Steering Committee for the Formulation of a National Greenhouse Gas Reduction Target (the Steering Committee).

The Steering Committee was established in January 2015 in order to recommend to the Israeli government a national GHG emissions reduction target for 2030, as well as abatement actions. The national target, after being approved by the government, will form the basis for Israel's Intended Nationally Determined Contribution (INDC) which it has to submit to the United Nations Framework Convention on Climate Change (UNFCCC), in accordance with UNFCCC Conference of the Parties decisions 1/CP.19 Further Advancing the Durban Platform (2013) and 1/CP.20 Lima Call for Climate Action (2014).

Specifically, the project informed the policy making process by carrying out the following objectives:

- Develop an updated projection of GHG emissions and electricity consumption under a business-as-usual (BAU) scenario through 2030.
- Conduct a qualitative analysis to identify the key technological abatement measures most relevant to Israel.
- Conduct a quantitative analysis of the abatement measures to determine both their abatement potential and their economic impacts, and in particular determine the abatement cost of each measure.
- Examine two different target scenarios based on uptake of the identified abatement measures, as follows: (a) a conservative target scenario, which could be achieved solely through the implementation of cost-effective abatement measures without a price of carbon, (b) an ambitious target scenario, which includes the implementation of all the abatement measures that were found to be feasible, including a number of measures that are not cost effective without accounting for a price of carbon.
- Provide a recommended GHG emissions reduction target for 2030 and a recommended interim target for 2025.
- Assess the overall economic impacts associated with meet

2 KEY FINDINGS

The key findings of the analysis are as follows:

GHG Emissions

- According to the latest GHG emissions inventory published by the CBS, in 2012 Israel's emissions were 83.04 $MtCO_2e$ (10.5 tCO_2e per capita).
- In the absence of further government action, under a BAU scenario GHG emissions in Israel are expected to increase by 27.05% from 2012 levels by 2030, reaching **105.5 $MtCO_2e$ (9.95 tCO_2e per capita)**.
- In the conservative target Israel can reduce its GHG emissions by 27.7% from business-as-usual levels, to **76.3 $MtCO_2e$ in 2030 (7.2 tCO_2e per capita)**.
- **A reduction target of 7.2 tCO_2e per capita could be achieved by the implementation of cost-effective measures only, without a price of carbon.**

Economic Impacts

- Implementation of the conservative target is expected to **yield significant benefits to the Israeli economy (net of associated costs), totalling an estimated NIS 218 billion** (present value).
- Of this, energy efficiency improvements are expected to yield significant economic benefits, with an **economic benefit (net of associated costs) of approximately NIS 56 billion** (present value).
- The decreased use of private vehicles due to investments in public transport infrastructure is expected to yield an **economic benefit (net of associated costs) of approximately NIS 149 billion** (present value). This economic benefit includes direct savings in fuel costs, along with avoided externality costs due to air pollution and related health impacts, as well as the economic benefit of reduced traffic congestion.
- Implementation of the renewable energy target is expected to yield an **economic benefit (net of costs associated with plant construction and operation as well as localized and hydro pumped storage) of nearly NIS 1.5 billion** (present value).

Results by Sector

Energy Efficiency - Electricity

- In the BAU scenario, electricity consumption is expected to grow by approximately 68% relative to 2012 levels, reaching approximately 96 TWh in 2030, with population expected to grow by 30% over the same period, along with increased industrial output and commercial growth.
- Energy efficiency potential in Israel's electricity consumption is estimated at **18-22% relative to BAU levels, in line with similar targets in advanced countries.**

- Within the context of this study, 18 measures that impact electricity consumption were analysed, with the greatest savings in both residential and commercial/public buildings resulting from HVAC (Heating, Ventilation and Air Conditioning) measures. In industry, where uptake of energy efficient equipment is in more advanced stages, the greatest savings can be achieved through Energy Management Systems.
- Of the total energy efficiency potential, implementation of the efficiency measures that were assessed in-depth are expected to achieve a 15% reduction in electricity consumption in the residential, commercial, public, industrial and water sectors, reducing Israeli electricity consumption to 74.8 TWh in 2030 (without the Palestinian Authority), and to 86.4 TWh including the Palestinian Authority.
- Implementation of the energy efficiency measures is expected to yield a total emission reduction of 5.3 $MtCO_2e$ in 2030.
- Additional significant energy efficiency potential, estimated at 6% of total Israeli electricity consumption (excluding transport), can be realised through additional energy efficiency measures that were identified by the working groups but were not subject to an in-depth cost-benefit analysis in the context of this project. Lack of sufficient data or evidence to substantiate the underlying assumptions regarding the abatement potential and cost estimations were the primary reasons for the exclusion of these measures from the final analysis. The measures can be classified into the following main categories:
  - Efficiency improvements in additional significant sources of electricity consumption, such as data centres and servers
  - Establishment of efficient cogeneration and trigeneration-based energy centres in the commercial sector and large residential blocs.
  - Implementation of smart grid and technologies that will enable remote electricity demand management by the grid manager
  - Application of efficiency measures in the agricultural sector, including efficiency improvements in cowsheds, poultry coups and greenhouses.
  - Accelerated implementation of policy mandating construction in accordance with the Green Building standards (No. 5281) in new public, commercial, and residential buildings as of 2018.

Renewable Energy

- In the conservative target scenario, **renewable energy technologies will account for 22.8% of total electricity generation in 2030**, as opposed to only 7.5% in the BAU scenario:
  - PV capacity totalling 7,565 MW will account for 13.1% of total electricity generation. Approximately 40% of this capacity will be installed on rooftops.
  - Onshore wind capacity totalling 800 MW will account for 2.7% of total electricity generation.
- Renewable energy technologies are expected to yield a **net benefit of nearly NIS 1.5 billion** (present value).

Merit Order Switch

- Currently, coal-fired power plants are operated prior to natural-gas fired combined cycle power plants, due the fact that, excluding externality costs from air pollution (such as health care costs), coal-fired units are cheaper to operate by approximately NIS 0.035 per kWh. Once externality costs are taken into account, coal-fired units will be more expensive to operate by approximately NIS 0.002 per kWh.
- In the conservative target scenario, coal-fired plants continue to operate at minimum operating levels as must run, but natural gas-fired combined cycle plants are operated up to full capacity, prior to ramping up the coal units. This change in the merit order of power plants is expected to **yield a significant emission reduction of 6.1 $MtCO_2e$ in 2030 at a total net economic benefit, including externalities, of approximately NIS 937 million** (present value).

Transport Sector

- In the conservative target scenario, private vehicle use - responsible for some 50% of transport GHG emissions in the BAU scenario - is reduced by 25% due to construction of advanced mass transit systems in Israel's metropolitan areas.
- Due to this measure, along with uptake of alternative-fuelled vehicles (such as CNG and electric vehicles) as well as more efficient conventional vehicles, the share of petroleum-based fuels used for overland transport is expected to fall from 97.1% in the BAU scenario to 74.2% in the conservative target scenario.
- Overall, the abatement measures in the transport sector are expected to yield **a total net economic benefit of approximately NIS 159 billion** (present value).

Other Key Findings

- Uptake of small scale cogeneration and additional fuel switching to natural gas in industry will reduce total HFO consumption in Israel by 73% relative to BAU levels.
- Currently existing as well as approved and budgeted waste recycling facilities in the BAU scenario are expected to be sufficient to reduce the percentage of municipal solid waste that is landfilled from the current 80% to approximately 50% in 2030. Additional emission reduction measures are expected to further reduce this to 18% in the conservative target scenario.
- In the BAU scenario, HFC emissions are expected to increase by 268% by 2030, due in large part to the gases' suitability as a replacement for HCFCs phased out in accordance with the Montreal Protocol. In the conservative target scenario, the abatement measures are expected to yield a 30% reduction in HFC emissions relative to BAU levels.

3 METHODOLOGY AND APPROACH

The projection of GHG emissions and the assessment of the reduction potential and associated economic impacts were carried out in close consultation with key stakeholders, who were involved in all stages of development, including development of the applicable modelling approach, identification of relevant abatement measures, as well as data collection and formulation of key assumptions used to assess the emission reductions and economic impacts.

While ad hoc stakeholders such as industry leaders and academics played a significant role, of particular importance were the following working groups which were comprised of key government ministries and agencies, industry associations and NGOs, and which were established as an integral part of the policy making process:

1. Power Sector Working Group
2. Buildings Energy Efficiency Working Group
3. Industry Sector Working Group
4. Transport Sector Working Group
5. Waste and Agricultural Sectors Working Group
6. Innovative Israeli Technologies Working Group

GHG emissions projections were developed using the Long-Rage Energy Alternatives Planning System (LEAP) modelling program, a widely used and accepted energy tool developed by the Stockholm Environment Institute and used by approximately 80 governments around the world.

The benefits of using LEAP include its track record and robustness as well as the large community of users worldwide which allow results from this work to be compared with other countries on a consistent basis. It also models energy production and consumption in significant detail, looking at the sources of primary energy, its transformation e.g. into electricity, and the sectors where it is used including the industrial and transport sectors. Further it captures important interactions between different sectors of the economy with key consequences for overall emissions, not least the interaction between electricity generation and demand.

As LEAP is an energy model, non-energy-related GHG emissions from activities such as decomposition of waste in landfill and from agriculture were calculated 'off model' and the resulting GHG figures inputted into LEAP.

The projection of GHG emissions and the assessment of the emission reduction potential were developed using the following methodology and approach:

- The latest GHG emissions inventory for Israel published by the Central Bureau of Statistics (2012) along with additional data sources, such as the Israel Pollutant Release and Transfer Registry (PRTR), were used to identify the key emitting sectors in Israel.

- An approach to forecasting BAU emissions was developed for each sector, by first identifying the sources of emissions and energy use, and then by identifying the key drivers most likely to affect future emissions.
- Where possible, emissions were projected in a bottom-up manner, using disaggregated data on the drivers for each sector. In particular, this approach was applied to the power and transport sectors, responsible for some 75% of GHG emissions.
- A list of over 120 abatement measures was developed, and a qualitative analysis of each measure was conducted to determine its suitability to Israel, based on a number of criteria, including technical readiness for deployment by 2030, appropriateness for local conditions in Israel (such as geography, climate and existing production processes), and technical feasibility of supporting infrastructure by 2030.
- 62 abatement technologies were identified as suitable to Israel and therefore assessed in depth to determine, for each measure, the extent of the uptake that could be expected by 2030 and the associated impact of the measure on GHG emissions.
- In addition, the associated additional economic impacts of each measure were assessed, using the social cost approach. Unlike retail costs, social costs do not include transfers within an economy - such as VAT and excise taxes - but do account for externality costs such as health costs associated with air pollution, and the economic costs of traffic congestion. Externalities were included for the key sectors - power and transport.
- The costs and emission reductions associated with each measure were used to develop Marginal Abatement Cost Curves (MACCs) for each sector and for the economy as a whole. The MACCs provide a visual representation of the total level of abatement that can be achieved in a given year at different levels of costs per tonne of GHGs abated.

Once developed, the results underwent a rigorous quality control and assurance process, including comparison against existing economy-wide and sector-specific projections. In addition, key parameters were sense-checked against international data where relevant. The comparisons were used to identify trends, similarities and systematic differences between the projections, and where necessary, to update the projections from this study.

Finally, this study included analysis of key policy measures that could be implemented to achieve the intended GHG reduction target. This was done on the basis of international best practice and in consultation with key stakeholders, utilizing the modelling results to assess the impacts of those policies in Israel.

4 BAU GHG PROJECTIONS

4.1 Definition

The BAU emission projection refers to the GHG emissions most likely to occur in the absence of further government policy or action. Government policies were accounted for in the baseline scenario in accordance with the Greenhouse Gas Protocol Policy and Action Standard developed by the World Resources Institute, a globally accepted standard used by countries to prepare emission reduction targets.

The Policy and Action Standard requires that BAU emission projections include the impacts of policies that are implemented. In addition, BAU emission projections should include the impact of adopted policies, to the extent those policies are "likely to be implemented". The inclusion of planned policies is not required.

Therefore, the BAU emission projections for Israel were developed taking into account the following key assumptions regarding the policy framework, as agreed with the Ministry of Environmental Protection:

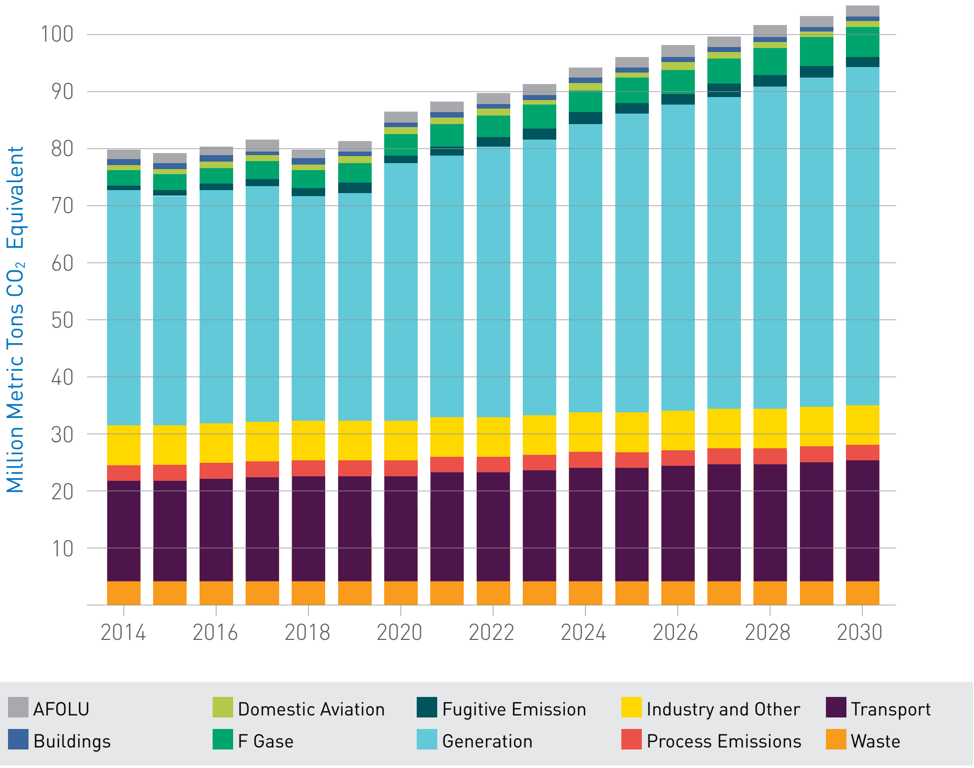
1. **The National Plan for the Reduction of Greenhouse Gases would not be reinstated**, after being frozen in 2013 (an assumption that was eventually confirmed).
2. Accordingly, and given the fact that the separate National Energy Efficiency Programme was not approved by Government, Israel's target for 2020 energy efficiency was not included in the BAU scenario and it was assumed that **only natural energy efficiency improvements would take place.**
3. **Israel was assumed to meet its target of 10% electricity generation from renewable sources by 2020**. However, as this policy has been adopted yet not fully implemented, and given the uncertainty surrounding the uptake of renewable capacity, it was assumed that in the BAU scenario **no further capacity would be added after 2020**.
4. Should the "Project D" power plant be required, it would be built as a **dual-fuel power plant with natural gas as its primary fuel and coal as a back-up**, in accordance with the current planned configuration
5. **No further fuel switching to natural gas in the industrial and commercial sectors** would occur in the BAU scenario, due to the uncertainty surrounding development of new natural gas reserves, as well as uncertainty surrounding the construction of the requisite distribution infrastructure. It should be noted that the vast majority of this potential has already been realized, as large factories have already converted to natural gas. While the number of small factories and commercial entities that could potentially convert to natural gas may be large, their cumulative potential consumption represents only a minor share of total consumption in the sector.

6. **Only existing mass transit systems** (e.g. the existing Jerusalem light rail), **and mass transit systems currently under construction** (e.g. the Tel Aviv "Red Line") were included due to the uncertainty surrounding construction of additional metropolitan advanced mass transit systems. achieve the intended GHG reduction target. This was done on the basis of international best practice and in consultation with key stakeholders, utilizing the modelling results to assess the impacts of those policies in Israel.

4.2 Key Results

Under the BAU scenario, GHG emissions in Israel will increase by 27.05% from 2012 levels by 2030, with total GHG emissions in 2030 expected to be 105.5 Mt CO_2e (9.95 t CO_2e per capita):

Figure 1 GHG emissions (MtCO_2e) to 2030 under 'business as usual'[4]



As can be seen in Figure 1 above, the power sector continues to be the dominant source of GHG emissions in Israel, accounting for 52.5% of total emissions in 2030, followed by the transport sector, which is projected to account for 20.6% of GHG emissions.

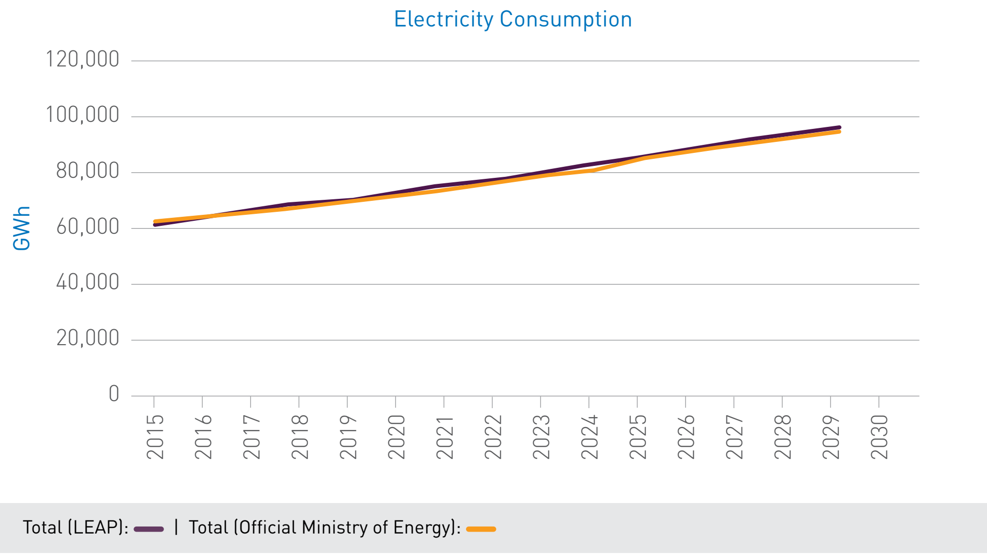
All sectors continue to show a rise in direct emissions, with the exception of direct combustion emissions from buildings, which fall by 11.2% due to continued trends away from fuel use in the residential and commercial sectors.

Emissions in the power sector are expected to decrease slightly through 2019, due to a combination of increased uptake of renewables as well as planned shut-downs of coal-fired power plants for major maintenance, before increasing significantly in the coming decade, driven by growth in electricity consumption, which is expected to increase by 68% relative to 2012 levels, to 96.02 TWh in 2030.

The increase in electricity consumption is driven by growth in consumption in all sectors, with commercial and public buildings accounting for 32.1% of total electricity consumption in 2030, followed by residential buildings, which account for 27.1%, and the industrial and water sectors, which together account for 24.9%.

It should be noted that the forecast for electricity consumption was found to closely match the official Ministry of Energy forecasts:

Figure 2 **BAU electricity consumption compared to Ministry of Energy forecast**



Existing and planned conventional power generation capacity was found to be sufficient to meet the increasing demand through 2024, at which point a new dual-fuel power plant with a capacity of 1,524 MW (Project D) is required. In all, it is expected that the increase in electricity consumption will require an additional 5,200 MW of conventional power generation capacity beyond the current and planned power stations:

Table 1 BAU Generation Capacity by Type (MW)

Plant Type	2020	2025	2030
Coal	4,840	4,840	4,840
Natural Gas (incl. Project D)	12,018	12,530	15,567
Other thermal1	1,094	1,094	1,094
Renewables	3,599	3,599	3,599
Hydro Pumped Storage	640	640	640
Total	22,191	22,703	25,740

Natural gas is expected to be the dominant fuel for power generation, comprising nearly 61% of the generation fuel mix in 2030. Renewables will peak at 10% in 2020 before declining to 7.5% in 2030, in line with the BAU assumptions:

Table 2 Percentage of electricity generation from different fuels key years

Fuel Type	2015	2020	2025	2030
Coal	45%	44%	37%	32%
Natural Gas	52%	46%	54%	60%
Other Fuels1	0%	0%	0%	0%
Renewables	3%	10%	9%	8%

In the transport sector, GHG emissions are expected to grow by 15% by 2030.

Passenger cars will continue to be the dominant emission source, accounting for approximately 50% of total transport GHG emissions. Passenger car use is expected to increase by approximately 46%, reaching more than 55 billion vehicle kilometres travelled nationwide in 2030.

Petroleum-based fuels will remain the dominant fuel for overland travel, accounting for 97.1% of total fuel consumed, the result of limited uptake of electric and CNG vehicles.

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[5] This plant will be built, in the BAU scenario, in two equal units - one in 2024 and the other in 2025

[6] Required capacity additions. The growth in total capacity is more limited, as some of the capacity additions are offset by planned decommissioning of existing units.

[7] Includes small back-up units and diesel cogeneration.

[8] Negligible amounts of diesel, HFO

Additional noteworthy results from the BAU projections include:

- The current waste recycling facilities, as well as planned facilities that have already been budgeted and approved, are expected to be sufficient to reduce the percentage of municipal solid waste that is landfilled from the current 80% to approximately 50% in 2030.
- HFC emissions are expected to increase by 268% by 2030, due in large part to the gases' suitability as a replacement for HCFCs phased out in accordance with the Montreal Protocol.

5 MITIGATION ANALYSIS

5.1 Mitigation Scenarios

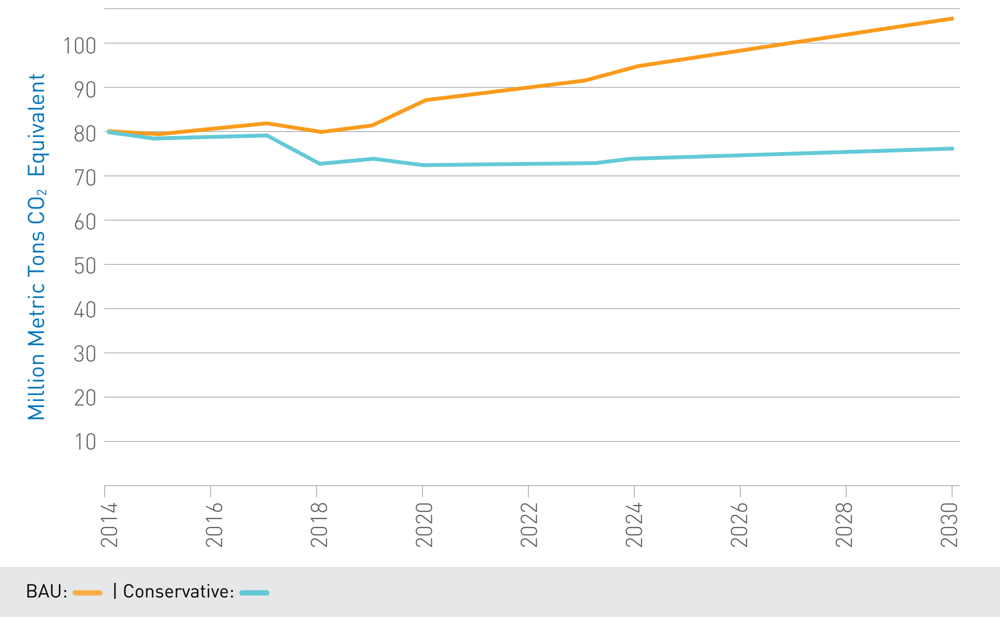
The mitigation analysis was performed to determine the level of emissions that would result in two different scenarios:

- A **conservative target scenario**, which includes uptake of almost solely cost-effective abatement measures
- An **ambitious target scenario**, which includes reasonable uptake of all abatement measures that were assessed

5.2 Abatement Potential

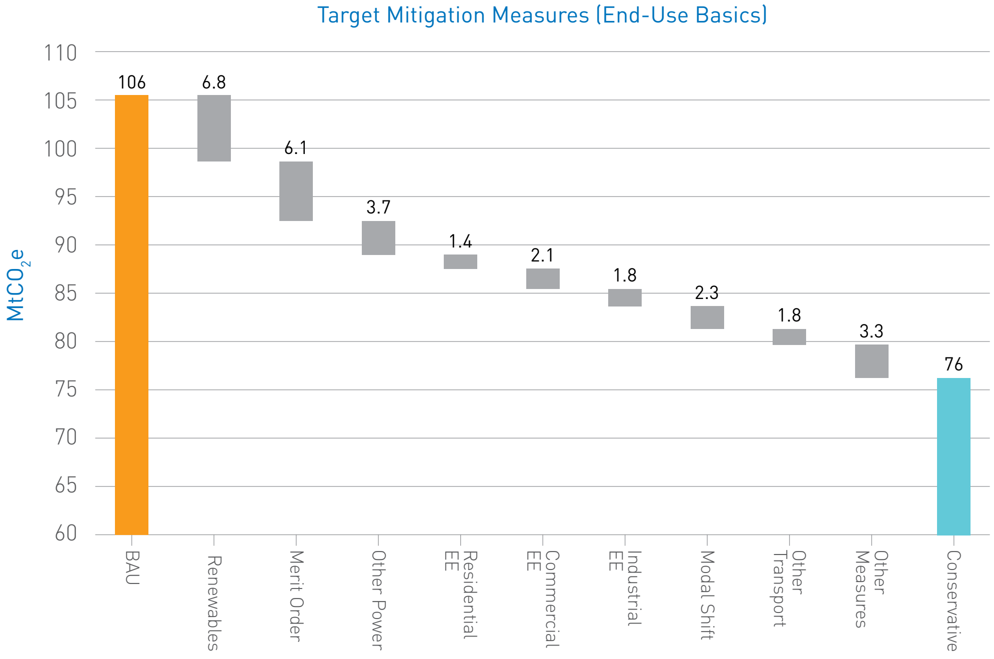
In the conservative target scenario, GHG emissions are expected to be reduced below BAU emissions by 27.7% in 2030, to a level of 76.3 $MtCO_2e$ in 2030 (7.2 tCO_2e per capita). It should be noted that this represents a growth in absolute emissions of 6% relative to historical 2005 levels, but an absolute emission reduction of 8.1% relative to 2012 levels:

Figure 3 GHG emissions (MtCO$_2$e) to 2030 under the BAU scenario and the 'conservative target' scenario



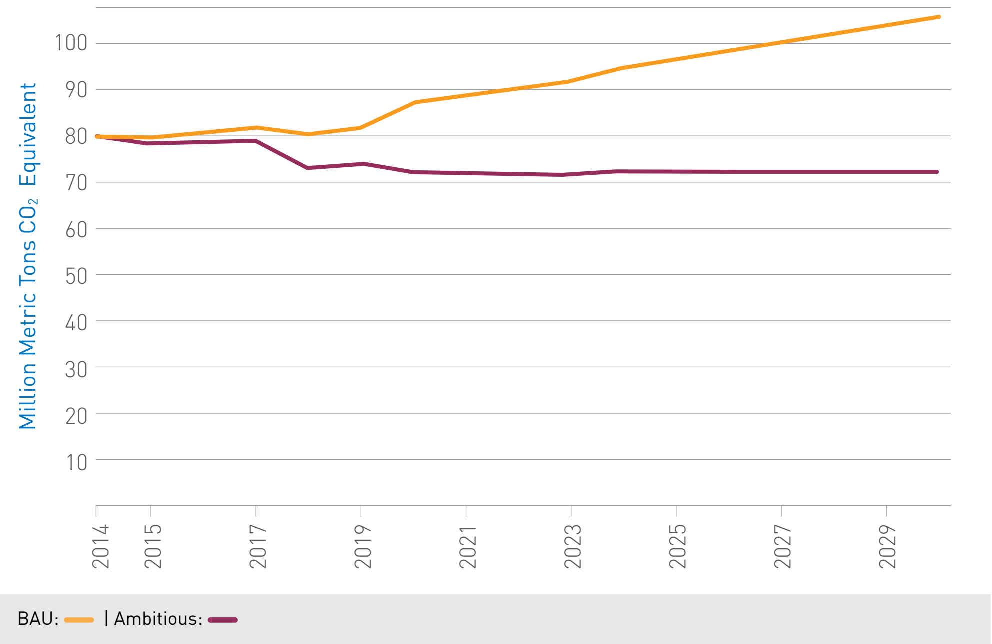
This emission reduction is achieved primarily by renewable energy (6.8 MtCO$_2$e, or 23% of the total reduction) and changes to the merit order for dispatch of conventional coal and natural gas-fired units (6.1 MtCO$_2$e, or 21% of the total reduction), energy efficiency measures (5.3 MtCO$_2$e, or 18% of the total reduction), and increased use of public transport as well as walking/cycling (2.3 MtCO$_2$e, or 8% of the total reduction):

Figure 4 Split of emissions reductions from different categories in the 'conservative target' scenario


Target Mitigation Measures (End-Use Basics)

In the ambitious scenario, GHG emissions could be reduced below BAU emissions by 31.6%, to 72.2 $MtCO_2e$ in 2030 (6.8 tCO_2e per capita):

Figure 5 GHG emissions ($MtCO_2e$) to 2030 under the BAU scenario and the ‘ambitious target’ scenario



5.3 Conservative Target: Key Results

Electricity and Energy Consumption

- Total energy efficiency potential in Israeli electricity consumption is estimated at 18-22% relative to expected BAU levels, in line with similar targets in advanced countries. Implementation of the efficiency potential in all sectors excluding transport will yield a 20% reduction in electricity consumption, or 16.8 TWh. This reduction will bring the total Israeli electricity consumption, including transport, to 67.6 TWh in 2030; electricity consumption including the Palestinian Authority is expected to be 79.2 TWh.
- Implementation solely of the efficiency measures that were assessed in-depth and included in the conservative target scenario, in all sectors excluding transport and agriculture, are expected to reduce electricity consumption in these sectors by approximately 15% (some 12 TWh). This is expected to bring the total Israeli electricity consumption, in all sectors, to 74.8 TWh (86.4 TWh including the Palestinian Authority).
- Overall, in the conservative target scenario, total primary energy consumption is reduced by 26.5% relative to BAU levels.
- Uptake of small scale cogeneration and additional fuel switching to natural gas in industry will reduce total HFO consumption in Israel by 73% relative to current levels.

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[9] This includes the residential sector, commercial/public, industry and water, and agriculture

Power Sector

- Renewable energy technologies will account for 22.8% of total electricity generation, approximately 58% of which will be PV, as opposed to only 7.5% in the BAU scenario.
- Due to the electricity efficiency measures, in conjunction with added renewable energy capacity, the power sector will not require the construction of the 5,200 GW additional conventional capacity required in the BAU scenario, including Project D:

Table 3 Conservative Scenario Generation Capacity by Fuel Type (MW)

Plant Type	2020	2025	2030
Coal	3,400	3,400	3,400
Natural Gas	13,458	12,346	11,783
Other thermal1	1,094	1,094	1,094
Renewables	3,599	6,509	9,346
Hydro pumped storage	640	940	940
Total	22,191	24,289	26,563

Due to other power sector measures, namely the merit order switch, the share of natural gas in the fuel mix will increase slightly, despite the increased renewable uptake:

Table 4 Percentage of electricity generation from different fuels key years

Fuel Type	2020	2025	2030
Coal	16.15%	14.12%	12.26%
Natural Gas	72.21%	67.10%	64.59%
Other fuels1	0.03%	0.03%	0.02%
Renewables	11.12%	18.31%	22.75%
RDF	0.50%	0.44%	0.38%

Coal consumption in the mitigation scenario in 2030 is reduced by 64% below BAU levels, from 12.13 million tons to 4.38 million tons.

Transport Sector

- Private vehicle use is reduced by 25% relative to BAU levels due to construction of advanced mass transit systems in Israel's metropolitan areas.
- Due to this measure, along with uptake of alternative-fuelled vehicles (such as CNG and electric vehicles) as well as more efficient conventional vehicles, the share of petroleum-based fuels used for overland transport is expected to fall from 97.1% in the BAU scenario to 74.2% in the conservative target scenario.

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[10] Reduction in coal capacity due to decommissioning of Orot Rabin units 1-4 in 2018 and replacement with a CCGT power plant, which was included as an abatement measure. Reduction in natural gas capacity is due to planned decommissioning of existing natural gas units.

[11] Includes small back-up units and diesel cogeneration.

[12] Negligible amounts of diesel, HFO

Other Key Findings

- Natural gas consumption remains relatively unchanged, increasing by 5.8% from BAU levels to 16.8 BCM in 2030, with reduced natural gas consumption in the power sector countered by increased consumption in industry and transport:

Table 5 Natural Gas Consumption in 2030 (BCM)

Sector	BAU	Conservative Target	Natural Gas Authority Forecasts (for comparison)
Power Sector	12.6	11.9	12.1
Industry and other	3.1	3.6	3.9
Transport	0.2	1.3	1.9
Total	15.9	16.8	17.9

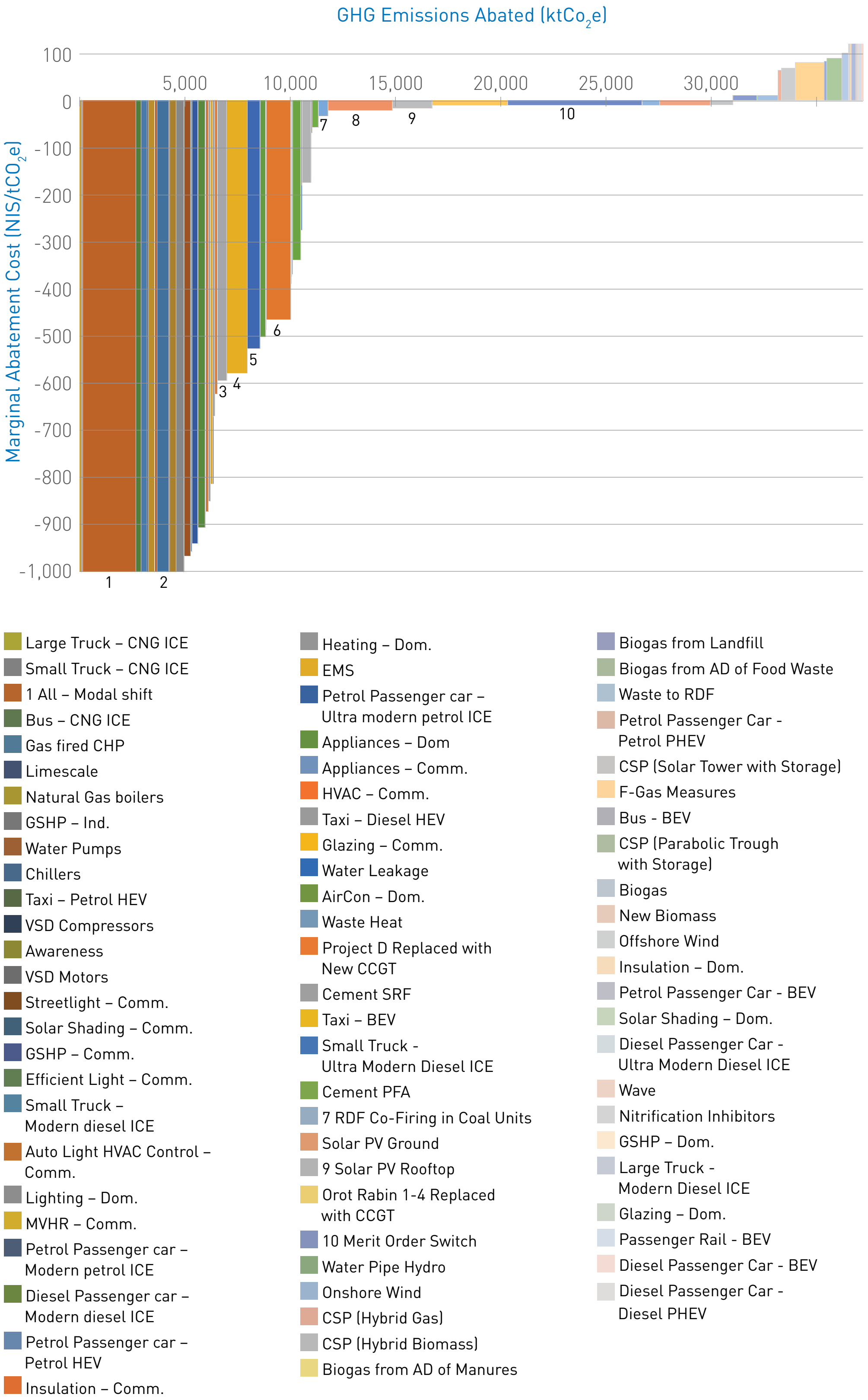
- As can be seen from the table above, the projected natural gas consumption in the BAU and conservative target scenarios are comparable, and even slightly lower, than the consumption forecasts previously compiled by the Natural Gas Authority.
- The percentage of municipal solid waste that is landfilled in 2030 is reduced from approximately 50% in the BAU scenario to 18%.
- HFC emissions are reduced by 30% relative to BAU levels.

5.4 Abatement costs and economic impacts

Of the total GHG emission reduction potential that was assessed, approximately 80% was found to be cost-effective, without a cost of carbon (i.e., assuming a carbon cost of NIS 0). These measures are represented by measures displayed below the x-axis on the MACC.

It should be noted that whilst the emission reduction potential presented in the MACC does account for interactions within each sector (for instance, the cumulative impacts of several measures that influence HVAC consumption in buildings), it does not account for interactions between the various sectors (most importantly, between electricity consumption and emissions from power generation). Therefore, the total abatement potential presented in the MACC represents an overestimation of the economy-wide abatement potential. Nonetheless, these interactions were accounted for by the LEAP model and are therefore reflected in the emissions projections for both mitigation scenarios, including the target recommendation (conservative scenario).

Figure 6 Economy-wide marginal abatement cost curve



As can be seen from the economy-wide MACC shown in Figure 6, the abatement measures vary considerably both in terms of emissions reduction potential (width of the measures on the horizontal axis) and cost effectiveness (height on the vertical axis). Among the cost-effective measures, those with the top abatement potential include:

Table 6 Top 10 cost-effective measures in terms of reduction potential

Measure Name	Abatement potential in 2030 ($ktCO_2e$)	Cost-effectiveness (NIS/tCO_2e)
Merit Order Switch	6,136	-5
Solar PV Ground	3,052	-22
All - Modal shift	2,535	-4291
Solar PV rooftop	1,882	-17
HVAC - Commercial	1,170	-467
Energy management systems	984	-580
Petrol Passenger car - Ultra modern petrol ICE	599	-528
Chillers - industry	543	-1069
RDF co-firing in coal units	461	-33
Heating - domestic	442	-596
Total	15,253	

The analysis found that replacement of the Orot Rabin units 1-4 with a natural gas-fired combined cycle power plant could yield a significant emission reduction of 3,585 $ktCO_2e$, and would also be cost effective at NIS -11 per tCO_2e.

The present value of the total gross economic benefits associated with meeting the conservative target are estimated at NIS 457 billion over the full lifetime of the measures, with present value of the total economic costs estimated at NIS 239 billion. As such, implementation of the conservative target is expected to **yield a cumulative net economic benefit of approximately NIS 218 billion**.

The greatest economic benefits are achieved by reducing private vehicle use due to increased investment in public transport (modal shift), which yields a net benefit of NIS 149 billion, as well as energy efficiency measures which yield a net benefit of NIS 56 billion:

Table 7 Economic impact of conservative target (Billion NIS, discounted to 2015)

Abatement Measure Category	Benefits	Costs	Net Benefits
Energy Efficiency	79.9	24.3	55.6
Renewable Energy	28.2	26.7	1.5
Merit Order Switch	4.0	3.1	0.9
Other Power Sector Measures	3.8	2.8	1.0
Modal Shift (Public Transport, walking/cycling)	305.1	155.8	149.3
Other Transport Measures	35.5	25.8	9.7
Other Measures	0.00	0.5	(0.5)
Total	456.6	239.1	217.5

6 CONCLUSIONS AND POLICY RECOMMENDATIONS

Based on the analysis conducted in this study, and in accordance with the conservative target, **the Government of Israel can adopt an economical GHG reduction target of 7.2 tCO_2e per capita for 2030, and an interim target of 7.5 tCO_2e per capita in 2025.**

Meeting this target is expected to **yield significant economic benefits for the country, estimated at NIS 218 billion**.

In formulating the policy framework required to meet this target, the implementation of the following key measures is recommended:
- Adoption of a renewable energy target on the order of 22-23% of electricity generation in 2030.
- Adoption of an energy efficiency target to reduce electricity consumption on the order of 18-20% by 2030.
- Adoption of a national target and associated action plan to reduce private vehicle use by 25% relative to BAU levels, by 2030.
- Adoption of policies to account for externality costs in electricity generation in both management of the power generation system as well as in the approval of new power plants
- Externality costs can be accounted for in the management of the power generation system through implementation of a pollution levy, which is expected to yield a change in the power plant merit order (as assessed in this study) as well as generate significant government income that will enable promotion of energy efficiency, assistance to low income households as well as the middle class, and improved competiveness in Israeli industry.
- Establishment of a mechanism to approve renewable energy quotas whilst minimizing economic costs, through a market mechanism based on bidding for tariffs. This mechanism shall account for, among other things, the economic benefits of various generation technologies, including benefits from reduction of air pollution and greenhouse gases.
- Establishment of a national energy efficiency fund to promote and catalyze private investment in energy efficiency and GHG reductions; such funds can be used to target investments in low-income households as well as SMEs.
- Establishment of additional national energy efficiency mechanisms, including incentives for the IEC and IPPs to carry out energy efficiency projects amongst consumers, and on the basis of the *'value of the saved kWh'*, whilst allowing consumers to pay for efficiency improvements via their electric bill.
- Adoption of the Israel Green Building Standard 5281 as a mandatory standard for new buildings, in a graduated manner and whilst taking into account socio-economic factors. Economic tools can be implemented to provide incentives and assistance in meeting this standard, through the national energy efficiency fund.

01

INTRODUCTION & BACKGROUND

This project was carried out by EcoTraders Ltd (lead contractor, Israel), Ricardo Energy and Environment (subcontractor, UK) and the Israeli Ministry of Environmental Protection, on behalf of the Inter-ministerial Steering Committee for the Formulation of a National Greenhouse Gas Reduction Target (the Steering Committee).

- Specifically, the project informed the policy making process by carrying out the following objectives:
- Develop an updated projection of GHG emissions under a business-as-usual (BAU) scenario through 2030.
- Conduct a qualitative analysis to identify the key technological abatement measures most relevant to Israel.
- Conduct a quantitative analysis of the abatement measures to determine both their abatement potential and their economic impacts, and in particular determine the abatement cost of each measure.
- Examine two different target scenarios based on uptake of the identified measures, as follows: (a) a conservative target scenario, which could be achieved solely through implementation of abatement measures cost-effective without a price of carbon, and an ambitious target scenario, which includes the reduction potential of all of the assessed abatement measures and which would require implementation of abatement measures that are not cost effective without accounting for a price of carbon.
- Provide a recommended GHG reduction target for 2030 and a recommended interim target for 2025.
- Assess the overall economic impacts associated with meeting the recommended target.

The projection of GHG emissions and the assessment of the reduction potential and associated economic impacts were carried out in close consultation with key stakeholders, who were involved in all stages of development, including development of the applicable modelling approach, identification of relevant abatement measures, as well as data collection and formulation of key assumptions used to assess the emission reductions and economic impacts.

While ad hoc stakeholders such as industry leaders and academics played a significant role, of particular importance were the following working groups which were comprised of key government ministries and agencies, industry associations and NGOs, and which were established as an integral part of the policy making process:

1. Power Sector Working Group
2. Buildings Energy Efficiency Working Group
3. Industry Sector Working Group
4. Transport Sector Working Group
5. Waste and Agricultural Sectors Working Group
6. Innovative Israeli Technologies Working Group

For a full list of involved stakeholders, please see the acknowledgments in Appendix 1.

02

OVERALL METHODOLOGY

2.1 General approach

The analysis of GHG emissions and mitigation in Israel was conducted in a sequential manner: first the emissions baseline was developed forecasting emissions to 2030, against which the mitigation potential was assessed.

The projection of GHG emissions and the assessment of the emission reduction potential were developed using the following methodology and approach:

- The latest GHG emissions inventory for Israel published by the Central Bureau of Statistics (2012) along with additional data sources, such as the Israel Pollutant Release and Transfer Registry (PRTR), were used to identify the key emitting sectors in Israel.
- An approach to forecasting Business As Usual (BAU) emissions was developed for each sector, based on two main stages:
  - Firstly, the sources of emissions and energy use in each sector were identified from the both the historical inventory and by considering likely future technological, behavioural and policy developments.
  - Secondly, the activities which were most likely to affect future emissions were identified - these are referred to as "key drivers".
- Where possible, emissions were projected in a bottom-up manner, using disaggregated data on the drivers for each sector. Disaggregated data was collected on the drivers for GHG emissions in each sector. In particular, this approach was applied to the power and transport sectors, responsible for some 75% of GHG emissions, which required, for example, information such as the number of vehicles, fuel efficiency and distances travelled of the different vehicle types. In the power sector, this required detailed data on existing as well as planned generation units, the load curve, as well as operational and policy constraints.
- Where the level of data disaggregation was not available, forecasts were instead developed using a more top-down approach, based on key historical trends and key macro-economic drivers. For instance, residential electricity consumption was projected based on energy intensity per household and projections of the numbers of apartments.
- A list of over 120 abatement measures was developed, and a qualitative analysis of each measure was conducted to determine its suitability to Israel. 62 abatement technologies were identified as suitable to Israel and therefore assessed in depth to determine, for each measure, the extent of the uptake that could be expected by 2030 and the associated impact of the measure on GHG emissions.
- In addition, the associated additional economic impacts of each measure were assessed; this assessment was used not only to determine the total economic impacts of the recommended target scenario, but also to develop Marginal Abatement Cost Curves (MACCs) for both the economy as a whole and for each sector. The MACCs provide a visual representation of the total level of abatement that can be achieved at different levels of costs per tonne.

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[13] http://www.mckinsey.com/client_service/sustainability/latest_thinking/greenhouse_gas_abatement_cost_curves

Once developed, the proposed forecasts of energy and emissions underwent several stages of quality control before they were finalised. In each sector, forecasts were compared against existing projections including the McKinsey study published in 2009, and existing projections held by relevant government ministries. These comparisons were then used to try and identify trends, similarities and systematic differences between the projections, and where necessary, to modify the projections from this study. Key parameters were also sense-checked against international comparators where relevant. Such checks included energy intensity per household, efficiencies of heat pumps, emissions per capita etc. Further, the forecasts were presented to and reviewed by groups of stakeholders via Steering Committee and face-to-face meetings.

Finally, this study included analysis of key policy measures that could be implemented to achieve the intended GHG reduction target, on the basis of international best practice and in consultation with key stakeholders, utilizing the modelling results to assess the impacts of those policies in Israel.

2.2 The LEAP model

GHG emissions projections were developed using the Long-Rage Energy Alternatives Planning System (LEAP) modelling program, a widely used and accepted energy tool developed by the Stockholm Environment Institute and used by approximately 80 governments around the world.

LEAP is a flexible model and can be used:

- As an 'accounting' framework, to track energy consumption, fuel use and track emissions
- To make projections concerning fuel, energy and emissions
- To optimise costs within the projected energy system
- To perform scenario analysis.

The benefits of using LEAP include its track record and robustness, the large community of users worldwide which allow results from this work to be compared with other countries on a consistent basis, and its ease of use compared to other models. It also models energy production and consumption in reasonable detail, looking at the sources of primary energy, its transformation e.g. into electricity, and the sectors where it is used including the industrial and transport sectors. Further it captures important interactions between different sectors of the economy with key consequences for overall emissions, not least the interaction between electricity generation and demand.

For most sectors, LEAP calculates emissions in a straightforward way - it takes an activity level in a sector and multiplies it by an emissions level. Take for example the heating demand in the commercial sector that is met by oil under a 'baseline' or 'business as usual' case. LEAP includes a profile over time for this heating demand (for example, in GJ per year) and a series of factors that specify the emissions (of carbon dioxide for example) that arise per GJ of oil use for heating.

LEAP then multiplies these together and reports the results in a very flexible way. In some sectors such as transport, LEAP also keeps track of the stock of installed equipment (e.g. the passenger car fleet) and uses this to determine the emissions per unit of activity.

As LEAP is an energy model, non-energy-related GHG emissions from activities such as decomposition of waste in landfill and from agriculture were calculated 'off model' and the resulting GHG figures inputted into LEAP. It should be noted, however, that as per the 2012 GHG Inventory published by the CBS, energy emissions account for approximately 85% of Israel's GHG emissions, and as such LEAP is particularly suited for the Israeli context.

2.3 Key BAU assumptions

The BAU emission projection refers to the GHG emissions most likely to occur in the absence of further government policy or action. Government policies were accounted for in the baseline scenario in accordance with the Greenhouse Gas Protocol Policy and Action Standard developed by the World Resources Institute, a globally accepted standard used by countries to prepare emission reduction targets. This standard defines policies according to the following categories:

1. **Implemented**: Policies and actions that are currently in effect, as evidenced by one or more of the following: (a) relevant legislation or regulation is in force; (b) one or more voluntary agreements have been established and are in force; (c) financial resources have been allocated; (d) human resources have been mobilized.
2. **Adopted**: Policies and actions for which an official government decision has been made and there is a clear commitment to proceed with implementation, but that have not yet begun to be implemented (for example, a law has been passed, but regulations to implement the law have not yet been established or are not being enforced).
3. **Planned**: Policy/action options that are under discussion and have a realistic chance of being adopted and implemented in the future, but that have not yet been adopted.

The Policy and Action Standard requires that BAU emission projections include the impacts of policies that are implemented. In addition, BAU emission projections should include the impact of adopted policies, to the extent those policies are "likely to be implemented". The inclusion of planned policies is not required.

Therefore, the BAU emission projections for Israel were developed taking into account the following key assumptions regarding the policy framework, as agreed with the Ministry of Environmental Protection:

1. **The National Plan for the Reduction of Greenhouse Gases would not be reinstated**, after being frozen in 2013 (an assumption that was eventually confirmed).
2. Accordingly, and given the fact that the separate National Energy Efficiency Programme was not approved by Government, Israel's target for 2020 energy efficiency was not included in the BAU scenario and it was assumed that **only natural energy efficiency improvements would take place**, i.e. those already made under existing policy or which occur in the market without further policy intervention.

3. **Israel was assumed to meet its target of 10% electricity generation from renewable sources by 2020**. However, as this policy has been adopted yet not fully implemented, and given the uncertainty surrounding the uptake of renewable capacity, it was assumed that in the BAU scenario **no further capacity would be added after 2020**.
4. Should the "Project D" power plant be required, it would be erected as **a dual-fuel power plant with natural gas as its primary fuel and coal as a back-up**, in accordance with the current planned configuration
5. **No further fuel switching to natural gas in the industrial and commercial sectors** would occur in the BAU scenario, due to the uncertainty surrounding development of new natural gas reserves, as well as uncertainty surrounding the construction of the requisite distribution infrastructure. It should be noted that the vast majority of this potential has already been realized, as large factories have already converted to natural gas. While the number of small factories and commercial entities that could potentially convert to natural gas may be large, their cumulative potential consumption represents only a minor share of total consumption in the sector.
6. **Only existing mass transit systems (e.g. the existing Jerusalem light rail), and mass transit systems currently under construction** (e.g. the Tel Aviv "Red Line") were included due to the uncertainty surrounding construction of additional metropolitan advanced mass transit systems.

2.4 Mitigation potential and the MACC approach

The first step to assessing abatement potential was to identify the appropriate abatement measures that are relevant to the Israel context. An initial comprehensive long list of more than 120 abatement measures was developed, and a qualitative analysis of each measure was conducted to determine its suitability to Israel, based on a number of criteria. The main criterion was technical feasibility, and the technical limitations in Israel were assumed to be:

- Insufficient infrastructure by 2030 (e.g. lack of refuelling infrastructure for hydrogen vehicles). This covers technical barriers to the infrastructure being ready by 2030, as opposed to commercial, political or other barriers
- Inadequate local conditions (e.g. a certain measure not being feasible due to local climatic and environmental conditions)
- Readiness for deployment (e.g. the lead times for development and testing mean that it is not feasible for a technology to be ready for deployment by 2030).

Other criteria that were also used to create the shortlist included:

- Promoting technologies that can be relied on across sectors rather than focusing on specific sectors/sub-sectors
- Reduced air emissions
- Impact on land and water resources
- Job creation potential
- Promoting the Israeli clean tech sector
- Reduced dependency on oil, promoting oil alternatives

Once identified, the assessment of the abatement potential was based on the following approach:

- Understand nature and efficiency of existing technology or process and determine the technologies that are most likely to be implemented in the absence of further government policy (BAU technology)
- Determine the level of uptake for each abatement measure expected in the absence of further government policy, as well as the level of uptake that can reasonably be achieved within the context of national GHG reduction policy; the difference between the two is the additional uptake that can be achieved.
- Assess the relative energy and GHG savings between the abatement measure and the BAU technology
- Assess the investment (CAPEX) and operating (OPEX) costs for both the abatement measure and the BAU technology, as well as the expected revenue (for instance, from energy savings). Investment costs were annualized based on the discount rate, such that the financial analysis reflected the annual cost of each measure. Those measures for which the annual revenues exceed the annualized costs were deemed cost-effective.
- Combine the annual costs with the annual GHG reductions to determine the cost of abatement.

In this approach, with the exception of a few cases in which no investment would be required in the BAU scenario, the operating assumption was that the processes would upgraded when technology is replaced in any case at end of typical asset life; as such, only the added costs of the abatement technology were relevant.

Further, the analysis of the cost-effectiveness was conducted using a social-cost rather than a private-cost approach. A social-cost approach calculates costs and benefits from the perspective of Israeli society as a whole. As such, transfers between different economic operators in Israel are not included in this analysis as from a social perspective these costs and benefits 'net-off' leaving no overall benefit or cost to accrue to society. On the other hand, a private-cost perspective assesses cost-effectiveness from the view-point of a single group of economic operators in Israel, typically the non-domestic private sector. In this analysis, one would also include transfers to and from private firms in the calculation of cost effectiveness. There are two key impacts for this analysis of taking a social-cost approach. The first is on the way the benefits of reducing fuel consumption are calculated. Rather than using a retail price which would be faced by private firms, the analysis uses a 'fuel cost'. This fuel cost removes transfers between economic operators which typically form part of a retail price, such as taxes, subsidies and profit margins. Second, the estimation of cost-effectiveness also includes other social impacts which are not captured by the price, such as externalities. These are included for measures in the power and transport sectors, which are the most significant emitting sectors.

Israel-specific data has been used where possible. Where this was not available, international data has been used as a proxy.

Marginal abatement cost curves (MACCs) were developed to assess and present the abatement potential in each sector. A MACC shows the economy-wide costs and potential for emissions reduction from different measures or technologies, ranking these from the cheapest to most expensive to represent the costs of achieving incremental levels of emissions reduction. Each bar on the MACC describes the cost and potential for emissions reduction from a specific measure. The total cost of delivering an emissions reduction target is represented by the area under the MACC up to the point where the emissions reduction target is reached. This assumes that all measures are taken up in sequence with the cheapest option first, up until the point where the target level of emissions reduction is achieved.

A MACC is a powerful tool for understanding the level of emissions abatement that can be delivered by specific technical and behavioural measures, at a given point in time. It also provides an understanding of the comparative costs of the measures. It is therefore useful for prioritising investment decisions, or determining which measures should be targeted by specific policy interventions. A MACC can also be used to help determine the cost of delivering a specific emissions abatement target, along with the basket of measures that need to be implemented to meet the target.

However, the information in a MACC represents a static snapshot at a given point in time. The estimates of abatement potential are underpinned by a scenario about how emissions will develop in the respective sector over time, as well as the availability and cost of measures to reduce emissions at that point in time. This means that the results from a MACC analysis are tied to certain under-pinning assumptions. In this way MACC models are not as dynamic as other modelling tools. This can also present challenges when attempting to consider sectoral inter-dependencies. For example, mitigation actions taken in one sector (e.g. power generation) will have an effect in other sectors (e.g. energy prices, and emissions factors for power generation).

The mitigation options were then characterised and modelled using the LEAP model to capture fully the interactions between mitigation measures within and between sectors.

2.5 Costs and benefits

Alongside assessing the impacts of potential mitigation measures on energy and emissions savings, as well as the abatement cost for each measure in a given year, the associated total costs and benefits of these measures have also been assessed. This assessment uses the same data-set used to define the MAC curves.

The impacts assessed for each measure are the additional investment and operating costs, and energy saving benefits relative to a measure-specific counterfactual: note the valuation of impacts does not include the value of the GHG emission reductions achieved. Upfront capital costs have been annualised over the lifetime of each measure.

The total economy-wide impacts of the target scenario have been calculated for all measures which are assumed to be implemented over the assessment period to 2030, but include all impacts associated with these measures over their lifetime.

All costs have been calculated using a 2014 price base, discounted to 2015, using a constant annual discount rate of 4%. The application of the discount rate is discussed below.

2.6 Common parameters

To ensure consistent assessment of mitigation potential across sectors and ensure comparability of MACCs, it was necessary to define a set of common parameters for use in the analysis. As with the mitigation analysis, for each parameter Israel-specific data was sought first, with international data used where this could not be found.

2.6.1 Discount rates, exchange rates, and price deflators

A social discount rate of 4% was assumed based on the European Commission's Impact Assessment Guidelines.

An exchange rate of 5.89 NIS to £1 was assumed for the analysis (3.58 NIS to $1; and 4.75 NIS to £1). This is based on average exchange rate data sourced from the Bank of Israel for 2014.

When estimating costs and benefits in the calculation of cost-effectiveness, all costs and benefits across different years of the appraisal were expressed in 'real terms' (i.e. stripping out the effects of inflation). To do this, 'price deflators' are used to adjust costs and benefits in different years to remove the effects of inflation from the value of costs and benefits, such that these are all expressed in a common 'price base' year (all prices in the analysis are in 2014 prices) and hence are comparable. These deflators have been used in the assessment of the cost-effectiveness of different abatement measures. They have been used to adjust cost information gathered from a range of literature produced by a number of countries which has been estimated or expressed in a different price base. Price deflators for the UK were sourced from the UK Treasury GDP Deflators, with deflators for the USD, NIS and EUR being sourced from the World Bank.

2.6.2 Global Warming Potentials and Emission factors

Global Warming Potentials (GWPs) for the GHGs were used from the IPCC Second Assessment Report. These GWPs are consistent with those used in the latest available historical GHG inventory.

GWP weighted emission factors (EFs) were derived from EF data provided by the CBS for different fuels split by GHG (see Appendix 6). These were combined with the standard energy intensity of fuels from the LEAP model.

2.6.3 Energy costs

The MACCs were developed to estimate cost-effectiveness from a societal rather than a 'private' perspective: i.e. the MACCs present the social return on investment in mitigation options.

As such, an energy cost representing the social value rather than an energy price (e.g. retail or wholesale) was used to estimate the value of the benefit associated with energy savings from mitigation options. Using social costs attempts to strip out elements which are captured by prices such as taxes, subsidies and margins but which in practice are transfers between different sectors of the economy, and hence should not be included (i.e. they net off) in analysis from a cross-societal perspective.

Data on energy prices, taxes and subsidies were collected. Information on VAT and on excise taxes was sourced from the Tax Authority. This information was then used to derive a set of energy costs for the MACC analysis.

The energy costs for 2015 and a description of the methodology used are included in Table 1.

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[14] http://ec.europa.eu/smart-regulation/guidelines/tool_54_en.htm

Table 1 Energy costs and methodology

Fuel	Energy cost assumed in 2015 (NIS/kWh unless stated)	Brief description of method
Electricity	0.53	Average electricity tariff provided by IEC, projected forward using coal price inflation; no adjustment needed for VAT and excise tax does not apply
Natural Gas[1]	0.08	Price data sourced from Natural Gas Authority; no adjustment required for VAT or excise tax. NG prices for the power sector were provided by the PUA, excluding VAT (adjustment made to remove excise tax[2])
LPG	0.25	Price data from 'theoretical fuel price' published by Ministry of Energy; no adjustment required for VAT or excise tax
Kerosene	0.23	Price data from 'theoretical fuel price' published by Ministry of Energy; no adjustment required for VAT or excise tax
Diesel oil	0.37	Price from Ministry of Energy modelling assumptions, excluding VAT. Adjustment made to remove excise tax
Fuel oil	0.18	Price data from 'theoretical fuel price' published by Ministry of Energy; no adjustment required for VAT or excise tax
Pet coke	0.04	Price data from 'theoretical fuel price' published by Ministry of Energy; no adjustment required for VAT or excise tax
Petrol	2.39 (NIS/litre)	Price published by Ministry of Energy, adjusted to remove VAT and excise tax
DERV	2.47 (NIS/litre)	Price data from 'theoretical fuel price' published by Ministry of Energy; no adjustment required for VAT or excise tax
Coal	0.04	Price from PUA, excluding VAT. Adjustment made to remove excise tax

2.6.4 Population and GDP

A forecast of population was sourced from the CBS. The CBS have provided three population projections: a low, central and high. The low estimate corresponds to 1.1% annual growth, the medium estimate to approximately 1.5-1.6%, and the high to 2.1%. Historical growth is around 1.9% (CBS data from 2005 to 2014), and the National Economic Council report "Future Housing Needs for Israel's Population" (2014) referred to 1.5% growth as the approximate forecast for the period 2015-2035. The medium projection was therefore used for this analysis.

The average number of people per household historically has stayed relatively constant over the period from 2001 to 2013, with a narrow range from 3.33-3.37 but shows a slight declining trend over time. The number of households has therefore been derived projecting forward from 2013 using an annual average decline in average persons per household of 0.1% which is derived from the historic data.

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[15] Natural gas price used was weighted average of prices across sectors based on sector share of consumption. For the power sector analysis, the gas price used was provided by the PUA and was $5.5/mmbtu (or 0.067 NIS/kWh)
[16] Data on excise taxes was sourced from the Tax Authority

Table 2 Population projections

Metric	Unit	2015	2020	2025	2030
Persons (CBS)	000 persons	8,388.8	9,105.9	9,844.9	10,604.6
Average persons per household (derived)	Persons per household	3.32	3.31	3.29	3.27
Households (derived)	000 households	2,524	2,754	2,992	3,239

A projection for GDP was determined by using the latest GDP data from the CBS, and projecting forward based on the annual GDP as per the GDP forecasts used by the Israeli Ministry of Energy's electricity projections modelling (1.9% GDP growth per capita scenario).

Table 3 GDP projection

GDP	Value	2015	2020	2025	2030
GDP (2010 prices)	NIS bn	1,034	1,242	1,351	1,701

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[17] Note that the 'Households (Derived)' figure does not exactly equal the 'Persons (CBS)' divided by the 'Average persons per household (derived), due to rounding.

03

BUILDINGS

3.1 METHODOLOGY

3.1.1 BAU

The ideal approach to calculating emissions in the buildings sector would be to start from the 'bottom-up': for example, to collect and combine data on numbers of appliances in residential and commercial buildings, split by type of appliance and sub-sector, and with information on the energy-intensity or energy efficiency of these appliances. Changes in these parameters over time could then be used to forecast energy-use and associated emissions from these sectors.

After undertaking wide-ranging evidence gathering, it was evident that sufficient disaggregated data was not available. Instead, given the quantity and nature of the data available, energy demand in residential and commercial sectors are projected using a 'top-down, driver-led' approach. A great deal of disaggregated data was available, and therefore used in the mitigation analysis for specific technologies. However, at the same time sufficient disaggregated data was not available at the level needed to fully project energy consumption for this sector, and as such a driver-led approach was deemed to be more accurate.

Under this approach, energy demand is projected on a sector-wide basis by energy type. To do so, first a key driver of emissions is identified. Historical trends in energy-intensity of the sector with respect to this driver were analysed, and both the driver and energy-intensity are projected forward on the basis of observed historical trends. When combined this produces a forecast of energy demand over the projection period.

The BAU assumes only natural energy efficiency improvements going forward: i.e. those made under existing policy or which occur in the market without further policy intervention.

3.1.1.1 Residential electricity demand

The starting point for electricity demand in the residential sector is the latest data available from the IEC: in 2013, residential electricity demand was 15,662 GWh.

In practice, residential electricity demand is influenced by a number of parameters, including: household size, income, appliance ownership, energy efficiency of appliances and national (and possibly international) policy. These parameters will also interact with one another to affect demand.

In particular, the number of housing units (apartments and private homes) has a significant impact on residential electricity consumption, correlating strongly with the number of key appliances, such as refrigerators, washers, dryers, and air conditioners. In addition, floor space can also drive residential consumption, impacting the amount of electricity needed for lighting and HVAC.

Given the housing shortage in Israel, and government plans to significantly increase the amount of new housing units being built over the coming 15 years, in conjunction with the National Economic Council the number of housing units was used as the key driver of residential energy demand.

Determining the historical trend in energy consumption per housing unit requires not only historical time-series data on energy consumption, but also on the housing stock. As this data was not sufficiently available, a trend in the housing stock in Israel was derived using data on the total housing stock published by the Ministry of Housing and Construction for 1996, as well as data on annual number of new units built from 1996-2013, as published by the CBS. This historical trend in number of apartments was then combined with IEC electricity consumption data to produce a historic energy intensity per apartment.

Table 4 Derived residential electro-intensity

Metric	Units	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013
Residential electricity demand (IEC)	GWh	12,319	12,747	13,365	13,517	13,719	14,313	15,049	15,201	15,117	15,591	15,909	17,244	15,662
Housing stock	000's	1,987	2,025	2,059	2,091	2,123	2,153	2,182	2,211	2,243	2,275	2,308	2,345	2,386
Derived energy intensity	kWh / apartment	6,198	6,294	6,492	6,463	6,463	6,649	6,898	6,875	6,740	6,852	6,892	7,355	6,565
Annual % change	%		1.5%	3.1%	-0.4%	0.0%	2.9%	3.7%	-0.3%	-2.0%	1.7%	0.6%	6.7%	-10.7%

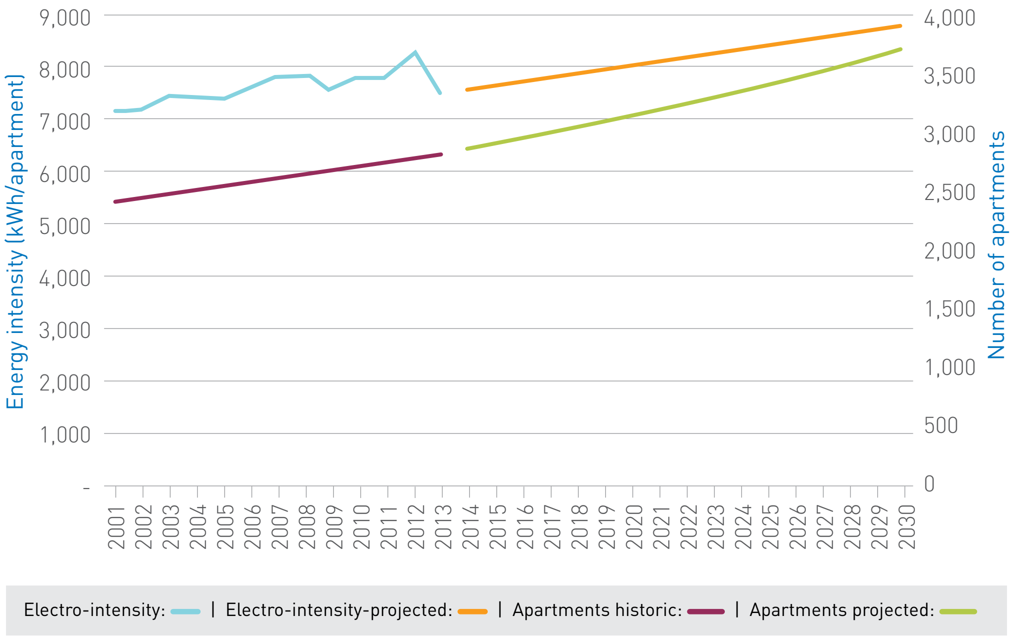
As can be seen from the table above, electro-intensity follows a fluctuating trend over the historic period. This is particularly the case for the derived figures for 2012 and 2013 which show a significant increase and subsequent reduction in electro-intensity. This is driven by unusual changes in underlying residential demand (i.e. after removing the influence of changes in the number of households). Anecdotal evidence states that 2012 was an exceptionally hot summer. An analysis done on CBS data backs this up - the average maximum temperature in the period from June to September 2012 was generally about 1 degree Celsius higher than in 1995-2009.

Energy-intensity is projected forward using historic trends. As noted above, the figures for 2012 and 2013 seem inconsistent with the rest of the period, so we excluded both values from the projection to avoid undue bias in the projection. Energy-intensity is therefore projected forward from 2013 using the annual average change of 1.1%, representing the average over the period 2001-11. This is similar to IEC data, which shows 1.3% annual average change.

This is combined with a projection for the annual construction of new apartments as per the National Economic Council report "Future Housing Needs for Israel's Population" (2014): 45,000-50,000 new apartments per year over the period 2015-2020 and 55-60,000 new apartments per annum for the years 2021-2035. For the latter period, the midpoint of 57,500 new apartments per annum was taken for the analysis.

The resulting trends in electro-intensity and housing stock are depicted in Figure 1 below:

Figure 1 Residential electro-intensity and number of apartments



3.1.1.2 Commercial / Public sector electricity demand

The starting point for electricity demand in the commercial/public sector was the latest data from the IEC showing demand in 2013 as 17,752 GWh.

As with the residential sector, commercial/public electricity demand will also be influenced by a number of parameters, not least growth in the different commercial/ public sub-sectors, appliance use and energy-efficiency policy. The key driver which drives energy demand in this projection is commercial/public floor space, and this was therefore selected as the parameter to use for the analysis, taking into account the floor space in the following sectors: accommodation, health, education, offices, commerce, and community buildings.

As with the residential sector, the requisite time-series data on historical stock of commercial and public buildings was not available. In conjunction with the buildings working group, and especially the CBS and the MoEP Green Buildings Division, the historical commercial and public floor space stock was derived as follows:

1. The basis of the stock data reported by local authorities on the amount of floor space per sector, which serves for municipal tax collection purposes, as provided by the CBS, by category.
2. This data in and of itself was not sufficient, as floor space reported in the context of municipal tax billing does not include those buildings that are exempt from paying municipal taxes, such as schools, kindergartens and places of worship. Therefore, the total floor space was adjusted upwards based on relevant GIS data provided by the MoEP, which showed the share of commercial and public floor space attributed to each building type.

The commercial and public building stock was then combined with the IEC electricity consumption data to derive a historical trend in electro-intensity for the commercial/public sector.

Table 5 Derived commercial/public electro-intensity

Metric	Units	2008	2009	2010	2011	2012	2013
Commercial/public electricity demand (IEC)	GWh	15,499	15,625	17,132	17,202	18,433	17,752
Floor space (derived)	000 sq m	48,178	51,804	55,401	50,966	52,891	55,844
Electro-intensity	kWh / sq metre	322	302	309	338	349	318
Annual % change	%		-6.2%	2.5%	9.1%	3.3%	-8.8%

While the change in electro-intensity can be seen to fluctuate widely over the historic period, the average change per annum in electro-intensity is approximately zero over the period from 2008-13. However, given the limited sample of years over which this average is taken, it is questionable how representative this average is of the historical period and hence how appropriate it is to use to project electro-intensity.

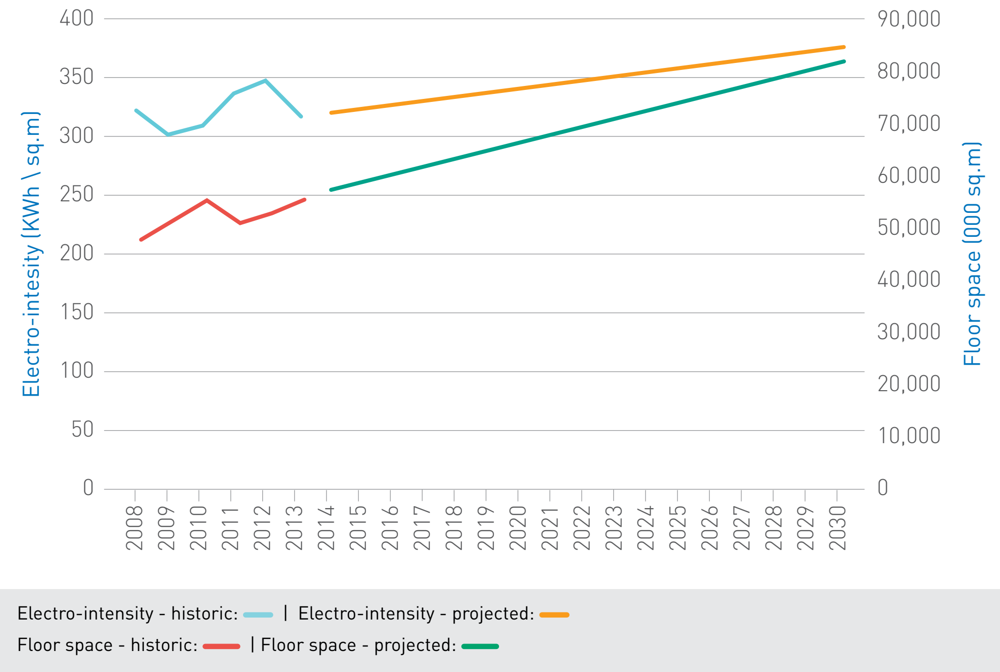
Over a longer period from 2001-13, data from the Odyssee database suggests growth in electro-intensity in Spain, Greece, and Portugal was much higher at 2.5%, 1.5% and 1.2% respectively.

A range of possible forecasts were investigated and the results compared to historical trends in electricity demand and existing projections of demand from other sources. On the basis of this assessment, it was considered using the growth rate from historical data of 0% would risk under-forecasting demand, given the volatility of the trend in electro-intensity in Israel over the historical period and small sample size. On the other hand, using a high rate from an international case study would risk over-forecasting given concerns around the applicability of these growth rates to Israel. As such a central annual average growth rate of 1% was judged to be the most appropriate approach.

Unlike the residential sector, no forecast of growth in commercial/public floor space was available with which to forecast energy demand. A forecast of the growth in floor space was derived by projecting from the stock level in 2013 using a growth rate each year going forward equivalent to the absolute annual change in floor space over the historical period.

The resulting projections in both commercial and public floor space as well as electro-intensity are shown below:

Figure 2 **Commercial/public electro-intensity and floor space**



3.1.1.3 Buildings sector fossil fuel demand

Historic data on fossil fuel demand was available both from the Fuel and LPG Authority, which provided total-market figures (excluding Palestinian Authority Consumption), and the CBS, which provided data on LPG, diesel and HFO consumption in industry from 2012, which was then used in the calculation of energy demand in the commercial/public section (see below).

Table 6 Historic energy consumption data (000 tonnes)

Fuel	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
Fuel and LPG Authority data for general market consumption and refinery self-consumption, excluding the Palestinian Authority consumption														
LPG Consumption - General Market	343	349	374	357	381	398	401	417	407	403	434	448	432	427
Diesel Consumption - General Market	168	156	126	137	153	128	102	85	82	46	48	35	23	15
Naphtha Consumption - General Market	53	42	45	38	27	20	23	23	18	25	16	19	4	2
HFO Consumption - General Market Total	1,269	1,210	1,102	1,106	1,105	1,065	910	968	886	706	610	629	458	317
HFO Consumption - Refinery Self Consumption	877	827	890	958	931	955	645	654	639	578	479	472	306	215
CBS industrial consumption figures (2012)														
LPG - Industry (CBS)												125		
Diesel - Industry (CBS)												93		
HFO - Industry (CBS)												689		

Note - If a cell in the table is blank, no fuel use was reported.

In order to project energy demand by sector, historical fuel consumption trends by sector were required. As such, the above Fuel & LPG Authority data was split between sectors based on the following assumptions:

Table 7 Assumptions to split fossil fuel demand

	LPG	Diesel						HFO - Refinery self-consumption	HFO - general market	Naphtha	NG
Year		All*	2001-6**	2007-8	2009-10	2011-12	2013-14				
Residential	30%	26%						0%	0%	100%	0%
Commercial/ public	42%	74%	50%	40%	30%	20%	10%	0%	20%	0%	0%
Industrial	28%		50%	60%	70%	80%	90%	100%	80%	0%	100%

* Split for all years is between residential and 'commercial/public and industry' sectors
** Split for individual periods is to split between commercial /public and industry sectors

The above split was derived as follows:

1. The share of residential consumption of each fuel was agreed with the Fuel & LPG authority, based on modelling assumptions used in development of the National Energy Sector Master Plan

2. The split between industrial and commercial / public consumption was determined as follows:
    - LPG: Based on the ratio of industrial consumption as provided by the CBS and total market consumption, for 2012.
    - Diesel and HFO: As agreed with the Fuel & LPG authority
    - Natural Gas: As agreed with the Natural Gas Authority

To project energy demand, the data required adjustment given the large discrepancy between industry diesel consumption from the CBS and economy-wide diesel consumption from the Fuel and LPG Authority: CBS data has industrial consumption at approximately 2.5 times the total market consumption. After consultation with both the CBS and the Fuel and LPG Authority, it was determined that the likely cause of this discrepancy is the use of diesel designated as transport fuel for industrial, non-transport purposes; therefore CBS data was agreed to be more accurate.

Using this information, the 'general market' diesel consumption figure is uplifted by a factor of 4.5 in all years (based on industry consuming 93 tonnes in 2012, which constitutes 80% of all industry and commercial/public consumption together, which in turn together constitutes 74% of total consumption; the resulting total consumption figure in 2012 is 4.5 times higher than the 35 tonnes reported in the 'general market'). Further, diesel consumption data for the commercial / public sector in 2013 was further adjusted slightly based on a bespoke survey conducted by the Natural Gas Authority of the fuels likely to be replaced by natural gas boilers in the sector.

This gives the historical demand for residential and commercial/public sectors as presented in the following tables.

Table 8 Derived historic residential fossil fuel demand (000 tonnes)

Fuel	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
LPG	103	105	112	107	114	119	120	125	122	121	130	134	130	128
Diesel	197	183	148	161	179	150	119	99	96	54	56	41	27	17
HFO	0	0	0	0	0	0	0	0	0	0	0	0	0	0
NG	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Naphtha	53	42	45	38	27	20	23	23	18	25	16	19	4	2

Table 9 Derived historic commercial/public fossil fuel demand (000 tonnes)

Fuel	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
LPG	144	147	157	150	160	168	169	176	172	169	183	188	182	180
Diesel	280	261	211	229	254	214	152	113	96	46	40	23	11	5
HFO	254	242	220	221	221	213	182	194	177	141	122	126	92	63
NG	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Naphtha	0	0	0	0	0	0	0	0	0	0	0	0	0	0

In the residential sector, LPG was projected using the driver led approach, as set out for electricity demand above. First a historic trend of LPG consumption per apartment was derived, then LPG-intensity was projected forward based on this historic trend and this was combined with the forecast number of apartments to project demand.

Upon review of projections with stakeholders, the driver led approach for diesel and naphtha were rejected. Instead, naphtha demand is forecast to stay constant at its 2013 value over the projection period and diesel demand is anticipated to remain constant until 2020, after which it reduces by 1.9% per annum, as per information provided by the Fuel & LPG Authority.

In the commercial/public sector, demand for LPG and HFO is forecast using the driver-led approach for this sector, with floor space as the key driver. Demand for diesel is expected to remain constant through 2020, after which it declines by 1.9% per annum.

Table 10 Residential fuel consumption by fuel type in key years

Fuel (TWh)	2015	2020	2025	2030
Electricity	16.76	19.28	22.49	26.00
Diesel	0.21	0.21	0.20	0.17
LPG	1.80	2.02	2.28	2.56
Naphtha	0.02	0.02	0.02	0.02

3.1.2 Mitigation

As per section 2.4, a short-list of potential abatement measures was identified for the residential and commercial/public sector in conjunction with the buildings working group. These measures represented those considered be most suitable to the Israeli context and hence should be considered for further assessment.

The assessment of the abatement potential and social cost for each measure required the following key data and assumptions:

- Baseline uptake assumptions
- Reasonable uptake potential in the mitigation scenario
- Technology lifetime
- Key data required to assess energy savings and emission reductions
- Cost data for both the mitigation and baseline technologies

A thorough data collection process was implemented, with an emphasis on Israel-specific data where available. Where this was not available, international data has been used as a proxy. This data was then presented to the working group and meetings were held on a team and on an individual basis in order to improve the assumptions. This included meetings with industry experts and academia, particular in the area of green buildings.

The list of measures assessed, along with key assumptions are included in the following tables.

Table 11 Residential abatement measures

<table>
<tr><th>MACC measure</th><th>Key assumptions</th></tr>
<tr><td>Replace diesel heating powered systems and electrical resistance heaters with air source heat pumps (ASHPs)</td><td>**BAU uptake assumptions**: 20% of apartments use electric resistance heating, 72.4% use ASHP and 7.6% use diesel (CBS data and expert judgement)
Mitigation uptake potential: 50% of diesel and 80% of electric resistance heating systems can be replaced with ASHP (Agreed with working group)
Lifetime: Electrical resistance heaters -25 years; diesel heating - 30 years; ASHP - 10 years (expert judgement)
Key data used to calculate savings: ASHP have COP of 3.5, relative to electric resistance heating COP of 1 and diesel of 0.65 (expert judgement)
Cost data: CAPEX of ASHP is 6000 NIS / apartment, NIS 2,400 per ASHP unit (market survey) and an average of 2.5 units per household (Ministry of Energy)
CAPEX of reference technology is NIS 2,000 per apartment, based on a cost of NIS 20,000 per central diesel heating system for a building with 10 apartment units (expert judgement)</td></tr>
<tr><td>Improve energy efficiency of commonly used electrical appliances (excluding a/c systems)</td><td>**BAU uptake assumptions**: Share of households with each appliance based on CBS data on penetration rates; BAU energy-efficiency based on average energy rating as per 2008 sales data from Tax Authority
Mitigation uptake potential: 90% of appliances replaced with most efficient category currently available (agreed with working group)
Lifetime: Appliances are replaced at rate of approximately 7% per annum, based on a lifetime of 15 years (expert judgement)
Key data used to calculate savings (based on Israel, UK efficiency data and expert judgement):</td></tr>
<tr><td>Improve energy efficiency of commonly used electrical appliances (excluding a/c systems)</td><td>
<table>
<tr><th>Appliance</th><th>BAU technology annual consumption (kWh)</th><th>Abatement technology annual consumption (kWh)</th></tr>
<tr><td>Refrigerators</td><td>298</td><td>135</td></tr>
<tr><td>Dryers</td><td>350</td><td>300</td></tr>
<tr><td>Dishwashers</td><td>529</td><td>441</td></tr>
</table>
Cost data (market survey):
<table>
<tr><th>Appliance</th><th>BAU technology cost (NIS)</th><th>Abatement technology cost (NIS)</th></tr>
<tr><td>Refrigerators</td><td>4,100</td><td>4,510</td></tr>
<tr><td>Dryers</td><td>1,948</td><td>1,845</td></tr>
<tr><td>Dishwashers</td><td>2,624</td><td>3,034</td></tr>
</table>
</td></tr>
<tr><td>Reduce heat losses and heat gains through improved wall and roof insulation</td><td>**Baseline uptake assumptions**: A negligible amount of existing buildings meet the Green Building Standard (5281) for insulation requirements. For new build, based on current penetration rates, about 6.5% of new build meets Green Building requirements (MoEP Green Building Division)
Mitigation uptake ambition: Insulation will be retrofitted in accordance with the Green Building Standard (5281) in 2% of existing buildings by 2030. Uptake of insulation and glazing that meets Standard 5281 in new buildings will increase gradually, and by 2030 will reach 50% of new buildings built in that year
Lifetime: 40 years (MoEP Green Building Division)
Key data used to calculate savings: Insulation delivers 20% saving in HVAC energy consumption existing and 15% in new buildings (working group, based on academic research)</td></tr>
</table>

MACC measure	Key assumptions
Reduce heat losses and heat gains through improved wall and roof insulation	**Cost Data**: For existing buildings, additional insulation costs of NIS 10,000 and NIS 40,000 were assumed for apartments and private homes, respectively. Apartments were assumed to comprise 70% of retrofitted units, with private homes comprising 30% For new build, additional insulation costs of NIS 3,750 and NIS 15,000 were assumed for apartments and private homes, respectively. Apartments were assumed to comprise 80% of new units, with private homes comprising 20% (MoEP Green Building Division, based on applicable studies)
Reduce heat losses and heat gains through window glazing	**Baseline uptake assumption**: A negligible amount of existing buildings meet the Green Building Standard (5281) for glazing requirements. For new build, based on current penetration rates, about 6.5% of new build meets Green Building requirements (MoEP Green Building Division) **Uptake ambition**: 2% of existing building will be retrofitted to meet the Green Building Standard by 2030; Uptake of insulation and glazing that meets Standard 5281 in new buildings will increase gradually, and by 2030 will reach 50% of new buildings built in that year. (MoEP Green Building Division) **Lifetime**: 20 years (expert judgement) **Key data used to calculate savings** - Glazing saves 4% of HVAC-related energy consumption (Ministry of Construction and Housing) **Cost data**: For existing buildings, additional glazing costs of NIS 5,000 and NIS 20,000 were assumed for apartments and private homes, respectively. Apartments were assumed to comprise 70% of retrofitted units, with private homes comprising 30% For new build, additional insulation costs of NIS 1,250 and NIS 5,000 were assumed for apartments and private homes, respectively. Apartments were assumed to comprise 80% of new units, with private homes comprising 20% (MoEP Green Building Division, based on applicable studies)
Improved efficiency of air conditioning (a/c) units	**Baseline uptake assumption**: Currently, 84% of households have A/C units (CBS). Households with A/C units have 2.5 units on average (Ministry of Energy). **Mitigation uptake potential**: Upgrade 90% of the units to more efficient units (working group) **Lifetime** - 10 years (expert judgement) **Key data used to calculate savings**: Average consumption of 1118 kWh/unit pa, calculated using total number of units and total household electricity which is consumed by HVAC. Assume all units upgraded to the current category D by 2030, i.e. the COP will improve to 3.65 in the baseline. Mitigation units will have a COP of 3.8, in line with category A **Cost data**: Added cost of a more efficient unit in 2030 will be 500 NIS, using a weighted average of an additional NIS 1000 for mini-centralized units and NIS 300 for standard split units (market survey)
Introducing ground source heat pumps (GSHPs)	**Baseline uptake assumption**: Negligible **Mitigation uptake potential**: 0.5% of households take up GSHP by 2030 (MoEP Green Building Division assessment) **Lifetime**: 10 (as per associated air conditioning units) **Key data used to calculate savings** - GSHP delivers 30% energy savings relative to ASHP, based on a report provided by MoEP which states that savings from GSHP could be 30-70% in heating and 20-50% in cooling **Cost data**: Unit cost of GSHP is 8800 NIS per apartment, based on a cost of £15,000 for a 10 apartment building, from the UK Energy Savings Trust, which includes installation as well as equipment costs

MACC measure	Key assumptions
Solar shading -brises soleils, reflective coatings to windows	**Baseline uptake assumption**: Negligible **Uptake ambition**: Reflective coatings - 10% of buildings; Brises soleil - 5% of buildings (working group) **Lifetime**: 30 years **Key data used to calculate savings** - Reflective window coating - 6% savings in HVAC energy consumption; Brises soleil - 8% savings (expert judgement) Assume rebound effect of 12% (ACEEE study) **Cost data** - Cost per apartment is 1800 and 4800 for window coating and brises soleil respectively. This includes NIS 300 per property for conducting study to locate applicable windows (MoEP Green Building Division, based on applicable studies)
Energy efficient lamps (Eco Halogen, CFLs, LEDs)	**Baseline uptake assumption**: 10% of residential electricity demand currently used for lighting (expert judgement); halogen and incandescent lamps are replaced with CFLs; 5% remain halogen and 5% remain incandescent (working group) **Mitigation uptake potential**: Halogen, incandescent, and CFLs are replaced with LEDs. 1% remain halogen, 1% remain incandescent and 12% remain CFL (working group) **Lifetime**: Halogen - 4 years; incandescent - 4 years; CFLs - 8 years; LEDs - 40 years (www.thelightbulb.co.uk)) **Key data used to calculate savings**: International data has been used to estimate the **comparative efficiency of lamp types**: lumens/watt (www.thelightbulb.co.uk) **Cost data** (£ - www.thelightbulb.co.uk): **CFL** 3.00 **Halogen** 1.50 **LED** 8.00 (assumed to fall by 30% by 2030, as per MoEP) **Incandescent** 1.00 **Fluorescent** 6.00
Public awareness and information campaigns and real time energy displays	**Baseline uptake assumption**: Negligible **Uptake ambition**: Real-time displays and smart meters - 10% and 5% of households, respectively (MoEP Green Buildings Division) **Lifetime**: 10 years (expert judgement) **Key data used to calculate savings**: National campaign - 1% of total residential energy consumption (working group) Real-time displays and smart meters - 5% and 10% per household, respectively (MoEP Green Buildings Division) **Cost data**: Cost of real-time display and smart meters assumed to be 500 and 1200 NIS/unit respectively (market survey) National campaign - NIS 4.15 million annually (based on previous MoEP national campaigns)
Lime scale build-up in pipes	**Baseline uptake assumption**: 86% of housing stock have regular solar heaters (CBS) **Mitigation uptake potential**: 90% will be replaced by solar heaters that that have a closed water cycle, and therefore do not accrue lime scale (working group) **Lifetime**: Reference - 10 years; mitigation - 15 years (expert judgement) **Key data used to calculate savings**: 15% savings in energy consumption for water heating, beginning in 5th year following heater replacement (expert judgement) **Cost data**: Additional cost is 300 NIS/unit, based on NIS 2,300 for mitigation technology and 2,000 for reference technology (expert judgement)

Table 12 Commercial/Public abatement measures

<table>
<tr><th>MACC measure</th><th>Comment</th></tr>
<tr><td>Improve the energy efficiency of commonly used electrical appliances (excluding HVAC systems)</td><td>

Baseline uptake assumption - BAU energy-efficiency based on average energy rating as per 2008 sales data from Tax Authority;

Mitigation uptake potential: 90% of appliances are replaced with most efficient category available today

Replacement rate / lifetime assumptions; Appliances are replaced at rate of about 7% per annum, based on lifetime of 15 years (expert judgement)

Lifetime: Appliances are replaced at rate of 7% per annum, based on a lifetime of 15 years (expert judgement)

Key data used to calculate savings (based on Israel data where available, UK efficiency data and expert judgement):

<table>
<tr><th>Appliance</th><th>BAU technology annual consumption (kWh)</th><th>Abatement technology annual consumption (kWh)</th></tr>
<tr><td>Refrigerators</td><td>298</td><td>135</td></tr>
<tr><td>Dryers</td><td>350</td><td>300</td></tr>
<tr><td>Dishwashers</td><td>529</td><td>441</td></tr>
</table>

Cost data (market survey):

<table>
<tr><th>Appliance</th><th>BAU technology cost (NIS)</th><th>Abatement technology cost (NIS)</th></tr>
<tr><td>Refrigerators</td><td>4,100</td><td>4,510</td></tr>
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</table>

</td></tr>
<tr><td>Reduce heat losses and heat gains through improved wall and roof insulation</td><td>

Baseline uptake assumption: A negligible amount of existing buildings or new build meet the Green Building Standard (5281) for insulation requirements (MoEP Green Building Division)

Uptake ambition: 4% of existing building will be retrofitted to meet the Green Building Standard by 2030; uptake of insulation that meets Standard 5281 in new buildings will increase gradually, and by 2030 will reach 55% of new buildings built in that year. (MoEP Green Building Division),

Lifetime assumptions: 50 years (expert judgement)

Key data used to calculate savings - Insulation delivers 14% savings in HVAC energy consumption in both new and existing buildings. This is based on academic data for savings in different sub-sectors, such as 15% in offices, 10% in hotels, health centres and educational facilities, and calculated proportionately to the floor space

Cost data - Additional insulation cost of 525 and 175 NIS/m2 of floor space for existing and new buildings, respectively (MoEP Green Building Division, based on applicable studies)

</td></tr>
<tr><td>Reduce heat losses and heat gains through window glazing</td><td>

Baseline uptake assumption: A negligible amount of existing buildings or new build meets the Green Building Standard (5281) for glazing requirements. (MoEP Green Building Division)

Uptake ambition: 6% of existing building will be retrofitted to meet the Green Building Standard by 2030; Uptake of glazing that meets Standard 5281 in new buildings will increase gradually, and by 2030 will reach 55% of new buildings built in that year. (MoEP Green Building Division)

Lifetime: 20 years (expert judgement)

Key data used to calculate savings: Glazing saves 3% (working group, based on existing studies)

Cost data: 87 and 57 NIS/m2 of floor space for existing and new buildings,

respectively (MoEP Green Building Division, based on applicable studies)

</td></tr>
</table>

MACC measure	Comment
HVAC efficiency measures including VSDs, cooling towers	**Baseline uptake assumptions**: VSDs - 70% of susceptible HVAC motors will have VSDs by 2030 (expert judgement) Chillers - Average chiller consumption of 670,000 kWh per year (see industry section below) **Mitigation uptake assumptions**: VSDs - 40% of those susceptible HVAC motors that do not have VSDs installed (expert judgement) Cooling towers - Can replace 10% of chillers in commercial sector Chillers - All chillers upgraded by 2030 with more efficient chillers **Lifetime**: VSD - 10 years; chiller - 15 years **Key data used to calculate savings**: VSDs - 15% energy savings (expert judgement) Cooling towers - 15% (MoEP research) Efficient chillers - 19% (as explained in the industry section below) **Cost data**: VSDs - 3.5 NIS/kWh saved. See industry section below Chillers - Estimated for 400 ton cooling unit. Reference - $452 per ton cooling ; Mitigation - $610 per ton cooling (MoEP data)
Introducing ground source heat pumps (GSHPs)	**Baseline uptake assumption**: Negligible **Mitigation uptake potential**: 10% of existing commercial HVAC electricity consumption **Key data used to calculate savings**: GSHP can deliver 40% energy savings (expert judgement) **Cost data** - 25% more per ton cooling than the reference technology, based on the assumption that only relevant to areas where drilling costs are relatively low. The alternative is $542 per ton cooling. (MoEP data)
Solar shading -brises soleils, reflective coatings to windows	**Baseline uptake assumption**: Negligible **Mitigation uptake ambition**: Reflective coatings - 10% of buildings; Brises soleil - 5% of buildings (MoEP Green Building Division) **Lifetime**: 30 years **Key data used to calculate savings**: Reflective window coating and brises soleil offer energy saving of 6% and 8% of HVAC consumption, respectively (expert judgement) - Reflective window coating - 6% savings in HVAC consumption; Brises soleil - 8% savings (expert judgement) **Cost data**: Cost per m2 of floor space is NIS 4 and 12 for window coating and brises soleil respectively (MoEP Green Building Division, based on applicable studies)
MVHR (Mechanical ventilation and heat/cooling recovery)	**Baseline uptake assumption**: Uptake by 2030 will be negligible, i.e. it was assumed only 1% of businesses will have this (expert judgement) **Lifetime**: 30 years (expert judgement) **Mitigation uptake ambition**: 20% of commercial HVAC electricity consumption (expert judgement) **Key data used to calculate savings**: 5% expected savings in energy consumption for HVAC (expert judgement)Cost data: Additional cost of 200 NIS / tonne cooling (expert judgement)

MACC measure	Comment
Automated lighting and HVAC control	**Baseline uptake assumption**: Negligible (expert judgement) **Mitigation uptake potential**: 90% of offices (expert judgement) **Lifetime**: 20 years (expert judgement) **Key data used to calculate savings**: 10% of property assumed lit and air conditioned when unoccupied (expert judgement) **Cost data**: NIS 650 per sensor (1 sensor per office). Number of offices estimated based on total HVAC consumption in offices and assuming 1 ton cooling capacity per office, 3000 operating hours per annum (expert judgement)
Energy efficient lamps - moving to T5 and to LEDs	**Baseline uptake assumption**: (expert judgement) T8, T5: 55% of lighting consumption CFL: 27% of lighting consumption Halogen: 4% of lighting consumption Sodium: 2% of lighting consumption Metal Halide: 8% of lighting consumption LED: 4% of lighting consumption **Mitigation uptake potential**: Replace all bulbs with LEDs **Lifetime**: (expert judgement) T8, T5, halogen, sodium, and metal halide: 8 years CFL: 4 years LEDs: 40 years in use **Key data used to calculate savings** - Assume all lighting replaced with LEDs which operate at 250 Lumens/watt by 2023 (expert judgement) **Cost data** - Reference technology - Weighted Average cost of £5 per lamp. Mitigation technology (LED) cost of £8 (international costs, based on www.thelightbulb.co.uk)
Street lighting	Baseline uptake assumption: Currently around 900k street lights all metal halide / high pressure sodium. Current total electricity consumption in street lighting estimated at about 2.5% of total electricity consumption (Ministry of Energy report) Mitigation uptake potential: All new lamps will be LED Lifetime: (expert judgement) High pressure sodium or metal halide: 20 years LED: 40 years Key data used to calculate savings - Difference in lumen/watt in reference and mitigation lamps yields 50% energy savings per bulb (expert judgement) Cost data - Total weighted average cost of about £54 per lamp in reference and £159 per lamp in mitigation (expert judgement)

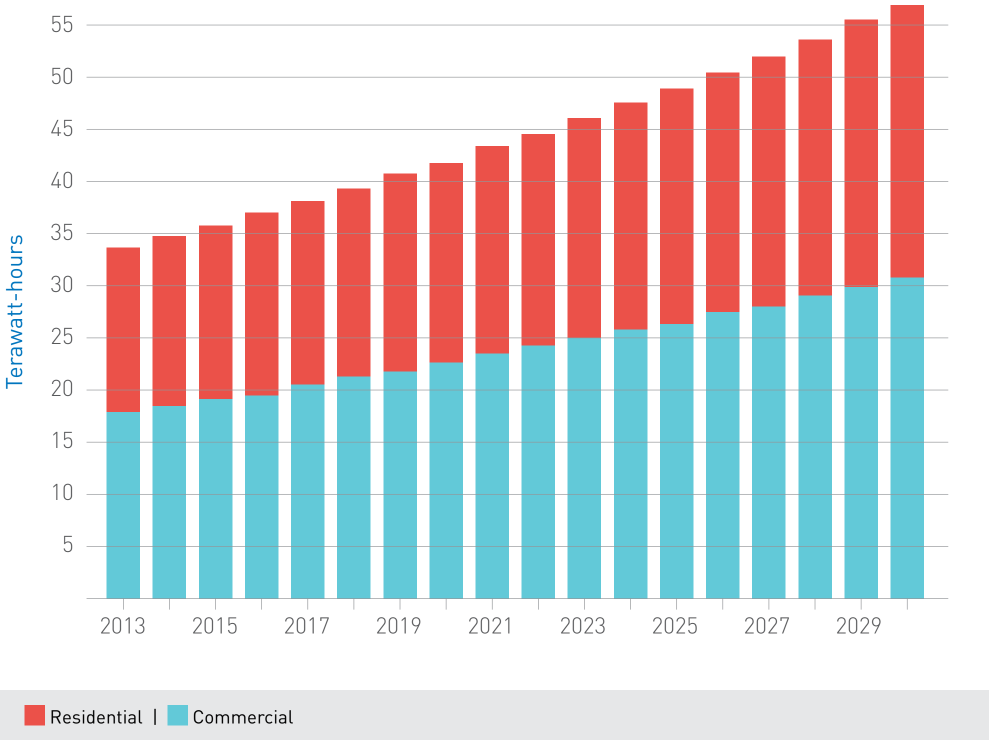
3.2 RESULTS

For this analysis we modelled GHG emissions from residential and commercial/public buildings. The latter also covers GHG emissions from street lighting, as this is part of the public sector.

3.2.1 BAU

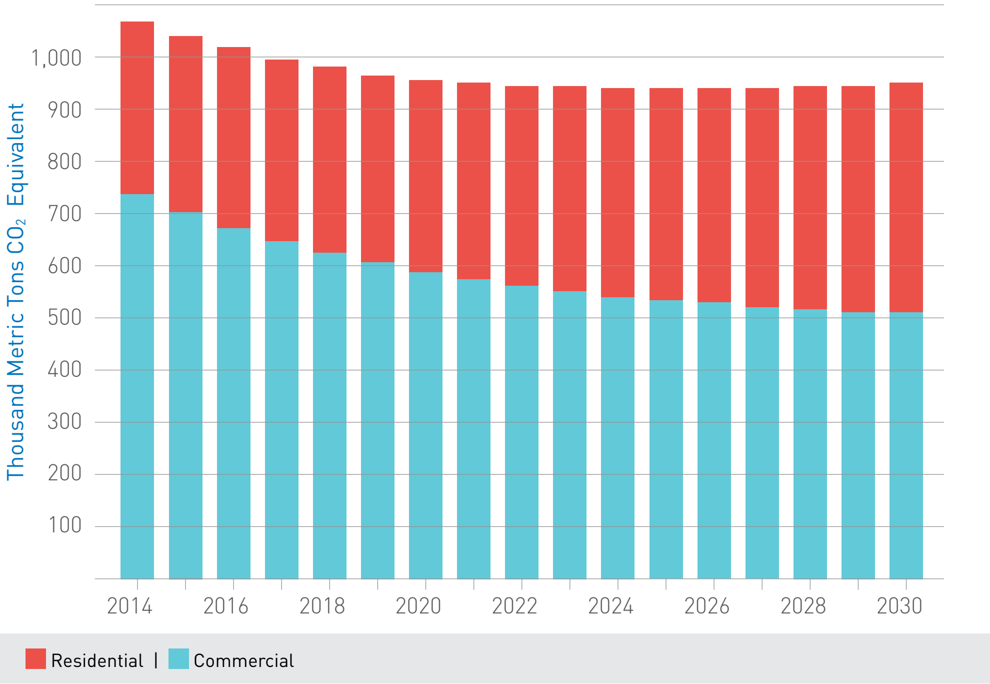
In the BAU, electricity demand from buildings is forecast to increase by 64% from 2014 levels to 2030 (60% in residential and 67% in commercial/public). Demand in 2014 is 34.7 TWh (16.3 TWh in residential and 18.4 TWh in commercial/public), increasing to 56.8 TWh (26.0 TWh in residential and 30.8 TWh in commercial/public) in 2030; see Figure 3.

Figure 3 BAU electricity demand in residential and commercial/public sector



In the BAU scenario, direct GHG emissions from all buildings are forecast to decrease by 11% from 2014 levels by 2030 (33% increase in residential and 31% decrease in commercial/public); see Figure 4. This is a reduction in emissions from 1,066 ktCO$_2$e in 2014 (329 ktCO$_2$e in residential and 737 ktCO$_2$e in commercial/public) to 946 ktCO$_2$e in 2030 (437 ktCO$_2$e in residential and 509 ktCO$_2$e in commercial/public). The trend in the residential sector is driven by increasing demand for LPG, which offsets small decreases in demand for diesel and naphtha. In the commercial/public sector, emissions are driven by decreases in HFO, which offset increasing demand for LPG.

Figure 4 **BAU emissions from buildings**



3.2.2 Mitigation

The measures included on the residential and commercial/public MACC's can reduce emissions in total by 1.7 Mt CO_2e and 2.6 Mt CO_2e respectively; see Figure 5 and Figure 6.

Figure 5 **Residential MACC in 2030**

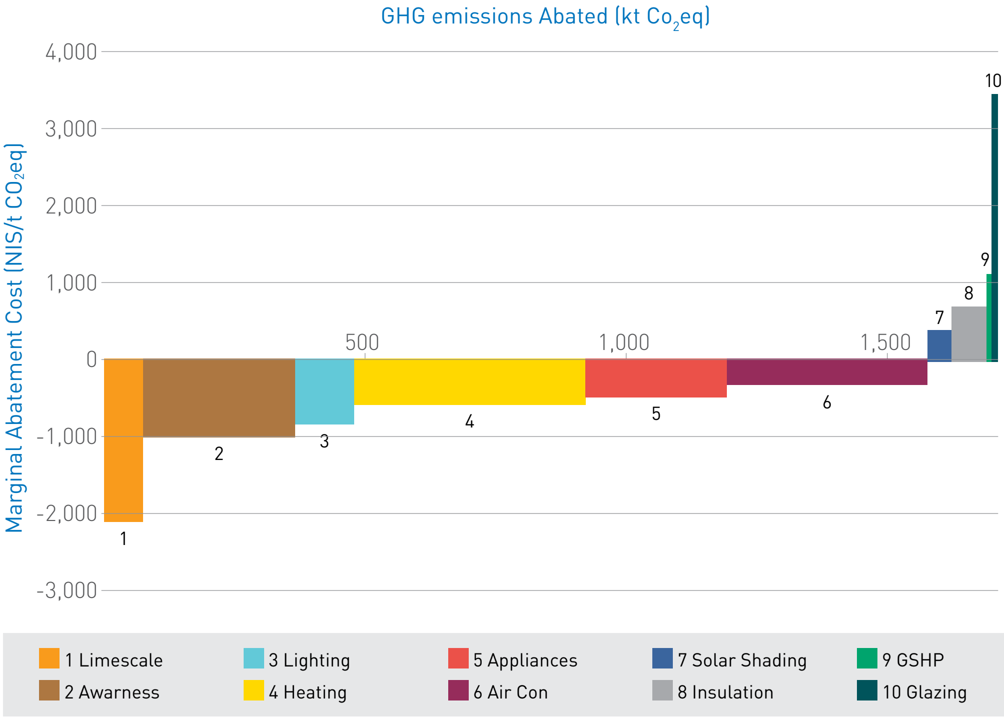


Figure 6 Commercial / Public MACC in 2030

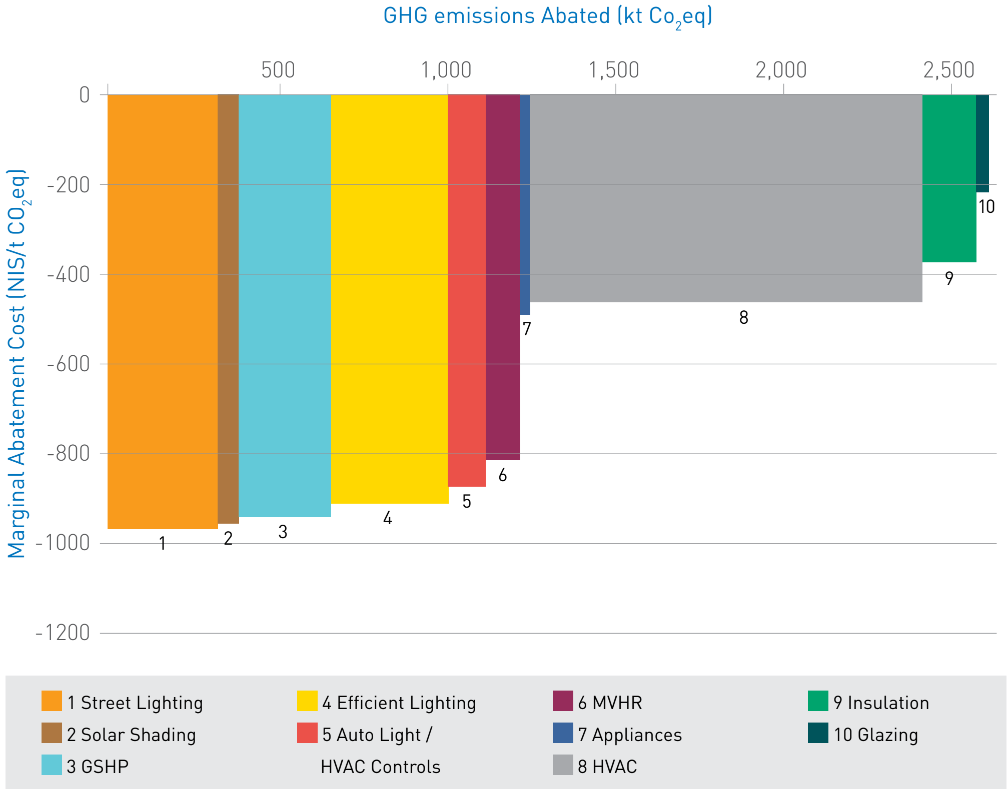


Table 13 Cost effectiveness and abatement potential of key measures

Measure Name	Cost-effectiveness (NIS/tCO₂e)	Abatement potential in 2030 (ktCO₂e)
Residential		
Awareness	-1020	293
Heating	-596	442
Air Conditioning	-339	387
Commercial/public		
Street Lighting	-969	322
Efficient Lighting	-908	345
HVAC	-467	1,170

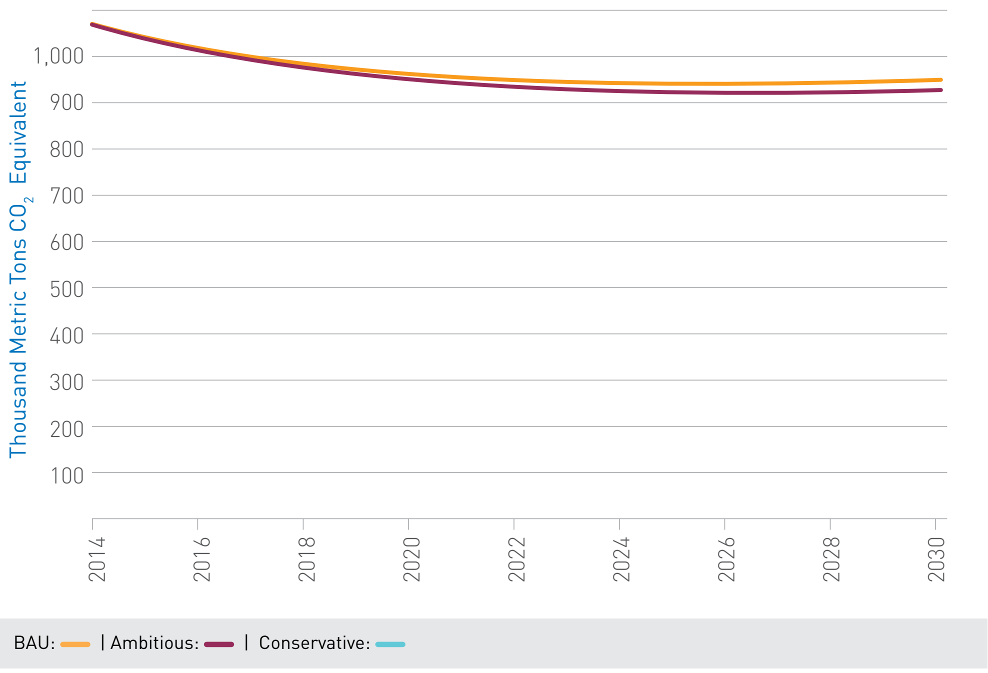
In the non-domestic sector, all the abatement potential identified on the MACC has been assessed as cost-effective. In the domestic sector, 92% of the abatement potential identified is cost-effective.

The MACCs include savings across both electricity and fossil fuels.

Direct emissions from buildings can be reduced by 2.4% by 2030 relative to BAU under both the 'conservative target' and 'ambitious target' scenarios (4.8% reduction in residential and 0.5% in commercial/public). The reduction in residential emissions is driven by a combined 3.2% reduction in diesel and LPG consumption for heating. The reduction potential that was identified in commercial/public buildings was limited because only the abatement measures improving glazing and insulation impacted fuel consumption. It should be noted that natural gas uptake in the commercial/public sector (in hotels and hospitals) was not viewed as an abatement measure due to the fact that the gas will also replace LPG, which is a less GHG intensive fuel.

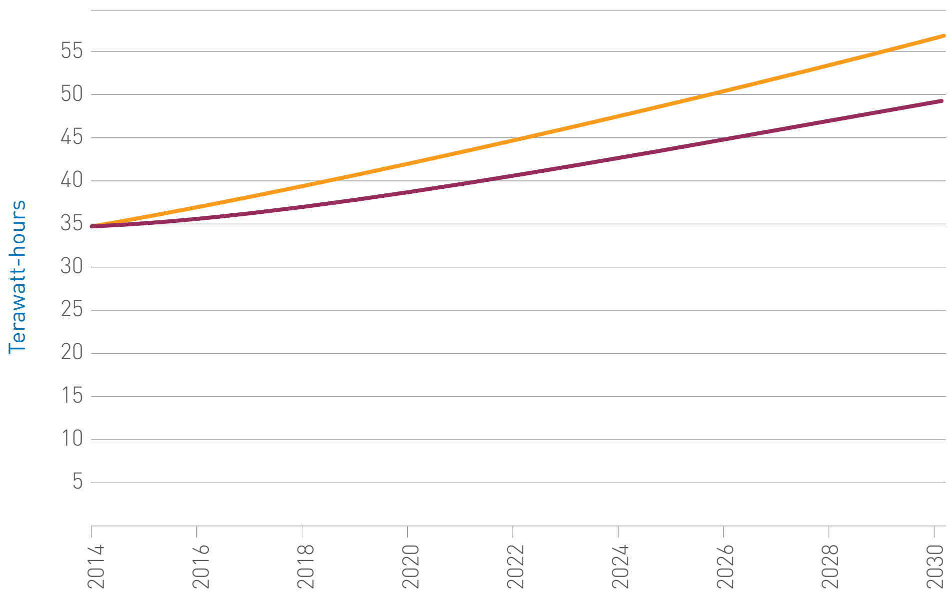
Please note that there is little difference in energy and emissions savings between the two abatement scenarios, due to the fact that the energy efficiency measures included in both scenarios are identical, with the sole exception of GSHP in residential buildings which was not included in the 'conservative target'. As a result, the two abatement scenarios are not discernible from each other in both the emissions graph as well as the electricity demand graphs below.

Figure 7 **Emissions under abatement scenarios**



In the buildings MACCs, more significant reductions are achieved in electricity demand; see Figure 8. Under the 'conservative target' and 'ambitious target' scenarios, electricity demand in buildings reduces by 7.5 TWh (13.3%). In residential buildings, electricity demand reduces by 3.0 TWh (11.5%), and in commercial/public buildings, electricity demand reduces by 4.6 TWh (14.8%) in both scenarios.

Figure 8 **Electricity demand in buildings**



BAU: ▬ | Ambitious: ▬ | Conservative: ▬

3.2.3 Observations

In the BAU and abatement scenarios, electricity is, and continues to be, the most important energy consumed in the buildings sector.

In the BAU scenario, growth in number of apartments in the residential sector and floor space in the commercial/public sector, combine with increasing energy intensity to drive an overall increase in demand for electricity over the forecast period.

In both buildings sectors, LPG use is forecast to continue to increase, again driven by increasing numbers of apartments and floor space. However demand for other, less significant fossil fuels is anticipated to fall.

In the mitigation scenarios, the greatest amount of energy savings and subsequent emissions savings are in electricity, again reflecting the dominant importance of this energy for the sector. These savings are delivered across a range of measures in each sector, with the most significant being implementation of air source heat pumps and improved air conditioning units in the residential sector, improving street lighting and HVAC units in the commercial/public sector and rolling out LED lighting across both sectors. However, all the mitigation measures together are not sufficient to overcome the drivers mentioned above (increasing numbers of apartments, floor space and energy intensity) which result in increasing demand for electricity over time.

Only minor savings are identified in direct emissions (i.e. emissions from combustion, as opposed to GHG savings from reduced electricity use). LPG demand continues to show an overall increasing trend under both mitigation scenarios in both sectors.

The mitigation measures in the conservative target scenario for the residential sector have an associated cumulative cost of NIS 7.5 bn by 2030 over their lifetime. The mitigation measures in the commercial/public sector under this scenario imply a lifetime cost of NIS 10.1 bn by 2030. Overall, the measures installed under the conservative target scenario in the residential and commercial/public sectors by 2030 are estimated to deliver net benefits of NIS 6.8 bn and NIS 21.3 bn (all figures are present values after discounting - see section 2.5 for more details).

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[20] Heating, ventilation and air conditioning.

04

INDUSRTY

4.1 METHODOLOGY

4.1.1 BAU

4.1.1.1 Industry electricity demand

As with the buildings sector, BAU energy demand in industry has been forecasted using the 'driver-led' approach given the lack of disaggregated data with which to take a more bottom-up approach. For this sector, industrial output is the key driver of energy demand.

First, trends in industrial output and energy-intensity were assessed over the historic period taking data on electricity demand from the IEC and on industrial output from the Ministry of Finance.

Table 14

Table 14: Deriving electro-intensity

		2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013
Historic industry elec demand (IEC)	GWh	9,232	9,423	9,728	9,880	10,237	10,387	11,178	11,218	10,329	10,647	10,987	11,849	10,372
Industrial output (2010 prices) (Ministry of Finance)	NIS m	80,517	76,222	80,082	83,450	90,493	99,191	106,547	109,633	104,917	117,546	117,553	121,008	124,903
Energy intensity (Ind. Output)	kWh/000 NIS	114.66	123.63	121.48	118.39	113.12	104.72	104.91	102.32	98.45	90.58	93.46	97.92	83.04

Energy intensity (with respect to industrial output) shows a varying trend over time, climbing in the first year then showing a declining trend for much of the rest of the period. The average annual change in energy intensity over the period from 2001-13 was -2.5% (i.e. a decrease). From the data it seems that the annual change in electricity intensity has a wide range: between 2001 and 2012 the range is from -8.0% to +7.8%, with 2013 seeing a significant decrease in electro-intensity of -15.2%. The 2013 figure appears particularly distinct - this calculated result is driven by the trend in overall electricity demand. Looking at total demand figures for industry, the average annual change in total electricity demand over the period 2001-12 was 2.4%: electricity demand then fell in 2013 by 12.5%. However, given the size of this downturn, this could potentially be an outlier which overly affects the average rate of change in energy intensity going forward.

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[21] All figures from Odyssee database.

The average annual change in electro-intensity over the shorter period from 2001-12 is -1.3%. When this analysis was presented to the industry working group, the consensus opinion was that both -2.5% and -1.3% electro intensity improvement would be unrealistic going forward, especially as a baseline assumption that does not take into account further policy. Therefore, a literature review was conducted of the electro-intensity improvements in similar countries. Over the same period, the average annual change in electro-intensity (relative to a measure of industrial production) was: 0.1% in Spain, 0.6% in Italy, 1.3% in Greece and -0.5% for the EU as a whole. Hence the Israeli specific figure of -1.3% lies outside this range of values. Using this Israeli-specific low rate of growth produces a forecast much lower than existing projections.

Based on both the literature review, and the concern of the work team, it was judged most appropriate to apply the average rate of growth of the EU (-0.5%) from the historic period to project electro-intensity into the future.

This is combined with a forecast of industrial output over the period, projected forward using the average annual growth rate of 3.6%.

4.1.1.2 Industry fossil fuel demand

The approach to projecting fossil fuel demand in industry follows the same 'driver-led' principle as set out for electricity above. The first step, as with the approach to buildings, is to derive historic data for industry fossil-fuel demand from the economy-wide data.

Historic data on fossil fuel demand was available both from the Fuel and LPG Authority, which provided total-market figures (excluding Palestinian Authority Consumption), and the CBS, which provided data on LPG, diesel and HFO consumption in industry from 2012.

Table 15 Historic energy consumption data (000 tonnes)

	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
Fuel and LPG Authority data for general market consumption and refinery self-consumption, excluding the Palestinian Authority consumption														
LPG Consumption - General Market	343	349	374	357	381	398	401	417	407	403	434	448	432	427
Diesel Consumption - General Market	168	156	126	137	153	128	102	85	82	46	48	35	23	15
Naphtha Consumption - General Market	53	42	45	38	27	20	23	23	18	25	16	19	4	2
HFO Consumption - General Market Total	1,269	1,210	1,102	1,106	1,105	1,065	910	968	886	706	610	629	458	317
HFO Consumption - Refinery Self Consumption	877	827	890	958	931	955	645	654	639	578	479	472	306	215
CBS industrial consumption figures (2012)														
LPG - Industry (CBS)												125		
Diesel - Industry (CBS)												93		
HFO - Industry (CBS)												689		
NG consumption (as per the Natural Gas Authority)														
NG Consumption - Heavy Industry (BCM)					0.02	0.07	0.09	0.23	0.25	0.49	0.82	0.67	1.48	2.01
NG Consumption - Distribution (BCM)													0.01	0.05

After making an adjustment to estimate national diesel demand, the 'general market' data is then split between sectors based on the assumptions in the following table.

Table 16 Derived historic industry fossil fuel demand (GWh)

	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
LPG	1,256	1,278	1,372	1,310	1,397	1,459	1,470	1,530	1,494	1,476	1,592	1,642	1,585	1,566
Diesel	3,369	3,139	2,534	2,758	3,062	2,572	2,241	2,040	2,149	1,304	1,440	1,120	772	539
HFO	21,127	20,041	19,784	20,572	20,263	20,171	15,327	15,947	15,046	12,758	10,797	10,888	7,515	5,233
NG	-	-	-	-	143	665	817	2,185	2,375	4,655	7,790	6,365	14,155	19,570

LPG demand has been forecast taking the driver-led approach, using historical trends of energy intensity (GWh/NIS industrial output), while taking projected growth in industrial output into account. In addition, both LPG and Naphtha are consumed in Israel by the petrochemical industry. Although these fuels are primarily consumed as feedstock - and therefore their use does not emit greenhouse gases - a small portion is combusted on site.

In line with feedback provided by the Fuel & LPG Authority, this was estimated as 3% of total consumption in the sector, and projected forward from 2014 data using the growth rate in all oil-based fuels across the Israeli economy over the forecast period.

As advised by the Ministry of Energy, diesel demand is anticipated to remain at its 2013 level until 2020 before declining at a rate of 1.9% per annum.

For natural gas, the average annual growth in energy intensity was 88% over the period 2005-13. This is predominantly driven by the low starting point of penetration of natural gas and strong uptake over this period driven by the discovery of indigenous resources. It is clear that this rate of change cannot be assumed going forward, otherwise this would result in a demand for natural gas in 2030 that would be unrealistic.

To account for this, given that natural gas predominantly replaces heavy fuel oil (HFO) as the dominant fuel in industry going forward, we project the demand for natural gas and HFO forward together using the driver-led approach, based on the historic combined average annual change in consumption of these fuels. The annual average combined change is -1.4%.

This rate is used to project the HFO and natural gas intensity of industrial output together to 2030, giving a projection for total HFO and natural gas for each year over the projection period.

It is assumed in the BAU scenario that there is no further growth of HFO demand after 2014. This was based on feedback provided by both MoEP and the Fuel and LPG Authority. As such, we held the consumption of HFO constant over the projection period with the remainder of the combined HFO and natural gas projection allocated to natural gas.

The sole source of pet coke demand in Israel is in cement production. As such, the projection for this fuel was developed based on a focused consideration of this sector. Current capacity of cement production is around 5.9 million tonnes per annum. In the forecast, we assume this increases to 7.5 million tonnes in 2024. Based on the historical rate of domestically produced clinker to cement production, this corresponds to a forecast of domestic clinker production of around 4.4 million tonnes rising to 5.5 million tonnes in 2024. The consumption of pet coke was then forecast forward combining the projection for domestic clinker production with an average pet-coke intensity of clinker production (derived from historic data) of 754 kWh/tonne clinker produced, and taking into account that the Nesher Ramle plant is expected to increase the use of RDF from 10% of kiln fuel consumption to 40% by 2020

4.1.1.3 Water sector electricity demand

To project electricity demand in the water sector, a forecast of water demand was taken from the Israel water sector master plan. This forecasts total water consumption to increase from 2,057 million m3 in 2012 to 2,765 million m3 in 2030.Water production by source and relevant electro-intensity of the different water resources are noted below.

Water production data is based on the following assumptions:

- Desalination plants' capacities (seawater and saltwater) in 2030, as provided by the Water Authority, with the assumption that units will run at 90% production capacity.
- Freshwater production was taken from the Israel water sector master plan.
- The production from the 'other water' category was a calculation of the amount of water required to reach the forecasted 2,795 million m^3 in 2030, after taking into account the desalination and freshwater. This category includes treated wastewater.

The projected consumption is combined with assumptions around the electro-intensity of each water source, as follows:

- Desalination of seawater consumes 3.5 kWh/m3 (Water Authority)
- Desalination of saltwater consumes 1.8 kWh/m3 (Ministry of Energy)
- Transmission of desalinated water (seawater and saltwater) consumes an additional 0.8 kWh/m3 (Ministry of Energy)
- Freshwater drawn from the Kinneret, along with its transmission, consumes 1.5 kWh/m3, while freshwater drawn from aquifers and wells, consume 0.8 kWh/m3 (Ministry of Energy). As the Israel water sector master plan combines these together into one category (freshwater), a weighted average of 0.94 kWh/m^3 was used, based on CBS data on the percentage of freshwater drawn from each source in 2012 (20% from the Kinneret, 80% from aquifers)
- Electro-intensity of water from other sources, such as treated wastewater supplied for use in agriculture, was assumed to be 1.13 kWh/m3 based on the total amount of water produced from other sources in 2012 (CBS), and the total associated electricity consumption in 2012. The electricity consumption was estimated by applying the above electro-intensity figures to the 2012 water production from each of the other sources (CBS); the remaining water sector electricity consumption, as reported by the IEC, was assumed to be consumed by water from other sources

Table 17 Forecast water consumption from Israel water sector master plan

Water production (mln m3)	2012	2030	Energy intensity (kWh/m3)
Desalination (seawater)	313.0	573.3	4.3
Desalination (saltwater)	34.8	51.6	2.6
Freshwater	995.0	1080.0	0.9
Other water	714.2	1060.1	1.1

4.1.2 Mitigation

As per section 2.4, a short-list of potential abatement measures were identified for the industrial and water sectors in conjunction with the industry working group. These measures represented those considered be most suitable to the Israeli context and hence should be considered for further assessment.

The assessment of the abatement potential and social cost for each measure required the following key data and assumptions:

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[22] http://www.water.gov.il/Hebrew/Planning-and-Development/Planning/MasterPlan/DocLib4/MasterPlan-en-v.4.pdf

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- Baseline uptake assumptions
- Reasonable uptake potential in the mitigation scenario
- Technology lifetime
- Key data required to assess energy savings and emission reductions
- Cost data for both the mitigation and baseline technologies

A thorough data collection process was implemented, with an emphasis on Israel-specific data where available. Where this was not available, international data has been used as a proxy. This data was then presented to the working group and meetings were held on a team and on an individual basis in order to improve the assumptions. This included meetings with industry experts.

The list of measures assessed, along with key assumptions are included in the following table.

Table 18 Industry abatement measures

Category	MACC measure	Key assumptions
Energy Supply	Employ gas fired CHP	**Baseline uptake assumptions**: As per current CHP capacity and plants with conditional licences (PUA) **Mitigation uptake potential**: Additional 300 MWe small-scale CHP capacity (Ministry of Economy) **Lifetime**: 20 years (expert judgement) **Key data used to calculate savings**: Baseline boiler efficiency of 80%. Power generated by small scale CHP estimated to be 5,085 MWh/MWe (based on 25 CHP schemes serving UK industrial installations, representing both gas turbines and reciprocating engines. The Schemes have power generating capacities in the range of 3-7 MWe, and the average capacity per scheme is 4.9 MWe) Results in an average of 18% displacement of fuel consumption. **Cost data**: CAPEX of 855 £/kWe and OPEX of £6.56/MWh (expert judgement)
Boilers, Steam Raising and Distribution	Switch to Natural Gas boilers	**Baseline uptake assumptions**: No additional fuel switching to natural gas **Mitigation uptake potential**: Gas-boilers can replace 70% of HFO-fired boilers (MoEP) **Lifetime**: 30 years (expert judgement) **Key data used to calculate savings**: Gas boilers offer improved efficiency (82%) relative to counterfactual boiler (77%) (expert judgement) **Cost data**: 3 - 3.5 million NIS per installation, for illustrative boiler consuming 1.5 million m3 per annum, based on NIS 1.5 million in connection costs to the natural gas distribution system (from the Natural Gas Authority) + NIS 1.5 - 2 million plant conversion costs, depending on size (Ministry of Economy)
Motors and Drives	Employ adjustable speed drives	**Baseline uptake assumptions**: By 2030, 30% of susceptible motors will have VSDs installed (expert judgement, in line with recent IEA study on motors sold in Germany). 50% of all motors are susceptible (Ecodesign IA study) **Mitigation uptake potential**: 90% of susceptible motors (working group) **Lifetime**: 15 years (expert judgement) **Key data used to calculate savings** - Systems achieve 30% energy savings with VSD (expert judgement) **Cost data** - Installation costs are 0.97 NIS/kWh of electricity saving (calculated based on Ecodesign IA report)

Category	MACC measure	Key assumptions
Compressed Air	Adopt VSD compressors for compressors ←30 kW.	**Baseline uptake assumption** - By 2030, 30% of susceptible compressors will have VSDs installed (expert judgement). 30% of air compressors are susceptible (Ecodesign IA study) **Mitigation uptake potential**: 90% of susceptible compressors (working group) **Lifetime**: 20 years (expert judgement) **Key data used to calculate savings**: Systems achieve 30% energy savings with VSD (expert judgement) **Cost data** - Installation costs are 0.93 NIS/kWh of electricity saving (Calculated, based on Carbon Trust and Gambica studies)
	Waste heat recovery from air compressors	**Baseline uptake assumption**: Negligible; 35% of waste heat is susceptible to recovery (expert judgement) **Mitigation uptake potential**: 80% of susceptible systems to be fitted with WHR **Lifetime**: 20 years (expert judgement) **Key data used to calculate savings**: 80% of electricity from compressors is lost as heat, of which 70% can be recovered and displaces heat from gas-fired boiler (Carbon Trust study) **Cost data**: CAPEX for a 100hp installation is NIS 70,000 (expert judgement)
Process Cooling	Employ chillers of state of the art efficiency.	**Baseline uptake assumption**: Current chillers operate at IPLV1 of 3.4 for air-cooled and 5.3 for water cooled (working group) **Mitigation uptake potential**: Replacement of 90% with state-of-the art chillers by 2030 (working group) **Lifetime**: 15 years (expert judgement) **Key data used to calculate savings**: Typical energy savings from state-of-the-art chillers are 17% for air-cooled and 37% for water-cooled (based on Turbocor data) **Cost data**: reference costs of USD$ 445 / ton cooling and mitigation costs of USD$ 610 / ton cooling (MoEP research paper)
	Employ shallow geothermal heat pumps for process cooling.	**Baseline uptake assumption**: Negligible **Mitigation uptake potential**: 5% of water cooled industrial chillers (working group) **Lifetime**: GSHP has **lifetime** of 20 years (DECC study), as opposed to chiller with 15 year **lifetime** (expert judgement) **Key data used to calculate savings**: GSHP has an IPLV of 9, based on actual data from a system installed in Jerusalem **Cost data**: 25% more per ton cooling than water based chiller with 400 kW cooling capacity (expert judgement, based on assumption that will only be installed where drilling costs are relatively low)
Generic	Energy management systems	**Baseline uptake assumptions**: 10% of industrial energy consumption will be covered by EMS by 2030 (expert judgement) **Mitigation uptake potential**: EMS are applicable to all industrial sites and up-take reaches 75% by 2030 (industry working group) **Lifetime**: 15 years (expert opinion) **Key data used to calculate savings**: 8% average energy savings per installation (Industry working group) **Cost data**: Payback period of 4 years (expert judgement)

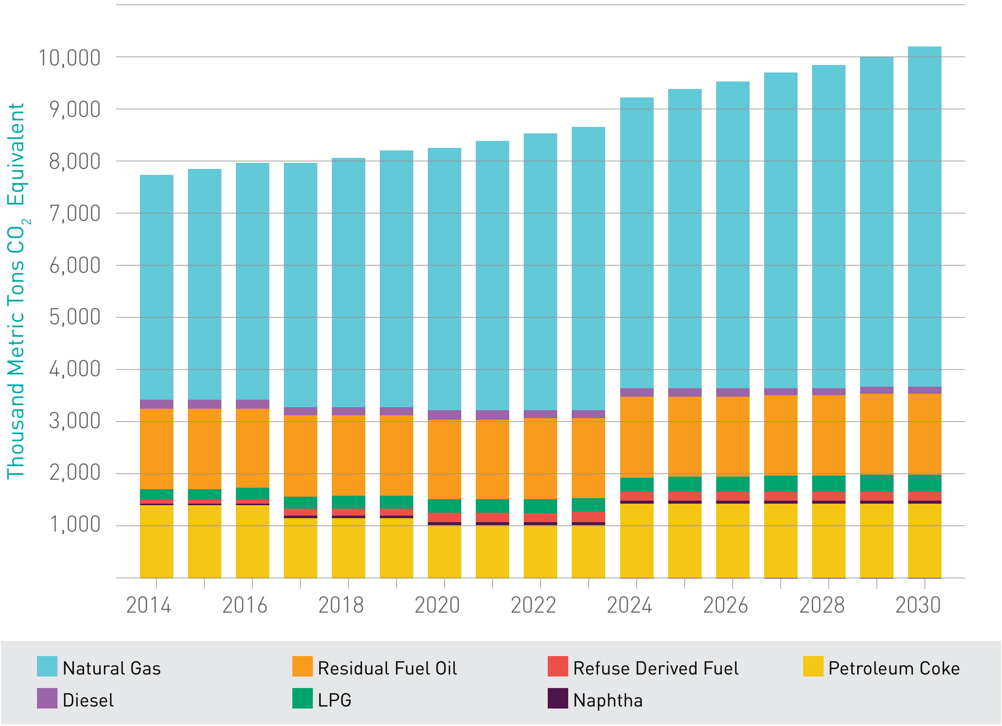
Category	MACC measure	Key assumptions
Cement Clinker Production	Use of waste fuel above current substitution levels	**Baseline uptake assumptions**: Current substitution of pet coke for alternatives is around 10% at the Nesher Ramle plant; this is assumed to increase to 30% in 2017 and 40% by 2020 (Nesher Israel Cement Enterprises) **Mitigation uptake potential**: Substitution of pet coke for waste fuels assumed to reach 60% by 2030 across all sites (industry working group) **Lifetime**: 20 years (expert judgement) **Key data used to calculate savings**: Pet coke consumption is 754 kWh/tonne clinker with 10% replacement at the Nesher Ramle plant only; Total capacity of cement production is currently 5.9m ton per annum increasing to 7.5m ton in 2024 (MoEP). **Cost data**: Requires CAPEX of 35m NIS per site that does not currently have RDF substitution (based on Nesher costs at Ramle site, adjusted for capacity of other sites); OPEX is assumed to by 1% of CAPEX (Ricardo-AEA report submitted to UK DECC). Zero cost for RDF is assumed.
	Increased use of Pulverised Fly Ash (PFA) as clinker substitute	**Baseline uptake assumptions**: 10% of cement mass (Nesher Israel Cement Enterprises) **Mitigation uptake potential**: 15% of cement mass (working group) **Key data used to calculate savings**: Reduced clinker production will reduce associated energy consumption and process emissions, as per modelling assumptions. **Cost data**: Additional capex is ~10m EURO for a site with 2m tonnes pa clinker production cap (ECRA study), no unit cost for fly ash (expert judgement)
Water sector	Improved efficiency of water pumps	**Baseline uptake assumptions**: Average consumption of existing pump is around 6.9MWh per annum with average efficiency of 66.5% **Mitigation uptake potential**: 90% of water pumps replaced (working group) **Lifetime**: 11 years **Key data used to calculate savings**: Efficiency of best available water pump is 73.4% **Cost data**: Reference technology of 1,431 Euro per pump and mitigation costs of 1,477 Euro per pump All data sourced from European Commission research report
	Reduced leakage	**Baseline uptake assumptions**: Rate of leakage in municipal ad urban infrastructure estimated at 12% (working group) **Mitigation uptake potential**: Improved to 8%, based on best practice in Israel (working group) **Lifetime**: 15 years (expert judgement) **Key data used to calculate savings**: Reduced leakage in municipal and urban infrastructure reduces energy demand for water sources used in residential sector, i.e. pumping of fresh water and desalination. Energy consumption per m3 desalinated and m3 pumped as per modelling assumptions. **Cost data**: Cost of pressure management systems installed is 2.69 pence per m3 saved (Deer Valley Water report); cost of active leakage control is 161 pence per m3 saved (Veolia report)

4.2 RESULTS

4.2.1 BAU

In the BAU scenario, direct GHG emissions from industry are forecast to increase by 32% from 2014 levels by 2030; see Figure 9. This represents an increase in industry sector emissions from 7.7 $MtCO_2e$ in 2014 to 10.2 $MtCO_2e$ in 2030. This trend is predominantly driven by increasing demand for natural gas, together with smaller increases in demand for pet coke and RDF (driven by increasing capacity in the cement sector), and in LPG and naphtha. Note: this refers only to direct combustion-related emissions in this sector - process and fugitive emissions are considered as part of the non-energy projections.

Figure 9 BAU emissions from industry



The graph above shows emissions from fuel combustion in industry. The key trends in fossil fuel consumption in industry are:

- An increase of 51% in natural gas demand
- An increase of 37% in LPG demand
- HFO demand remains constant

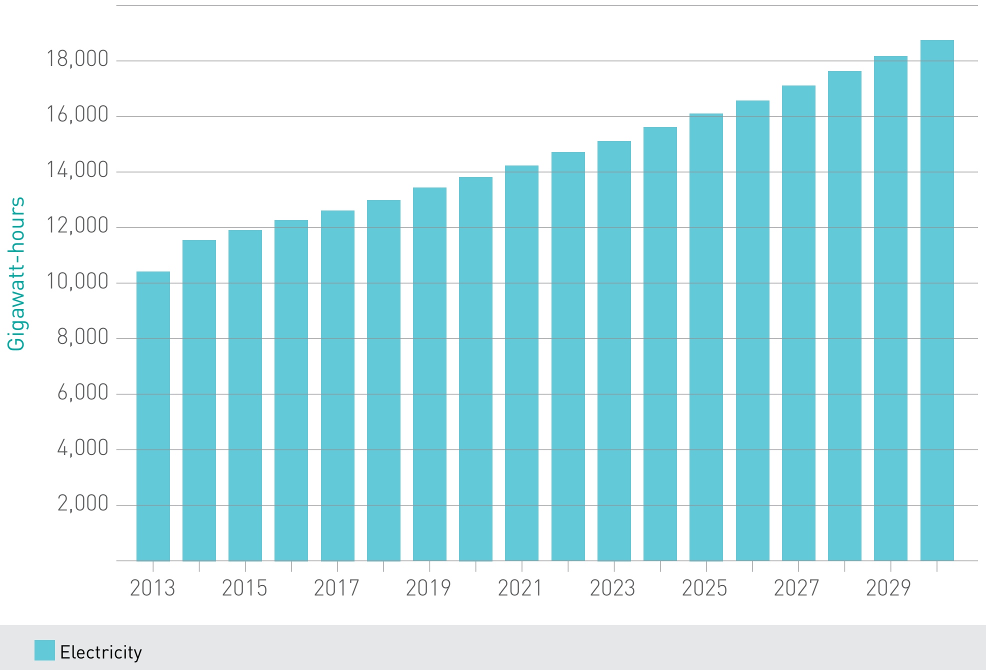
Pet coke consumption decreases until 2020, due to partial replacement with RDF at the Nesher Ramle plant; it then increases again in 2024, due to the addition of new cement production capacity.

Table 19 Fossil fuel consumption in industry

Fuel	Proportion of demand in 2014	Proportion of demand in 2030
Natural Gas	64%	70%
Diesel	2%	1%
Residual Fuel Oil (HFO)	17%	12%
LPG	5%	5%
Refuse Derived Fuel	1%	3%
Naphtha	1%	1%
Petroleum Coke	11%	8%
Total	100%	100%

In the BAU scenario, electricity demand from industry is forecast to increase by 62% from 2014 to 19.1 TWh in 2030:

Figure 10 BAU electricity demand in industry sector



In the BAU scenario, electricity demand from the water sector is forecast to increase from 3,108 GWh in 2013 to 4,809 GWh in 2030, bringing total BAU demand from the industry and water sectors to 23.9 TWh in 2030.

4.2.2 Mitigation

In total, the measures on the MACC are estimated to deliver 2.5 $MtCO_2e$ of savings in 2025, rising to 3.4 $MtCO_2e$ in 2030 (across direct, indirect and process savings)[24]; see Figure 11.

Figure 11 **Industry MACC in 2030**

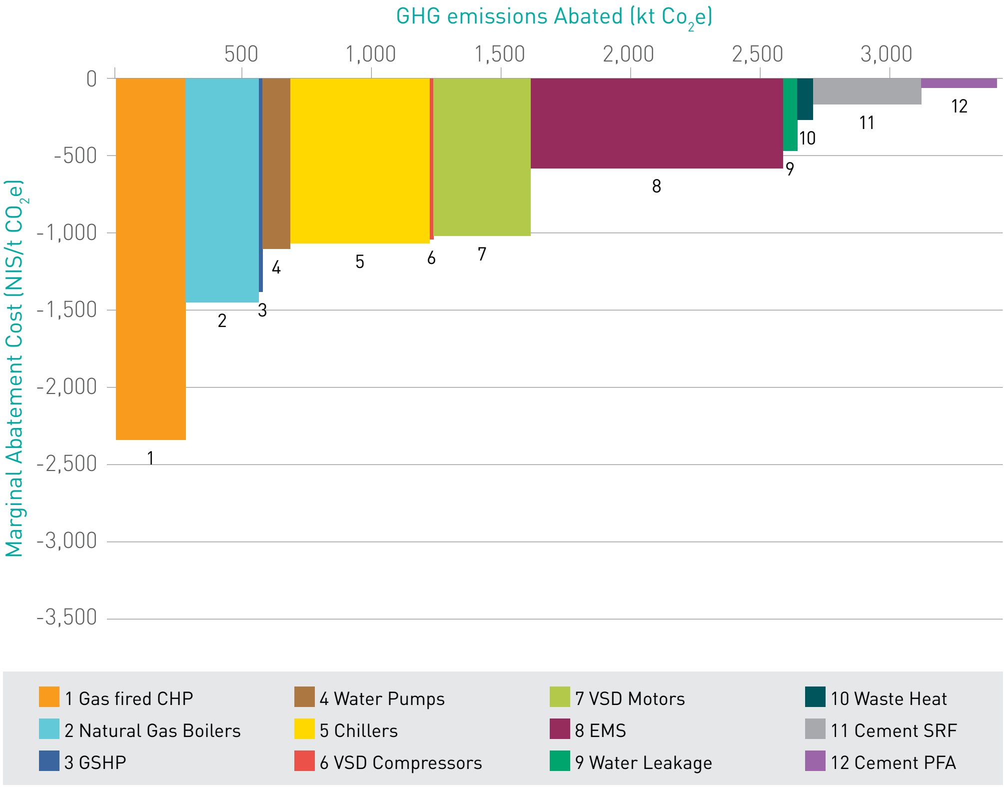


Table 20 Top 4 cost-effective industry abatement measures in terms of abatement potential

Measure Name	Cost-effectiveness (NIS/tCO_2e)	Abatement potential in 2030 ($ktCO_2e$)
Chillers	-1069	543
VSD Motors	-1018	377
EMS	-580	984
Cement SRF (RDF)	-175	415

All abatement potential identified in the industry sector as part of this study has been assessed as cost-effective.

Direct emissions from industry can be reduced by 7.3% (or 743 $ktCO_2e$) by 2030 relative to BAU under both the 'conservative target' and 'ambitious target' scenarios; see Figure 12. There is no difference in measures included (and hence also in emissions savings) between the 'conservative target' and 'ambitious target' scenarios in industry, given

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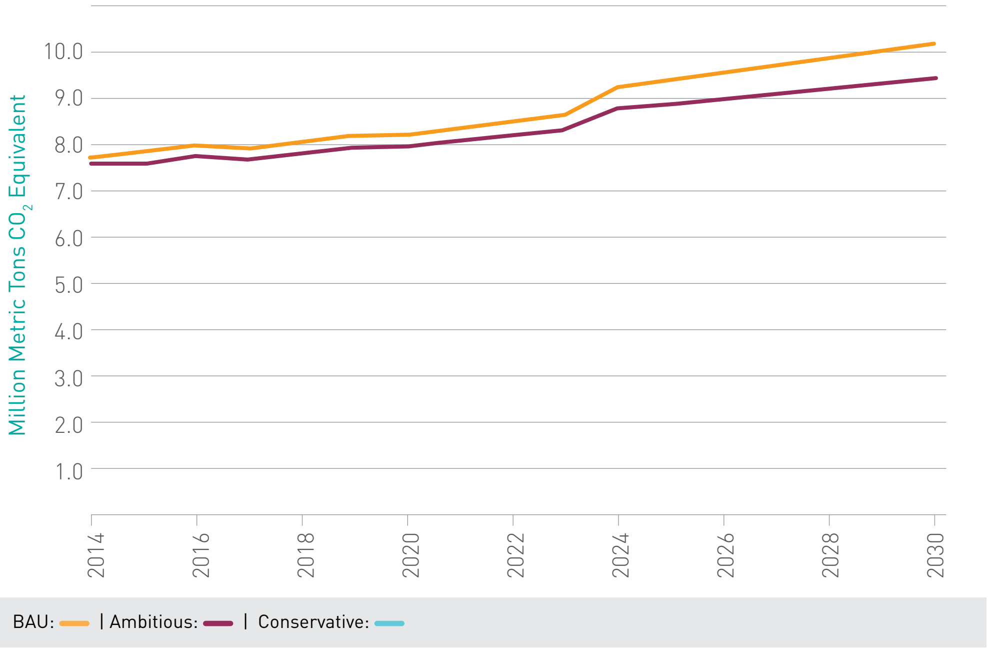
[24] Note: this does not take into account interactions with the power sector

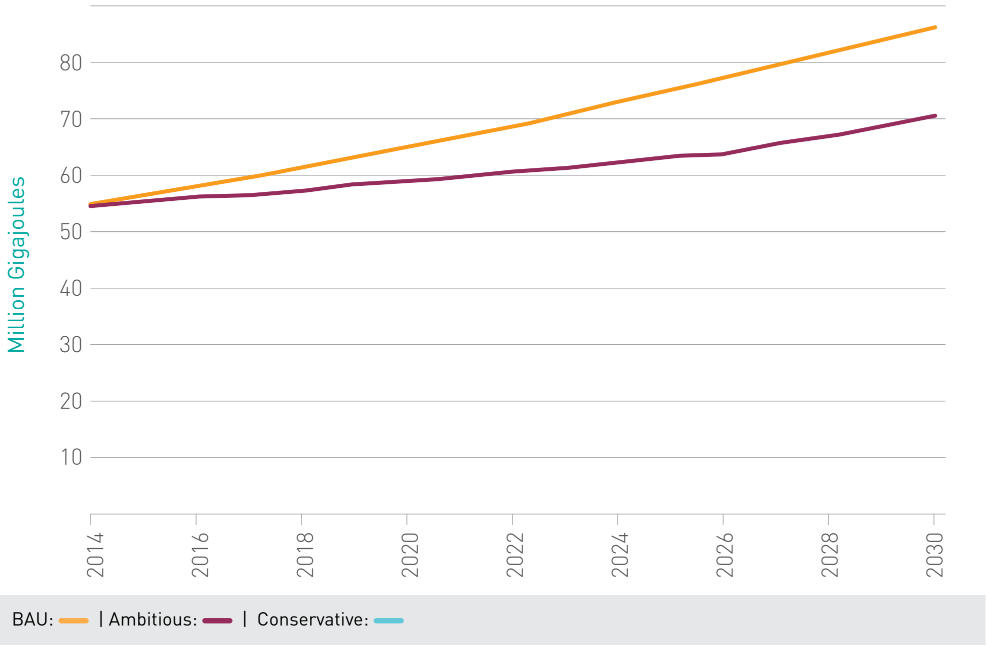
all abatement measures identified in the industry sector have been assessed as cost-effective; as such the two are not discernible from each other in the two graphs below.

Figure 12 **Emissions under abatement scenarios**



In the industry MACC, significant reductions are also achieved through reductions in electricity demand. Under the 'conservative target' and 'ambitious target' scenarios, electricity demand in industry falls by 18.5% in 2030 relative to BAU; see Figure 13.

Figure 13 **Electricity demand in industry and water**



4.2.3 Observations

Even though the electro-intensity of industry output is assumed to decline over the forecast period, overall electricity demand from industry is forecast to continue to grow in the BAU scenario, driven by continued strong growth in industrial output.

In addition, natural gas use is anticipated to show continued strong growth over the projection period, driving an overall increase in direct emissions, with other fossil fuels showing relatively little change out to 2030. A key exception to this is pet coke use, which shows a step up in demand in 2023 in conjunction with the opening of the new cement production facility anticipated for that year.

In the abatement scenarios, abatement is delivered across a range of measures (rather than being concentrated through one or two key measures). In particular, environmental management systems (0.98 $MtCO_2e$ in 2030), improving efficiency in chillers (0.54 $MtCO_2e$) and substitution of pet coke with RDF (refuse-derived fuel) in cement (0.41 $MtCO_2e$) deliver substantial emissions savings. Relative to the BAU scenario, the key changes in fuel consumption are that both HFO and pet coke now show a declining trend over time under the mitigation scenarios. In particular, as a result of the abatement measures, HFO demand reduces by 74% in 2030 under the conservative target scenario relative to the BAU scenario.

As in the buildings sector, the MACC measures deliver the largest amount of GHG savings through reductions in demand for electricity. In particular the reduction in grid electricity demand through gas-fired CHP, and improving energy efficiency through more efficient chillers, variable speed drive installation and environmental management systems deliver 92% of electricity savings.

However, as in the case of buildings, even with the impact of abatement measures included, electricity demand and direct emissions continue to increase over the period to 2030.

The total cumulative cost of the measures included under the conservative target scenario to 2030 for industry implies a total lifetime cost of NIS 6.7 bn. These measures are estimated to deliver lifetime benefits of NIS 34.3 bn, resulting in an overall net benefit of around NIS 27.6 bn (all figures are present value after discounting).

05

TRANSPORT

5.1 METHODOLOGY

5.1.1 BAU

The foundation of the transport BAU scenario is total vehicle kilometres (vkm) for all modes out to 2030. The LEAP model then uses the percentage share of total vkm for all modes and fuel efficiency data to calculate fuel use per mode. Fuel emission factors then covert fuel use to emissions data. However it should be noted that for rail, domestic aviation and shipping a slightly different approach was taken due to data availability. For these modes, fuel use was inputted directly into LEAP, bypassing the need for more detailed data on stock (numbers of vehicles), demand and efficiency.

This approach is in line with the approach used by both the Ministry of Energy as part of the Energy Sector Master Plan, and the Petroleum Alternatives Administration.

5.1.1.1 Stock

The starting point for all road transport modes (excluding e-bikes and walk/cycle modes) was taken from 2013 CBS data:

Table 21 Number of vehicles for road transport (CBS)

Stock	2013
Passenger car	2,338,687
Taxi	19,821
Minibus	14,238
Bus	16,917
Motorcycle	121,218
Small Truck	256,659
Large Truck	78,419

Projected stock post 2013 has been calculated using annual growth rate assumptions for each individual mode. The growth rate assumptions were agreed with the transport working group, and calibrated based on a model for 2030 vehicle demand and annual mileage provided by Finance and Transport Ministry consultant Nir Sharav, at request of the Finance Ministry.

Table 22 Assumed annual growth rate in number of vehicles, for select road transport modes

Mode	Growth rate (%)
Passenger car	2.38%
Taxi	2.30%
Minibus	2.10%
Bus	2.10%
Motorcycle	2.20%
Small Truck	2.30%
Large Truck	2.30%

For e-bikes, the stock in 2013 was taken to be 130,000, based on data received from the transport working group, and projected out to 2030 in line with the growth of the Israeli population. For walk/cycle modes the stock was simply assumed to be the Israeli population out to 2030. The full stock projections are presented in Appendix 3.

5.1.1.2 Demand

Using the stock data, the resulting demand data (vkm) was calculated by multiplying annual mileage per vehicle per year and stock. The annual mileages assumed for each road transport mode are shown below in Table 23. As can be seen it was assumed that annual mileage per mode would remain fixed over time in the BAU scenario, with the exception of full battery electric powertrains for private vehicles. For these vehicles, the annual mileage has been assumed to be around 50% of a standard power train mileage to account for these vehicles being limited to the mileage they can do due to limitations in battery range, but is assumed to increase slightly over time.

Table 23 Annual mileage per vehicle for road transport

Annual mileage per vehicle (km)	2013	2020	2025	2030
Passenger car - Petrol	16,183	16,183	16,183	16,183
Passenger car - Diesel	16,183	16,183	16,183	16,183
Passenger car - Petrol hybrid	16,183	16,183	16,183	16,183
Passenger car - Diesel hybrid	16,183	16,183	16,183	16,183
Passenger car - Electricity	8,092	8,253	8,253	8,415
Passenger car - LPG	16,183	16,183	16,183	16,183
Motorbike - Petrol	7,194	7,194	7,194	7,194
Motorbike - Electricity	7,194	7,194	7,194	7,194
Taxi - Petrol	82,741	82,741	82,741	82,741
Taxi - Diesel	82,741	82,741	82,741	82,741
Taxi - Diesel hybrid	82,741	82,741	82,741	82,741
Taxi - Electricity	30,000	30,000	30,000	30,000
Taxi - LPG	82,741	82,741	82,741	82,741
Bus - Diesel	56,157	56,157	56,157	56,157
Bus - CNG	56,157	56,157	56,157	56,157
Minibus - Diesel	50,288	50,288	50,288	50,288
Minibus - Hybrid diesel	50,288	50,288	50,288	50,288
Truck ←3.5t - Petrol	23,763	23,763	23,763	23,763
Truck ←3.5t - Diesel	23,763	23,763	23,763	23,763
Truck ←3.5t - Hybrid diesel	23,763	23,763	23,763	23,763
Truck →3.5t - Petrol	38,255	38,255	38,255	38,255
Truck →3.5t - Diesel	38,255	38,255	38,255	38,255
Truck →3.5t - CNG	38,255	38,255	38,255	38,255
e-Bike*	3,900	3,900	3,900	3,900
Walk or Cycle**	500	500	500	500

*Based on 15km per weekday annually
**Taken from previous R-AEA work in this area

The final parameter required to calculate total vehicle demand was the split of vehicles for each powertrain. This was based on CBS data in 2013 and projected forward based on input from the transport work team. The results of this are shown in Table 24.

Table 24 Powertrain split of road transport vehicles (%) - CBS and Ministry of Transport Data for 2013, projected forward based on input from the transport working group

Split by powertrain (%)	2013	2014	2020	2025	2030
Passenger car - Petrol	94.9%	93.5%	89.0%	84.0%	77.0%
Passenger car - Diesel	3.4%	5.0%	8.0%	10.0%	15.0%
Passenger car - Petrol hybrid	1.2%	1.5%	2.0%	3.0%	4.0%
Passenger car - Diesel hybrid	0.0%	0.0%	0.0%	1.0%	1.0%
Passenger car - Electricity	0.0%	0.0%	1.0%	2.0%	3.0%
Passenger car - LPG	0.5%	0.0%	0.0%	0.0%	0.0%
Motorbike - Petrol	99.7%	100.0%	100.0%	100.0%	100.0%
Motorbike - Electricity	0.3%	0.0%	0.0%	0.0%	0.0%
Taxi - Petrol	1.7%	0.0%	0.0%	0.0%	0.0%
Taxi - Diesel	97.1%	98.0%	95.5%	93.0%	90.0%
Taxi - Petrol hybrid	0.8%	0.0%	0.0%	0.0%	0.0%
Taxi - Diesel hybrid	0.0%	2.0%	4.0%	6.0%	8.0%
Taxi - Electricity	0.0%	0.0%	0.5%	1.0%	2.0%
Taxi - LPG	0.4%	0.0%	0.0%	0.0%	0.0%
Bus - Diesel	100.0%	100.0%	95.0%	90.0%	90.0%
Bus - CNG	0.0%	0.0%	5.0%	10.0%	10.0%
Minibus - Diesel	100.0%	100.0%	100.0%	100.0%	100.0%
Minibus - Hybrid diesel	0.0%	0.0%	0.0%	0.0%	0.0%
Truck ←3.5t - Petrol	17.2%	13.0%	8.0%	5.0%	0.0%
Truck ←3.5t - Diesel	82.8%	87.0%	92.0%	95.0%	100.0%
Truck ←3.5t - Hybrid diesel	0.0%	0.0%	0.0%	0.0%	0.0%
Truck →3.5t - Petrol	0.9%	0.0%	0.0%	0.0%	0.0%
Truck →3.5t - Diesel	99.1%	100.0%	97.0%	95.0%	95.0%
Truck →3.5t - CNG	0.0%	0.0%	3.0%	5.0%	5.0%
e-Bike	100.0%	100.0%	100.0%	100.0%	100.0%
Walk or Cycle	100.0%	100.0%	100.0%	100.0%	100.0%

Using the aforementioned stock projections as well as the data in Table 23 and Table 24, the total demand for all relevant transport modes in Israel (out to 2030) could be calculated and is shown in Table 25.

Table 25 Total demand for road transport

Total Demand (Million vkm)	2013	2014	2020	2025	2030
Passenger car	37,847	38,718	44,221	49,490	55,446
Taxi	1,640	1,676	1,907	2,126	2,374
Minibus	716	730	822	908	1,005
Bus	950	969	1,091	1,205	1,334
Motorcycle	872	891	1,008	1,118	1,243
Small Truck	6,099	6,234	7,091	7,907	8,827
Large Truck	3,000	3,067	3,488	3,889	4,342
Ebike	507	507	560	603	648
Walk or Cycle	4,060	4,056	4,482	4,826	5,191

5.1.1.3 Rail and Light Metro

The rail and light metro modes were dealt with differently to the road transport sector due to the availability of data. For rail, forecasts out to 2030 for rail vkm and the split between electric and diesel rail, were provided from Israel Railways via the Petroleum Alternatives Administration.

Additional rail service requires additional government action, and therefore rail service was assumed to increase through 2020, but beyond that remain constant subject to additional abatement action.

Table 26 Rail demand (from Israel Railways via the Petroleum Alternatives Administration)

Rail Demand (Million vkm)	2013	2014	2020	2025	2030
Passenger	8.35	10.13	19.23	19.23	19.23
Freight	1.56	1.71	3.51	3.51	3.51

The BAU scenario included only limited electrification planned to take place through 2018 (with the launch of the Tel Aviv-Jerusalem route, currently under construction).

Table 27 Powertrain split of rail sector (%)

Demand by powertrain (%)	2013	2014	2020	2025	2030
Passenger rail - Diesel	100.0%	100.0%	84.8%	84.8%	84.8%
Passenger rail - Elec	0.0%	0.0%	15.2%	15.2%	15.2%
Freight rail - Diesel	100.0%	100.0%	100.0%	100.0%	100.0%
Freight rail - Elec	0.0%	0.0%	0.0%	0.0%	0.0%

Light rail demand in 2030 was provided by transport consultant Nir Sharav, who at request of the Finance Ministry assisted with providing forecasts for the planned infrastructure improvements (such as the Jerusalem light rail project). Demand in 2030 was assumed to be 4.5 million vkm. Using this figure, the time series below was developed for light rail demand in Israel.

Table 28 Light rail demand (Million vkm)

Demand - Million vkm	2013	2014	2020	2025	2030
Light rail	-	2.2	4.5	4.5	4.5

5.1.1.4 Fuel efficiency

Efficiency data up to 2030 was taken direct from the Ministry of Energy transport model unless otherwise stated. These efficiencies (a LEAP input) are shown below in Table 29, detailing the resulting BAU efficiency improvement assumed out to 2030. These efficiency improvements over time are based on assumed improvements to vehicle powertrain technologies and generally are driven by policies and regulations to reduce CO_2 emissions in transport (such as the EU 2020 target of 95 gCO_2/km for cars) that would occur in the baseline scenario without further policy intervention.

Appendix 3 also presents the following in alternative units (MJ/km as well as in CO_2 terms).

Table 29 Fuel efficiency data (MoE data model unless otherwise specified)

Fuel efficiency (Alternative units)	Units	2013	2014	2020	2025	2030
Passenger car - Petrol	Km/L	11.20	11.38	12.60	13.39	14.18
Passenger car - Diesel	Km/L	16.00	16.25	18.00	19.13	20.25
Passenger car - Petrol hybrid	Km/L	14.40	14.63	16.20	17.21	18.23
Passenger car - Diesel hybrid	Km/L	17.76	18.04	19.98	21.23	22.48
Passenger car - Electricity	Km/kWh	3.50	3.54	3.83	4.00	4.17
Passenger car - LPG[25]	Km/L	8.03	8.16	9.04	9.60	10.17
Motorbike - Petrol	Km/L	20.38	20.38	20.89	23.65	26.25
Motorbike - Electricity[26]	Km/kWh	6.37	6.34	6.87	7.16	7.46
Taxi - Petrol[27]	Km/L	11.20	11.38	12.60	13.39	14.18
Taxi - Diesel	Km/L	16.00	16.25	18.00	19.13	20.25
Taxi - Diesel hybrid	Km/L	17.76	18.04	19.98	21.23	22.48
Taxi - Electricity	Km/kWh	3.50	3.54	3.83	4.00	4.17
Taxi - LPG	Km/L	8.03	8.16	9.04	9.60	10.17
Bus - Diesel	Km/L	1.40	1.40	1.42	1.45	1.48
Bus - CNG[28]	Km/Kg	1.85	1.85	1.87	1.91	1.96
Minibus - Diesel	Km/L	6.72	6.77	7.15	7.31	7.48
Minibus - Hybrid diesel	Km/L	7.39	7.45	7.87	8.04	8.22
Truck ←3.5t - Petrol	Km/L	6.40	6.50	7.20	7.50	7.80
Truck ←3.5t - Diesel	Km/L	8.78	8.85	9.35	9.78	10.20
Truck ←3.5t - Hybrid diesel	Km/L	11.17	11.46	13.50	14.25	15.00
Truck →3.5t - Petrol[29]	Km/L	2.14	2.15	2.38	2.53	2.68
Truck →3.5t - Diesel	Km/L	3.06	3.08	3.18	3.24	3.30
Truck →3.5t - CNG[30]	Km/Kg	3.09	3.09	3.36	3.48	3.60
Passenger rail - Diesel	Km/L	0.16	0.16	0.17	0.17	0.18
Passenger rail - Elec[31]	Km/kWh	0.04	0.04	0.05	0.05	0.05
Freight rail - Diesel	Km/L	0.14	0.14	0.14	0.14	0.15
Freight rail - Elec[32]	Km/kWh	0.04	0.04	0.04	0.04	0.04
Light rail and Metro[33]	Km/kWh	0.10	0.10	0.10	0.10	0.10
e-Bike[34]	Km/kWh	17.50	17.68	17.68	17.68	17.68

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[25] Assumed to be the same as petrol efficiency for cars
[26] Calculated based on difference between petrol and electric car
[27] Assumed to be the same as cars
[28] Assumed to be the same as diesel efficiency for buses
[29] Calculated based on difference between petrol and diesel car
[30] Assumed to be the same as diesel efficiency for large trucks
[31] From MoE transport assumptions on electricity use in rail sector
[32] From MoE transport assumptions on electricity use in rail sector
[33] Based on weighted average efficiencies of light rail and metro train cars. Assumptions on energy per passenger km taken from DECC Conversion Factors
[34] Market Survey

Rail efficiencies were calculated based on an approximate fuel consumption in 2014 (74 million litres of diesel use) in the rail sector (for both passenger and freight rail) provided by Israel Railways data via the Petroleum Alternatives Administration. For electric trains, information was provided by the MoE on the expected electricity fuel use from the rail sector by 2020. This allowed an efficiency assumption to be calculated for electric trains using this fuel use and the vkm demand.

These efficiency values were projected out to 2030 using the MoE baseline efficiency improvement scenario, as agreed with the working group.

Table 30 Rail efficiency improvements (from MoE)

Year	2015	2020	2025	2030
Percentage efficiency improvement	100%	97%	95%	93%

5.1.1.5 Domestic aviation and shipping

Table 31 presents fuel use data for domestic aviation and domestic shipping modes in Israel. Domestic aviation data was taken from the Fuel and LPG Authority forecasts while domestic shipping fuel use was assumed to be negligible, as per Fuel & LPG Authority feedback.

For aviation, the figures are based on an assumption that domestic aviation accounts for 5% of civil aviation fuel consumption (the rest being non-domestic), as per consultations with both industry stakeholders and the Fuel & LPG Authority.

Table 31 Domestic aviation and shipping fuel use

Fuel use (PJ)	2013	2014	2020	2025	2030
Domestic aviation	15.36	13.63	15.36	15.14	15.03
Shipping	-	-	-	-	-

5.1.2 Mitigation

Table 32 below shows all the measures which have been agreed to be taken forward for further analysis. When analysing the potential of each of the following measures, only passenger cars, buses, taxis, trucks and rail modes were considered. These modes contribute over 95% of transport emissions in Israel and therefore it makes sense to focus in terms of policy intervention here.

The mitigation measures, which were discussed and agreed with transport working group, fall into three major categories. These are;

1. Behavioural measures (modal shift driven by improved public transport infrastructure)
2. Technical measures to improve the petrol and diesel fleet
3. Uptake of alternatively fuelled vehicles (including the electrification of rail)

For modal shift, an appropriate level of shift was agreed with an external consultant as well as a cost associated with this level of shift. For the other two technical measures, the only parameter detailed in the baseline that was adjusted was the composition of the powertrain split.

Modal shift will be prioritised in this analysis, given that this behavioural measure will reduce the demand of private vehicle use (and subsequently the stock of private vehicles). It therefore must be considered first to properly take account of interactions between the measures.

Table 32 Proposed mitigation measures

Category of mitigation measure	Disaggregated mitigation measure
Modal shift	Shift from private vehicles to public transport (bus and rail/light rail/metro)
	Shift from private vehicles to electric bicycles and walk/cycle modes
Increased efficiency to petrol and diesel fleet	Modern vehicles ('Level 1') will include two or three suitable additive technologies aimed at increasing vehicle efficiency.
	Ultra-modern vehicles ('Level 2') will include four or five suitable additive technologies aimed at increasing vehicle efficiency.
Uptake of alternatively fuelled road vehicles	Alternative fuels - Petrol HEV
	Alternative fuels - Petrol PHEV
	Alternative fuels - Diesel HEV
	Alternative fuels - Diesel PHEV
	Alternative fuels - EV
	Alternative fuels - CNG
Electrification of rail	Electrification of rail

NB - All mitigation measures will only consider passenger cars, buses, taxis, trucks and rail (where appropriate).

5.1.2.1 Modal shift

The term modal shift in this context means building better public transportation systems and encouraging people to use them.

For passenger transport, the highest potential for GHG reductions from modal shift exists in dense urban areas and on major inter-urban routes. In dense urban areas, there is significant potential by making some GHG-efficient modes, particularly cycling, electric (public) transport and private/public bus transport (as long as the utilisation rates are relatively high) relatively more attractive than other modes. See Table 33 for how the emissions of different modes of transport compare on a passenger km basis. As can be seen for cars, trains and buses, the larger the capacity of the mode, the greater the savings.

Increasing the use of the least GHG intensive modes for each journey could be achieved by making these modes more attractive, e.g. through investment in infrastructure.

Within this study, we considered the following modal shift scenarios;

1. Shift from private vehicles to public transport (bus and rail/light rail/metro)
2. Shift from private vehicles to bicycles

The justification behind the scenarios above is that this is where the most significant savings in CO_2 could be made due to modal shift measures.

Table 33 Passenger efficiency assumed for relevant modes

Fuel efficiency	Units	2014	2020	2030
Passenger car (Petrol)	g CO_2/pkm	214.05	193.22	171.77
e-Bike	g CO_2/pkm	31.25	31.25	31.25
Bus (Diesel)	g CO_2/pkm	83.49	82.44	78.89
Light rail and Metro	g CO_2/pkm	134.26	134.26	134.26
Walk/Cycle	g CO_2/pkm	0.00	0.00	0.00
Passenger rail (Diesel)	g CO_2/pkm	68.66	66.72	64.11
Passenger rail (Electric)	g CO_2/pkm	49.36	47.97	46.09

5.1.2.2 Shift from private vehicles to public transport and walk/cycle modes

Costs and benefits

Schemes to improve bus and rail networks vary widely and are extremely country specific. The following information was provided by transport consultant Nir Sharav. It shows expected costs and benefits (including externalities associated not only with air pollution, but also, more importantly, with congestion) as well as the level of shift that can be expected given the public infrastructure improvements that are proposed for the next 15 years.

Table 34 Public transport infrastructure cost, benefits and potential

Metric	Unit	Base	Public transport plan	Change
Total expenditure (annualised over 40 years)	mil. IS	-	-219,720	-
Annual benefits	mil. IS	-	22,232	-
Car	mi. Vkm	55,446	41,509	-25%
Total Public Transport	mi. Vkm	351	380	+8%
Rail	mi. Vkm	36	52	+59%
Light rail/Metro	mi. Vkm	4	24	+428%
Bus/BRT	mi. Vkm	311	304	-2%

In addition to this, the analysis included a level of shift towards walk and cycle modes which has been estimated to cost NIS 5 billion (annualised over 40 years).

Potential

Table 35 presents the project team's proposal for this measure (based on previous work performed in the EU by Ricardo Energy & Environment[35]). The potential is based on the information in Table 34.

Table 35 Assumptions on modal shift (% vkm shift) for improved passenger intermodality

Modal Shift	2025	2030
FROM:		
Car	-12.15	-25%
Bus	-1.1%	-2%
TO:		
Train	23.4%	58.7%
Light rail/Metro	166.7%	428.0%
e-Bike	395.2%	1132.0%
Walk/Cycle	67.0%	119.2%

It should be noted that the e-bike and walk/cycle modes have large increases in vkm in this scenario. This is because it was decided that overall demand was to remain fixed between the BAU scenario and mitigation scenarios (in order to observe mitigation potential from modal shift solely and not simply from a reduction in demand). Therefore, given the information provided by transport Ministry consultant Nir Sharav, demand in 2030 was calibrated for e-bikes and walk/cycle modes in order for the overall demand to remain fixed. It should be noted that what ultimately influences emissions is the demand for emitting modes such as private vehicles and public transport; as emissions per vkm for the e-bike and walk/cycle modes are negligible, this adjustment has no material impact on the analysis.

5.1.2.3 Increased efficiency of petrol and diesel fleet

Technology

Currently, the internal combustion engine (ICE) is by far the most common mode for propulsion in road transport. In improving the efficiency of an ICE-powered vehicle there are several 'strategies' that can be followed either each in isolation or combined:

- Improvement of the combustion process
- Decrease of mechanical losses in the engine (friction and pumping losses)
- Decrease of mechanical losses in the transmission
- Decrease of inertial 'losses' (i.e. energy irreversibly expended to accelerate the vehicle's mass) and losses due to aerodynamic drag and rolling resistance
- Recuperation of energy (e.g. kinetic energy upon braking or waste heat from the exhaust)
- Reduction of energy demand from peripheral processes (i.e. by improving the efficiency of auxiliary components).

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[35] Skinner I, van Essen H, Smokers R and Hill H (2010) Towards the decarbonisation of EU's transport sector by 2050 Paper produced as part of contract ENV.C.3/SER/2008/0053 between European Commission Directorate-General Environment and AEA Technology plc; see: www.eutransportghg2050.eu

Within the BAU scenario, it is assumed that low rolling resistance tyres as a technical option will already be included in the reference (BAU) vehicle, as Israel has adopted European transportation standard EC 661/2009, which requires this.

For the purpose of this study, a short list of technical options have been reviewed, and two 'packages' of technologies are applied to vehicles. These two 'packages' represent two levels of efficiency improvement:

1. Level 1 - Modern vehicles that will be modelled using the baseline reference vehicle and a 'package' of three technologies.
2. Level 2 - Ultra-modern vehicles that will be modelled using the baseline reference vehicle and a 'package' of five technologies.

A proposal for both of these scenarios is shown below in Table 36 and Table 37. The 'packages' of technologies in both tables have been chosen based on the fact that these technologies will be among the most popular options for CO_2 reduction as well as all being fairly easy to interpret and understand.

Table 36 Proposed level 1 technology packages for cars and trucks

Level 1		
Diesel Trucks	Diesel Cars	Petrol Cars
Mild downsizing (15% cylinder content reduction)	Mild downsizing (15% cylinder content reduction)	Mild downsizing (15 % cylinder content reduction)
Start-stop hybridisation	Start-stop hybridisation	Start-stop hybridisation
Mild weight reduction	Mild weight reduction	Mild weight reduction

Table 37 Proposed level 2 technology packages for cars and trucks

Level 2		
Diesel Trucks	Diesel Cars	Petrol Cars
Medium downsizing (30% cylinder content reduction)	Medium downsizing (30% cylinder content reduction)	Medium downsizing (30% cylinder content reduction)
Start-stop hybridisation	Start-stop hybridisation	Start-stop hybridisation
Variable valve actuation and lift	Variable valve actuation and lift	Variable valve actuation and lift
Strong weight reduction	Strong weight reduction	Strong weight reduction
N/A	Auxiliary systems efficiency improvement	Auxiliary systems efficiency improvement

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[36] Valves control the air and fuel intake and exhaust expulsion of the engine's combustion chambers (cylinders). During each cycle these valves are opened and closed for a certain amount of time. Variable valve timing allows adjustment of the timing (i.e. adjustment of the phase not the duration) of opening and closing during engine operation and therefore optimization to specific engine demands

[37] The total weight of a vehicle with standard equipment, all necessary operating consumables such as motor oil, transmission oil, coolant, air conditioning refrigerant, and a full tank of fuel, but excluding passengers or cargo

These options are explained in short below:

- **Engine downsizing** - Downsizing, i.e. the reduction of engine volume while retaining the same power (which implies the need for a turbo), permits a reduction of the fuel consumption due to reduced pumping losses, reduced friction losses etc.
- **Start-stop hybridisation** - 'Start-stop' technology, also known as 'idle-off', shuts down the engine when the car comes to a stop, reducing fuel consumption.
- **Variable valve actuation and lift** - Variable valve control encompasses a series of technologies that allow (continuous) control over the valve actuation[36]. Besides variable valve timing it includes technologies that enable control over the amount of lift of the valves, which implies control over the duration of the valve's opening and closing.
- **Weight reduction** - Weight reduction can be achieved by use of new materials. Steel is currently the main material used in vehicles, averaging 70% of vehicle 'curb' weight[37]. It can be expected that in the mid to long term, steel will be increasingly replaced by high strength steel (allowing less material for a given construction), lightweight metals, such as aluminium or magnesium, or plastics and composites.
- **Auxiliary systems efficiency improvements** - This relates to efficiency improvements to components such as air conditioners, lighting, power steering etc.

Costs and benefits

Table 38 presents the additional costs and CO_2 reduction potential of each of the proposed options to analyse in the study.

Table 38 List of technical options including their costs and CO_2 reduction potential (on a per vehicle basis)[38]

Technology	Diesel Truck		Diesel Cars		Petrol Cars	
	CO_2 reduction (%)	Additional cost per vehicle (Euros)	CO_2 reduction (%)	Additional cost per vehicle (Euros)	CO_2 reduction (%)	Additional cost per vehicle (Euros)
Mild downsizing (15% cylinder content reduction)	2.74%	50	2.74%	50	3.42%	250
Medium downsizing (30% cylinder content reduction)	4.79%	290	4.79%	450	5.47%	435
Start-stop hybridisation	1.58%	200	1.58%	200	1.97%	200
Variable valve actuation and lift	0.44%	50	0.44%	280	4.39%	280
Mild weight reduction	5.69%	38	6.44%	38.75	6.44%	39
Strong weight reduction	16.09%	2046	18.89%	922.50	18.89%	923
Auxiliary systems efficiency improvement	N/A	N/A	11.00%	440	12.00%	440

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[38] http://ec.europa.eu/clima/policies/transport/vehicles/cars/docs/study_car_2011_en.pdf

The grouping of these technologies into packages from a CO_2 reduction basis needs to be done in a multiplicative way, so as not to overestimate the combined impacts; the impact combination is in most cases not additive. For example, for change in demand between two different scenarios, the total impact was calculated to be equal to:

Combined impact of change of X% and Y% = ((1+X%) x (1+Y%) - 1)

For costs, the individual technologies can simply be summed in order to calculate the total cost of a package.

Potential

The results of the CO_2 reduction potential of both levels of packages are shown in Table 39 and Table 40. These costs and benefits are assumed to stay fixed over time in lieu of better data/information.

Table 39 Potential of level 1 technology packages for cars and trucks (on a per vehicle basis)

Level 1							
Diesel Trucks		Small diesel trucks		Diesel cars		Petrol cars	
CO_2 reduction (%)	Additional cost per vehicle (Euros))	CO_2 reduction (%)	Additional cost per vehicle (Euros))	CO_2 reduction (%)	Additional cost per vehicle (Euros)	CO_2 reduction (%)	Additional cost per vehicle (Euros)
9.9%	14,110	8.3%	288	8.9%	289	10.8%	489

Table 40 Potential of level 2 technology packages for cars and trucks (on a per vehicle basis)

Level 2							
Diesel Trucks		Small diesel trucks		Diesel cars		Petrol cars	
CO_2 reduction (%)	Additional cost per vehicle (Euros)	CO_2 reduction (%)	Additional cost per vehicle (Euros)	CO_2 reduction (%)	Additional cost per vehicle (Euros)	CO_2 reduction (%)	Additional cost per vehicle (Euros)
18.2%	17,610	18.5%	2,586	27.7%	2293	34.9%	2,278

Table 41 Modern conventional vehicle capital costs[39] (CAPX) versus baseline (NIS prices)

Mode	Powertrain Types	Baseline powertrain	Premium vs Baseline powertrain (2025)	Premium vs Baseline powertrain (2030)
Passenger car	Modern petrol	Petrol ICE	2,263	2,263
Passenger car	Ultra-modern petrol	Petrol ICE	10,544	10,544
Passenger car	Modern diesel	Diesel ICE	1,337	1,337
Passenger car	Ultra-modern diesel	Diesel ICE	10,613	10,613
Small Truck	Modern diesel	Diesel ICE	1,331	1,331
Small Truck	Ultra-modern diesel	Diesel ICE	11,970	11,970
Large Truck	Modern diesel	Diesel ICE	65,324	65,324

*Note - In the MACC, all marginal costs are annualised over the lifetime of the vehicle with an appropriate discount rate.

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[39] Including electric charging infrastructure costs

Table 42 Modern conventional vehicle yearly maintenance cost[40] versus baseline (NIS)

Mode	Powertrain Types	Baseline powertrain	Premium vs Baseline powertrain (2025)	Premium vs Baseline powertrain (2030)
Passenger car	Modern petrol	Petrol ICE	-470	-498
Passenger car	Ultra-modern petrol	Petrol ICE	-1,515	-1,602
Passenger car	Modern diesel	Diesel ICE	-207	-219
Passenger car	Ultra-modern diesel	Diesel ICE	-647	-684
Small Truck	Modern diesel	Diesel ICE	-553	-594
Small Truck	Ultra-modern diesel	Diesel ICE	-1,236	-1,327
Large Truck	Modern diesel	Diesel ICE	-3,245	-3,568

*Assumptions on the price of different fuels are found in Section 2 and annual mileage for each vehicle type are found in Appendix 3.

5.1.2.4 Uptake of alternative fuelled road vehicles

Technologies

The abatement cost analysis was conducted based on the additional costs of the abatement vehicle, relative to the reference (baseline) power train.

Table 43 presents the list of alternative powertrain types analysed in this study and their corresponding baseline powertrain for the marginal abatement analysis.

Table 43 Alternative powertrains to be analysed and their baseline counterparts

Mode	Powertrain Types	Fuels	Baseline powertrain
Passenger car	Petrol PHEV	Petrol/Electricity	Petrol ICE
Passenger car	Diesel PHEV	Diesel/Electricity	Diesel ICE
Passenger car	BEV	Electricity	Petrol ICE
Passenger car	Petrol HEV	Petrol	Petrol ICE
Passenger car	Diesel HEV	Diesel	Diesel ICE
Taxi	Diesel HEV	Diesel	Diesel ICE
Taxi	BEV	Electricity	Diesel ICE
Taxi	Petrol HEV	Petrol	Petrol ICE
Bus	BEV	Electricity	Diesel ICE
Bus	CNG ICE	Natural Gas	Diesel ICE
Small Truck	CNG ICE	Natural Gas	Diesel ICE
Small Truck	Diesel HEV	Diesel	Diesel ICE
Large Truck	CNG ICE	Natural Gas	Diesel ICE

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[40] Includes fuel costs only

Costs and benefits

In the abatement analysis, all marginal costs are annualised over the lifetime of the vehicle with an appropriate discount rate (see section 2.6 on common parameters).

Table 44 - Table 46 present the difference in cost and CO_2 potential against corresponding baseline vehicles. All efficiency data is taken from the BAU scenario and all cost data[41] is taken from previous Ricardo Energy & Environment[42], [43], work on the total cost of ownership of various vehicle/powertrain types.

Table 44 Alternative powertrains efficiency reduction versus baseline

Mode	Powertrain Types	% CO_2 reduction vs Baseline powertrain (2025)	% CO_2 reduction vs Baseline powertrain (2030)
Passenger car	Petrol PHEV	30.5%	29.0%
Passenger car	Diesel PHEV	14.8%	12.7%
Passenger car	BEV	67.5%	66.2%
Passenger car	Petrol HEV	22.2%	22.2%
Passenger car	Diesel HEV	9.9%	9.9%
Taxi	Diesel HEV	9.9%	9.9%
Taxi	BEV	66.0%	66.0%
Taxi	Petrol HEV	22.2%	22.2%
Bus	BEV	20.6%	20.4%
Bus	CNG ICE	24.0%	24.0%
Small Truck	CNG ICE	10.5%	10.2%
Large Truck	CNG ICE	6.7%	8.2%

Table 45 Alternative powertrains capital costs[44] (CAPX) versus baseline (NIS prices deflated to 2014)

Mode	Powertrain Types	Premium vs Baseline powertrain (2025)	Premium vs Baseline powertrain (2030)
Passenger car	Petrol PHEV	20,315	15,676
Passenger car	Diesel PHEV	19,395	14,794
Passenger car	BEV	49,632	35,413
Passenger car	Petrol HEV	7,647	5,634
Passenger car	Diesel HEV	6,467	4,578
Taxi	Diesel HEV	6,467	4,578
Taxi	BEV	44,476	30,290
Taxi	Petrol HEV	7,647	5,634
Bus	BEV	247,623	184,139
Bus	CNG ICE	38,362	32,887
Small Truck	CNG ICE	2,477	1,990
Large Truck	CNG ICE	48,123	38,551

*Note - In the MACC, all marginal costs are annualised over the lifetime of the vehicle with an appropriate discount rate.

Table 46

Alternative powertrains yearly maintenance cost[45] versus baseline (NIS)

Mode	Powertrain Types	Premium vs Baseline powertrain (2025)	Premium vs Baseline powertrain (2030)
Passenger car	Petrol PHEV	-1,510	-1,716
Passenger car	Diesel PHEV	-51	-155
Passenger car	BEV	-1,849	-2,042
Passenger car	Petrol HEV	-964	-1,019
Passenger car	Diesel HEV	-231	-244
Taxi	Diesel HEV	-1,181	-1,249
Taxi	BEV	804	409
Taxi	Petrol HEV	-4,928	-5,212
Bus	BEV	-6,615	-14,378
Bus	CNG ICE	-71,952	-80,575
Small Truck	CNG ICE	-4,132	-4,558
Large Truck	CNG ICE	-19,541	-22,385

*Assumptions on the price of different fuels are in Section 2, and on the mileage are in Appendix 3.

With respect to uptake rates of the vehicles described above, the following tables show the proposed fleet makeup used in abatement scenario modelling.

The uptake of alternative vehicles was determined based on intensive discussions with the transport working group, and in particular the Petroleum Alternatives Administration, the Transport Ministry, and the Fuel & LPG Authority, taking into account analyses conducted by those organizations regarding market barriers and potential, as well as vehicle replacement rates.

Table 47

Split of car stock by powertrain (%)

Powertrain	2015	2020	2025	2030
Petrol	93.5%	68.4%	50.0%	40.0%
Diesel	5.0%	5.0%	5.0%	5.0%
Level 1 - Modern petrol	0.0%	15.0%	13.4%	5.0%
Level 2 - Ultramodern petrol	0.0%	0.0%	10.0%	20.0%
Level 1 - Modern diesel	0.0%	2.0%	2.0%	0.0%
Level 2 - Ultramodern diesel	0.0%	0.0%	1.0%	2.0%
HEV petrol	1.5%	6.0%	6.6%	7.0%
HEV diesel	0.0%	0.0%	1.0%	3.0%
PHEV petrol	0.0%	2.0%	5.0%	7.0%
PHEV diesel	0.0%	0.5%	1.0%	1.0%
EV	0.0%	1.1%	5.0%	10.0%

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[41] Excluding VAT and taxes
[42] Environmental Support to the Development of a London Low Emission Vehicle Roadmap (a study for Transport for London, 2013)
[43] A review of the efficiency and cost assumptions for road transport vehicles to 2050 (study for the Committee on Climate Change, 2012)
[44] Including electric charging infrastructure costs
[45] Includes fuel costs only

Table 48 Split of taxi stock by powertrain (%)

Powertrain	2015	2020	2025	2030
Petrol	0.0%	0.0%	0.0%	0.0%
Diesel	98.0%	80.0%	40.0%	0.0%
HEV diesel	2.0%	7.5%	26.5%	45.0%
HEV petrol	0.0%	7.5%	26.5%	45.0%
EV	0.0%	5.0%	7.0%	10.0%

Table 49 Split of bus stock by powertrain (%)

Powertrain	2015	2020	2025	2030
Diesel	100.0%	80.8%	53.4%	26.0%
EV	0.0%	8.4%	16.2%	24.0%
CNG	0.0%	10.8%	30.4%	50.0%

Table 50 Split of small truck stock by powertrain (%)

Powertrain	2015	2020	2025	2030
Petrol	13.0%	7.0%	0.0%	0.0%
Diesel	87.0%	72.0%	66.0%	55.0%
Level 1 - Modern diesel	0.0%	12.0%	13.0%	14.0%
Level 2 - Ultramodern diesel	0.0%	4.0%	6.0%	9.0%
CNG	0.0%	5.0%	15.0%	22.0%

Table 51 Split of large truck stock by powertrain (%)

Powertrain	2015	2020	2025	2030
Petrol	0.0%	0.0%	0.0%	0.0%
Diesel	100.0%	82.0%	70.0%	61.0%
Level 1 - Modern diesel	0.0%	3.0%	5.0%	5.0%
CNG	0.0%	15.0%	25.0%	34.0%

5.1.2.5 Electrification of rail

Technology

Electric traction is already a mature, proven technology in the European rail sector. Indeed it is actually the rail traction technology of choice in many countries, which is illustrated by the fact that 80% of European rail traffic is undertaken by electric traction, measured in passenger km and tonne km, whilst just 51% of European tracks are electrified[46].

Costs and benefits

Taking the UK as an example, given that the cost of electrification is estimated at around £550k to £650k per single-track km, the rail sector tends to seek Government support to fund the investment in electrical infrastructure. Indeed capital cost is the main barrier to electrification.

Whilst this high capital cost has proved prohibitive in some instances, the switch to electric traction can yield significant carbon savings. For instance, the UK Railway Forum estimate that there is a 20% to 40% carbon advantage compared to diesel in the UK with the current generating mix[47]. Network Rail estimate the advantage is 20-30% on average[48]. UIC estimates CO_2 savings of up to 50% for the electrification of diesel lines (although this depends on the national energy mix)[49]. As grid electricity is decarbonised this gap should widen significantly and the rail sector has the potential to become very low carbon indeed.

Other benefits include improved air quality at stations, improved energy security due to the diverse electricity generation mix and increased availability of rolling stock (fully electric trains tend to need less maintenance since they are inherently simpler and more reliable). Network Rail, which maintains the rail infrastructure in the UK, estimates that electric trains are twice as reliable in terms of miles per breakdown.
Table 52 shows the calculated carbon reduction in Israel.

Table 52 CO_2 reduction from rail electrification

Mode	% CO_2 reduction from diesel train (2025)	% CO_2 reduction from diesel train (2030)
Passenger rail - Electric	29.6%	28.1%

Table 53 Electrified rail capital costs[50] (CAPX) versus baseline (NIS)

Mode	Premium vs Baseline powertrain (2025)	Premium vs Baseline powertrain (2030)
Passenger rail - Electric	10,574,067	10,574,067

Note - In the MACC, marginal costs here are annualised over 40 years with an appropriate discount rate.

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[46] International Union of Railways (2008) Rail Transport and Environment, Facts and Figures
[47] Railway Forum Website - position on Electrification (2008) http://www.railwayforum.com/electrification.php
[48] Ian Coucher, CEO of Network Rail (2009) Network Rail Press Release: CONSULTATION ON ELECTRIFICATION STRATEGY LAUNCHED http://www.networkrailmediacentre.co.uk/Content/Detail.asp?ReleaseID=4359&NewsAreaID=2&SearchCategoryID=2
[49] UIC (2007) CO_2 Emissions Reduction Guidelines, International Union of Railways (UIC).
[50] Including electric charging infrastructure costs

Table 54 Electrified rail operational costs (OPEX) versus baseline (NIS)

Mode	Premium vs Baseline powertrain (2025)	Premium vs Baseline powertrain (2030)
Passenger rail - Electric	-231,359	-314,857

Note that the change in operational costs between 2025 and 2030 in Table 54 above is due to the interaction between electricity and diesel fuel price over time. More money saved on fuel by switching to battery electric vehicles in 2030, whilst the diesel fuel price would increase faster than electricity.

Potential

The assumed uptake of electric train cars is given below in Table 55 for passenger rail, based on Israel Railways data for potential electrification, and as agreed with the transport sector work team.

Table 55 Split of passenger rail vehicle kilometres by powertrain (%)

Passenger rail powertrain split (%)	2015	2020	2025	2030
Diesel	100%	50%	15.9%	15.9%
Electric	0%	50%	84.1%	84.1%

5.2 RESULTS

5.2.1 BAU

The BAU scenario shows fuel use, and therefore GHG emissions, from transport increasing over time, with total transport GHG emissions increasing from 18.9 $MtCO_2e$ in 2015 to 21.7 $MtCO_2e$ in 2030, an increase of 15%. This is driven largely by an increase in fuel use for all modes, with particularly large increases in rail (both freight and passenger), large trucks and buses; see Figure 14. This increase in fuel use is down to the growth rate of vehicle ownership. Passenger cars remain the main emission source, comprising almost 52% of GHG emissions in the current year and 49% by 2030. In the road and rail transport sectors, 93.5% of all fuel use is from oil based products. This high dependency only marginally drops by 2030 to 91.5% in the baseline scenario.

Figure 14 Transport emissions by mode (BAU)

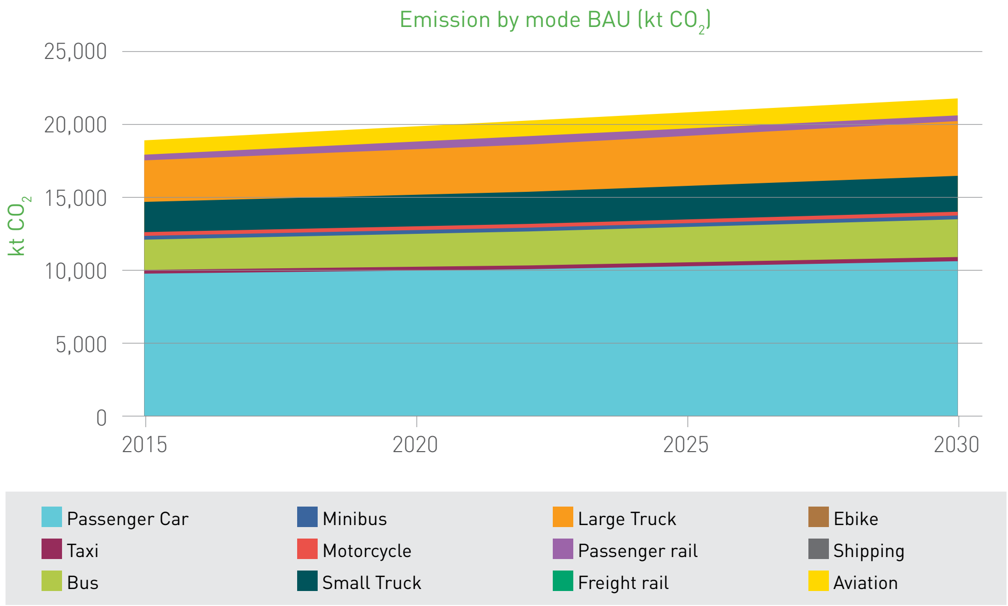

Table 56 Transport fuel use by fuel (BAU)

Fuel use by fuel (PJ)	2015	2020	2025	2030
Electricity	0.3	0.6	0.8	1.1
Gasoline	110.9	108.8	108.8	105.7
Diesel	99.8	109.9	119.5	135.3
CNG	0.5	2.9	5.7	6.1
Jet Fuel	13.9	15.4	15.1	15.0
Residual fuel oil	0.0	0.0	0.0	0.0
Total	225.4	237.4	249.9	263.3

Detailed information on transport fuel use and transport GHG emissions by mode and by fuel can be found in Appendix 3.

5.2.1 Mitigation

Table 57 below shows abatement potential and cost effectiveness data for various technologies within the Israeli transport sector for 2030.

Table 57 MACC results with externality costs included

Technology	2030	
	kt CO_2	Annual cost (NIS) per t CO_2
Large Truck - CNG ICE	90.28	-8130.68
Small Truck - CNG ICE	56.29	-6695.91
All - Modal shift	2535.31	-4290.86
Bus - CNG ICE	244.29	-3390.17
Taxi - Petrol HEV	48.93	-1056.75
Small Truck - Modern diesel ICE	28.96	-874.92
Petrol Passenger car - Modern petrol ICE	46.48	-814.85
Petrol Passenger car - Ultra modern petrol ICE	598.53	-528.14
Petrol Passenger car - Petrol HEV	57.13	-671.16
Small Truck - Ultra modern diesel ICE	41.58	-69.37
Taxi - Diesel HEV	12.43	-389.54
Taxi - BEV	17.90	-160.59
Diesel Passenger car - Ultra modern diesel ICE	32.96	428.09
Petrol Passenger car - Petrol PHEV	173.73	63.81
Bus - BEV	124.54	82.60
Large Truck - Modern diesel ICE	18.98	1456.14
Petrol Passenger car - BEV	206.56	313.71
Passenger rail - BEV	96.78	2716.61
Diesel Passenger car - BEV	110.77	2946.24
Diesel Passenger car - Diesel PHEV	7.57	5106.34

Looking at all the measures as a whole (Table 58), Israel is capable of reducing its transport GHG emissions by almost 21% by 2030 of which 17% can be done cost effectively.

Figure 15 2030 Marginal abatement cost curve for transport sector

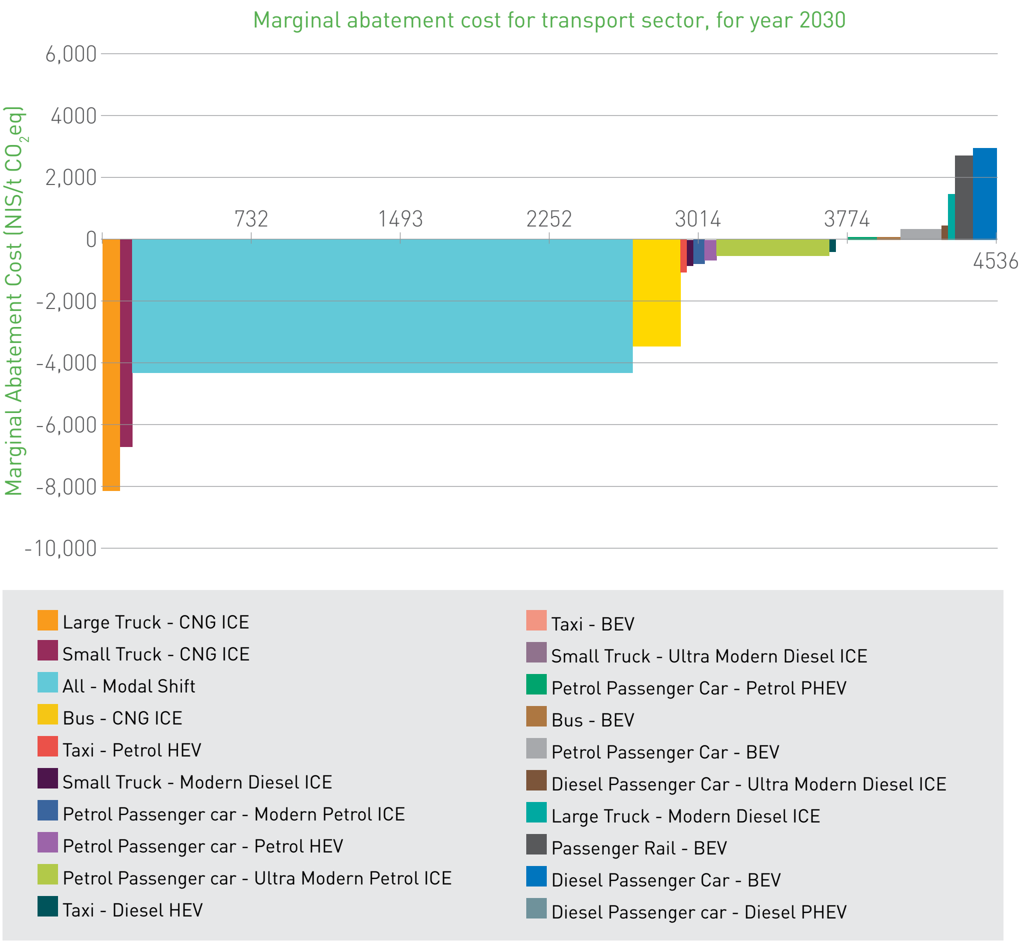

Table 58 2030 MACC Summary

2030 MACC summary		
'ambitious target'	4.550	Mt CO_2 Abated
Technical	8.8%	
Behavioural (modal shift)	11.7%	
Electric rail	0.4%	
Total	20.9%	Reduction
Cost effective measures only	3.778	Mt CO_2 Abated
	21.74	Mt CO_2 (BAU)
Total	17%	Reduction

Table 59 2030 Abatement by mode

Mode	Share (%)
Light Duty Vehicles	29%
Heavy Duty Vehicles	10%
Other (primarily modal shift)	61%

5.2.1.1 Without externality costs

The results without externality costs included are shown in Appendix 3.

5.2.2 Observations

Focusing on results with externality costs factored in, most abatement options, particularly those concerning conventional ICE improvements, come at a benefit to society - i.e. there is a positive payback over the lifetime of a vehicle when subtracting fuel cost savings (and any maintenances costs) from the initial additional investment in more efficient vehicle technology. Outliers to this trend are ultra-modern diesel vehicles and large modern diesel trucks.

Those other measures that also do not see a payback over their lifetime are generally more advanced vehicle technologies such as battery electric vehicles (BEVs) and plug-in hybrid electric vehicles (PHEVs) where the cost of these technologies (even up to 2030) is still too high to return a payback. In time, learning rates will reduce the costs of these vehicles and positive payback results will start to be seen.

The largest abatement potential from the technical measures is ultra-modern petrol cars that could abate almost 600 ktCO$_2$e by 2030. Coupling this with improvements in public transport infrastructure to induce and encourage modal shift away from private vehicles could yield up to 3.1 MtCO$_2$e in GHG savings, all at net benefit to society (including externalities covering health, noise and further air quality pollutants) of 4291 NIS/tCO$_2$e.

Other key levers to note are switching away from conventional buses to CNG which will yield 244ktCO$_2$e savings at a cost of -3390 NIS/tCO$_2$e, 'ultra' modernisation of petrol cars will yield the almost 600ktCO$_2$e GHG savings mentioned above at a cost of -528 NIS/tCO$_2$e (i.e. a net benefit). The most cost effective measure is CNG large trucks which can potentially abate 90ktCO$_2$e in 2030 at a cost of -8131 NIS/tCO$_2$e. Out of the 21% reduction potential that has been identified in the transport sector in 2030, 17% can be achieved cost effectively.

The impact of these mitigation measures would reduce car demand (vkm) to 34% of emissions by 2030 (down from 49% in the BAU) and would also drastically change the transport fuel use mix in Israel in the following ways:

1. Dependency on oil: Excluding the aviation and shipping sectors, in this mitigation scenario, 74.2% of fuel use is from petroleum based products. This is down from 97.1% in the BAU
2. Electricity use is 3.5% of the total fuel use in 2030 (up from 0.4% in the BAU) whilst gas use is up to 22.3% of the total fuel use in 2030 (up from 2.3% in the BAU).

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[51] In the case of PHEVs and BEVs, additional charging infrastructure costs to implement and maintain vehicle charging points is also a factor in their cost effectiveness.

06

POWER SECTOR

6.1 METHODOLOGY

6.1.1 LEAP in context

6.1.1.1 The power sector in LEAP

In essence, the LEAP model simulates power generation systems by matching electricity generation to demand for electricity from each sector. LEAP will choose to run existing power plants on the basis of user-selected dispatch rules. It is common to use a merit order as the dispatch rule for the majority of generation capacity. The model also includes efficiency and availability data, applicable load profiles (sometimes known as load duration curves) and transmission and distribution effects.

LEAP is capable of following instructions about what additional capacity to build or can be allowed to make choices if necessary. This can be done by directly specifying new capacity, by giving LEAP some basic build options or by cost-optimisation. This last process is more data intensive and more complex. In our approach we utilised a combination of the first two options.

Using these inputs, LEAP generates a number of outputs. Generally, generation by plant, fuel usage, capacity (by type) and GHG emissions are the most important outputs from this part of the model.

6.1.2 BAU

6.1.2.1 Approach

In most other sectors, the objective of the BAU modelling exercise is to project demand for a certain mix of fuels. The power sector differs from these other sectors because it is necessary to start with an exogenous demand for electricity.

6.1.2.2 Key assumptions

The detailed assumptions are described below. Key assumptions include new capacity build figures form the PUA, and an assumption that 10% of electricity will be from renewable sources by 2020. No new renewables will be built after 2020 in the BAU scenario.

In the BAU scenario, additional generating capacity can be added if required to maintain a sufficient reserve margin. It is assumed that the dual-fuel Project D will be built first, followed by further gas-fired open cycle turbines as necessary. The timing of this is decided by the LEAP model rather than being an input to the model.

6.1.2.3 Generation capacity

In developing a baseline for the power sector we started by recreating the current Israeli power sector to the best extent possible. We then undertook an analysis of planned or expected developments in order to create a projection of generation capacity in the BAU scenario. These additions are implemented in the model as exogenous capacity additions, which means that they are built regardless of any other inputs or outputs from the model. Finally, we created a set of 'build options' based on projects that may or may not be built. These capacity additions are not necessarily going to be built; LEAP will decide what to build in the model and in what quantity on the basis of the instructions given to it, i.e., the planning reserve margin and forecast electricity demand from other sectors, and the load curve.

This development process was initially informed by a review of Israeli policy in this area and was iteratively refined following the receipt of data and recommendations from the relevant government ministries. In nearly all cases the Public Utilities Authority (PUA) and the Ministry of Energy (MoE) were key sources of data and advice. The inputs were further refined following input from key stakeholders in the power sector working group.

The initial baseline was tested using projections of electricity demand from sources such as Israel's Second National Communication to the United Nations Framework Convention on Climate Change[52], the official Ministry of Energy projections approved by the Yogev Committee as well as draft updated MoE electricity demand projections. The completed draft baseline was then refined using the results for electricity demand projections from other sectors, incorporating comments and data from relevant ministries and key stakeholders, as above.

Generation capacity is split by operator and then by plant type. There are two classes of operator in the model: the Israel Electric Corporation (IEC) and independent power producers (IPPs). The specification of an operator does not have any direct impact on the results, but this structure allows a more detailed representation of the power sector and permits a better understanding of what it will look like in the future. IPP generation capacity is further sub-divided into conventional and cogeneration plants. Renewable capacity is not subdivided into IEC or IPP capacity, although the majority if not all renewables will likely be owned by IPPs. The power sector module does not account for the heat generated by cogeneration plants; the fuel consumption for this component is included in the industrial sector. This is in line with the Natural Gas Authority methodology.

Conventional plant types include coal steam generation, gas-fired combined cycle (grades E and F) turbines, gas-fired open cycle turbines and other gas turbines. Other gas turbines are fired by diesel or natural gas. BAU renewable capacity types includes solar PV (ground-based and rooftop), concentrated solar power (both parabolic trough and solar tower), onshore wind, biogas and micro-hydropower.

6.1.2.4 Capacity additions

Capacity additions are either exogenous or endogenous. The difference between these two is that exogenous additions are automatically built whereas endogenous additions are added by LEAP to maintain a planning reserve margin. Total BAU capacity over time is summarised in Table 60.

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[52] http://unfccc.int/resource/docs/natc/isrnc2.pdf

Data for exogenous IEC capacity are taken from PUA recommendations. There are no exogenous capacity additions to IEC capacity.

IPP capacity is projected on the basis of PUA forecasts through 2020. Renewable capacity is also forecast using this dataset with two exceptions. Solar PV capacity is assumed to be higher than the PUA forecast in order to ensure that Israel generates 10% of its electricity from renewable sources in 2020. Biogas capacity is also slightly higher for this reason, although it is capped at 45 MW on the basis of modelling results from the waste sector.

Table 60: Generation capacity by type in the BAU scenarioTable 21: Number of vehicles for road transport (CBS)

Plant Type	2015	2020	2025	2030
IEC Coal	2,825.0**	3,400.0	3,400.0	3,400.0
Orot Rabin 1-4	1,440.0	1,440.0	1,440.0	1,440.0
IEC NG Steam Generator	1,622.0	1,340.0	228.0	0.0
IEC Diesel Gas Turbine	542.0	542.0	542.0	542.0
IEC NG Gas Turbine	1,028.0	1,028.0	1,028.0	1,028.0
IEC Jet Gas Turbine	504.0	504.0	504.0	504.0
IEC CCGT E	995.0	995.0	995.0	660.0
IEC CCGT F	4,083.0	4,083.0	4,083.0	4,083.0
IEC Project D*	0.0	0.0	1,524.0	1,524.0
IPP CCGT F	2,320.0	3,368.0	3,368.0	3,368.0
IPP OCGT NG*	0.0	0.0	100.0	3,700.0
IPP OCGT HFO	28.0	0.0	0.0	0.0
IPP Cogeneration CCGT F	561.0	827.0	827.0	827.0
IPP Cogeneration OCGT	109.0	165.0	165.0	165.0
IPP Cogeneration NG Steam Generator	212.0	212.0	212.0	212.0
IPP Cogeneration Diesel Turbine	48.0	48.0	48.0	48.0
Micro and Small Hydro	6.6	6.6	6.6	6.6
Solar PV (Ground)	445.0	1,723.3	1,723.3	1,723.3
Solar PV (Rooftop)	290.9	1,126.8	1,126.8	1,126.8
CSP Solar Tower	0.0	131.0	131.0	131.0
CSP Parabolic Trough	0.0	131.0	131.0	131.0
Biogas	27.0	45.0	45.0	45.0
Onshore Wind	6.2	435.0	435.0	435.0
Hydro-Pumped Storage	0	640	640	640
Total (Excluding energy storage)	**17,092.7**	**21,550.7**	**22,062.7**	**25,099.7**
Total (Including energy storage)	**17,092.7**	**22,190.7**	**22,702.7**	**25,739.7**

*This indicates endogenous capacity.
**Due to planned temporary shutdowns of coal-fired units, as per the PUA

The IEC plant descriptions supplied by the PUA include data for expected retirements. These have been implemented in the model and are shown in the table below. Please note that these retirements were also taken account of in the capacity figures in Table 60.

Table 61 Capacity retirements from PUA baseline

Plant Type	Retirement (MW)	Date
NG Steam Generator (Haifa 3)	141	2017
NG Steam Generator (Haifa 4)	141	2018
NG Steam Generator (Reading D 3 and Eshkol 8,9)	670	2021
NG Steam Generator (Reading D 4)	214	2022
NG Steam Generator (Eshkol 6)	228	2024
NG Steam Generator (Eshkol 7)	228	2028
CCGT E (Ramat Hovav CC 34)	335	2029

The reserve margin is maintained at 20% in the BAU scenario, in line with the recommendations of the Yogev Committee and the Ministry of Energy[53].

Endogenous capacity additions will start with the construction of Project D, which takes the form of two units of 762 MW and which is assumed to operate on natural gas with coal as a back-up fuel; as such, it has the characteristics of a natural gas steam plant except for the efficiency which is included in the PUA description of IEC capacity (see below). LEAP then constructs additional natural gas OCGT capacity in units of 100 MW, as per assumptions provided by the PUA according to which additional capacity should be open cycle. The characteristics of these plants are detailed in the next section.

6.1.2.5 Characteristics of capacity

It is necessary to consider a selection of key characteristics in modelling these plants. These include capacity (MW), efficiency (%), maximum availability (%) and capacity credit (%). Exogenous capacity is defined as the pre-existing or scheduled generation capacity that exists in the model before simulation begins in addition to any generation capacity that will definitely be constructed (or retired) in future years. Maximum availability refers to the maximum possible operation time for a given plant type over a yearly period, specified as a percentage of that year. The capacity credit is used to determine how much a plant type contributes to the reserve margin. It is important to note that LEAP does not take account of availability when calculating the reserve margin[54].

Efficiencies

Efficiency data for thermal generation capacity are supplied by the PUA for plants operating at varying levels, ranging from 20% rated capacity to 100% rated capacity (i.e. operating at full capacity). These are used to decide the efficiency of operation at minimum rated capacity and at full capacity for a range of thermal plants.

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[53] However, as the Ministry of Energy definition of reserve margin includes the deleterious effects of transmissions and distribution, whereas LEAP calculates the reserve margin after these effects, maintaining consistency with the Ministry of Energy definition required adjusting the margin to remove transmission and distribution losses.

[54] The reserve margin is calculated based on the nameplate capacity of the plants, times the capacity credit.

Table 62 Efficiencies of generation capacity

Plant Type	Efficiency (%)
IEC Coal (excluding Orot Rabin 1-4)	38.5
Orot Rabin 1-4	38.5
IEC NG Steam Generator	38.5
IEC Diesel Gas Turbine	27.0
IEC NG Gas Turbine	33
IEC Jet Gas Turbine	25.9
IEC CCGT E	48.8
IEC CCGT F	54.6
IEC Project D	47.1
IPP CCGT F	54.6
IPP OCGT NG	41.4
IPP OCGT HFO	36.9
IPP Cogeneration CCGT F	54.6
IPP Cogeneration OCGT	36.9
IPP Cogeneration NG Steam Generator	38.5
IPP Cogeneration Diesel Turbine	30.6
Micro and Small Hydro	-
Solar PV (Ground)	-
Solar PV (Rooftop)	-
CSP Solar Tower	-
CSP Parabolic Trough	-
Biogas	30
Onshore Wind	-

The efficiencies of some OCGT plants are taken from Ministry of Energy modelling assumptions, namely OCGT HFO and IPP cogeneration OCGT. Where data for efficiencies are not available, these are calculated using the heat rates from PUA data describing IEC capacity. This method is employed for diesel gas turbines, natural gas turbines and jet gas turbines.

The efficiency figures above account for self-consumption, demonstrating net efficiency by technology at full rated output. It is assumed that self-consumption is 4% for steam generators, 2.5% for CCGT units and 1.5% for OCGT units, in line with data provided by the PUA. The minimum rated capacity is assumed to be 45% for coal units and 60% for gas turbine units.

Equation 1 - Incorporating self-consumption into percentage efficiency

$$\eta f = \frac{\eta i}{\eta i(1+SC)}$$

where η is percentage efficiency (initial and final), and SC is self-consumption (%)

Availability

Availability factors for conventional plants are derived from PUA data. This is done by calculating the availability of each plant based on the following formula and then finding the weighted average by plant type. In this case, IPP plants are assumed to be available for 92% of the year, in accordance with their contractual obligations as per the PUA.

Equation 2 - Maximum availability

$$A=1-\left(\frac{d_{pm}}{365}+EFOR\right)$$

where A is availability (%), dpm is days planned maintenance (days) and EFOR is equivalent forced outage rate (%)

It is important to note that for non-dispatchable renewable resources in LEAP the maximum availability is conceptually equivalent to the capacity factor. The capacity factors are taken from data supplied by the PUA, the Ministry of Energy and international sources, where necessary.

This gives the availability figures shown in Table 63 below.

Table 63 Availability

Plant Type	Availability (%)
IEC Coal (excluding Orot Rabin 1-4)	85
Orot Rabin 1-4	54.6
IEC NG Steam Generator	82
IEC Diesel Gas Turbine	81
IEC NG Gas Turbine	81
IEC Jet Gas Turbine	80
IEC CCGT E	87
IEC CCGT F	87
IEC Project D	87
IPP CCGT F	92
IPP OCGT NG	95
IPP OCGT HFO	92
IPP Cogeneration CCGT F	92
IPP Cogeneration OCGT	92
IPP Cogeneration NG Steam Generator	92
IPP Cogeneration Diesel Turbine	92
Micro and Small Hydro	84
Solar PV (Ground)	21
Solar PV (Rooftop)	20
CSP Solar Tower	43
CSP Parabolic Trough	47 (22 without storage)
Biogas	85
Onshore Wind	35

Based on the opinion of the PUA and a review of operation in recent years, it is assumed that jet gas and diesel turbines operate for 20 hours a year. This is implemented in the model by assuming that these technologies have a low availability and are 'must-run'[55]. It is assumed that Orot Rabin operates based on a seasonal availability profile such that it only operates from 01 December until 15 March and 01 June until 15 September, further subject to a 94% availability constraint to reflect expected forced outages, based on PUA data showing EFOR[56] of 6%.

Capacity Credit

Capacity credit is defined as the percentage of the nameplate capacity that is used when calculating the amount of generation that is assumed to be available at peak times, and is used for calculating the reserve margin - that is, the amount by which potential electricity supply (generation) exceeds peak demand. In LEAP, this is used to decide when to build new capacity (if the capacity margin falls too low).

The capacity credits of thermal plants and some renewables are taken from Ministry of Energy modelling assumptions, which give capacity credits both for the winter and the summer. Although it is not truly a capacity credit, the table below includes a value of 90% for natural gas turbines, as per the Ministry of Energy, due to the fact that they suffer a capacity reduction in the summer months, and the summer peak represents the greatest strain on the reserve margin.

The capacity credit of solar PV (without ancillary storage) is assumed to vary with deployment, as per the findings of the National Economic Council (NEC) It is assumed to be 75% for the first 600 MW, 50% for capacity between 600 and 1200 MW, 30% for capacity between 1200 and 1800 MW, 10% for capacity between 1800 MW and 2400 MW and 0% for any additional capacity. The capacity credit of solar PV with the effects of energy storage is assumed to be 85%, also on the basis of the findings of the NEC, although ancillary storage is only included as an abatement measure. It is assumed that pumped hydro storage does not affect the capacity credit of renewables.

The wind capacity credit was based on the Ministry of Energy report "Policy on Integration of Renewable Energy Sources into the Israeli Electricity Sector".

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[55] That is, for modelling purposes they run for 20 hours per year irrespective of what other plants are doing or what demand is.
[56] Equivalent Forced Outage Rate.

Table 64 Capacity credit figures by technology

Plant Type	Capacity Credit (%) (including capacity reduction for NG power plants in the summer months)
IEC Coal (excluding Orot Rabin 1-4)	100
Orot Rabin 1-4	100
IEC NG Steam Generator	100
IEC Diesel Gas Turbine	90
IEC NG Gas Turbine	90
IEC Jet Gas Turbine	90
IEC CCGT E	90
IEC CCGT F	90
IEC Project D	100
IPP CCGT F	90
IPP OCGT NG	90
IPP OCGT HFO	90
IPP Cogeneration CCGT F	90
IPP Cogeneration OCGT	90
IPP Cogeneration NG Steam Generator	90
IPP Cogeneration Diesel Turbine	90
Micro and Small Hydro	100
Solar PV	34.74 (75% for the first 600 MW, 50% for the next 600 MW, 30% for the next 600 MW, 10% for the next 600 MW, and 0% for anything above the first 2400 MW, without localized storage. Capacity with localized storage assumed to have a capacity credit of 85%. Effective capacity credit for PV in BAU is an average of 34.74%)
CSP Solar Tower	85
CSP Parabolic Trough	85
Biogas	100
Onshore Wind	25

6.1.2.6 Treatment of energy storage

Hydro pumped storage is modelled by considering the effects that it could have on the Israeli power sector. There are two important impacts that were included in LEAP, which are improving the reliability of non-dispatchable renewable energy sources and providing a peak-shaving function[57].

In terms of the wider energy system, the effect of energy storage is addressed by flattening the demand curve accordingly. This is done using an Excel-based model, which assumes that pumped hydro storage both charges and discharges for a period of four hours per day and shifts this quantity of energy from the highest to the lowest levels of the demand. This reduces the need for reserve capacity and allows baseload plants to meet a greater proportion of electricity demand. This method is explained in more detail in Section 6.1.3.

To simulate the impact of energy storage on renewables, one approach could be to assume

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[57] These options are the suggested workarounds from LEAP's makers, SEI.

that the capacity credit of installed renewable capacity rises as storage deployment increases. However, given that the energy storage is already assumed to reduce the capacity requirement by means of peak-shaving, it is assumed that simulating the effect of energy storage on the capacity credit of renewables would be double-counting. As such it is assumed that there is no change in the capacity credit of renewables unless the energy storage units are explicitly attached to the generation units, as in the case of some solar PV and solar CSP plants. Energy storage units are not assigned a capacity credit for the same reason. In cases where localised storage is used, it is assumed that this does not contribute to the peak shaving effect, as this would be double counting the effect of these units.

PUA forecasts predict 640 MW of pumped hydro energy storage by 2020. There is no battery storage in the BAU scenario as this is considered a mitigation option.

6.1.2.7 Merit order

The merit order in LEAP is expressed as a numerical order. For example, if coal steam were '1' and combined cycle plant were '2', LEAP would push coal steam generation to rated capacity and then utilise the combined cycle plant.

The merit order used is as follows and is based on Ministry of Energy modelling assumptions used as part of the Natural Gas Authority's forecasting model, modified based on comments from the PUA:

1. The following (as must run / must take):
   - Renewables
   - Coal, at minimum operating level (45% - see below)
   - Cogeneration plants, operating at full capacity
   - Dalia, OPC and Dorad Plants (see below)
2. Coal, operating at full load
3. The following:
   - Efficient combined cycle units, at minimum operating level (60%)
   - Project D, if needed[58]
4. Efficient combined cycle units, operating at full capacity
5. Less efficient combined cycle units
6. Steam Generators
7. Gas turbines
8. Emergency capacity (diesel and HFO units)

This merit order requires differentiation between the minimum load of certain plants

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[58] While Project D is a steam generator, it is assumed to operate at a higher load factor than the older steam generators shown at position 6 in the merit order. This is why it is shown at an earlier position in the order

and the remaining load. This has been implemented in LEAP by dividing coal steam capacity into two distinct 'energy technologies'. The first represents the minimum rated capacity and the second represents the additional capacity making up the remainder of the rated capacity for that generation type.

Note that when generation capacity is split between minimum and rated capacity, a special method is used to calculate the efficiency. The 'minimum' capacity group runs at the minimum load efficiency as indicated in the dataset. The 'rated' capacity group runs at a slightly higher efficiency than the maximum efficiency listed in the dataset. This is done because the maximum efficiency is intended to apply to all units of capacity, whereas in LEAP the 'minimum' group will still be running at a lower efficiency. This is a limitation of the LEAP software. The efficiency of the 'rated' group is raised in such a way that the two together are operating at the specified maximum level of efficiency.

Note that coal steam generators are instructed to run constantly at no less than minimum capacity, rather than in proportion to other generation units that are also first in the merit order[59]. The Dalia and OPC CCGT plants operate at an average of 80% capacity, taking into account availability. In addition, the Dorad CCGT plant operates for 4,000 hours over the year, at an average load factor of 85%. This is done on the basis of recommendations from the PUA.

6.1.2.8 Annual load profile

The variation of electricity demand across the year is captured in the load profile used in LEAP. The approach taken is to divide the year into three seasons - summer, winter and transitionary. Within each season, a typical 24 hours is taken to represent the normal variations of demand in that season. This gives 3*24=72 time slices across the year. Typical demand figures for each time slice are taken from historic data supplied by the PUA. The model represents load in each time slice as a percentage of total annual load. As noted above, there are 72 time slices in the model. Since there are 8,760 hours in a year, each time slice represents demand over a number of hours; in order to account for the relative length of each season, the winter, transition and summer time slices are 87, 203 and 73 hours respectively. These sizes were calculated such that they reflect the ratio between the lengths of the seasons and ensure that the 72 time slices add to 8,760 hours. These are then used in conjunction with the length of each season to calculate the amount of load distributed across each of the 72 time slices.

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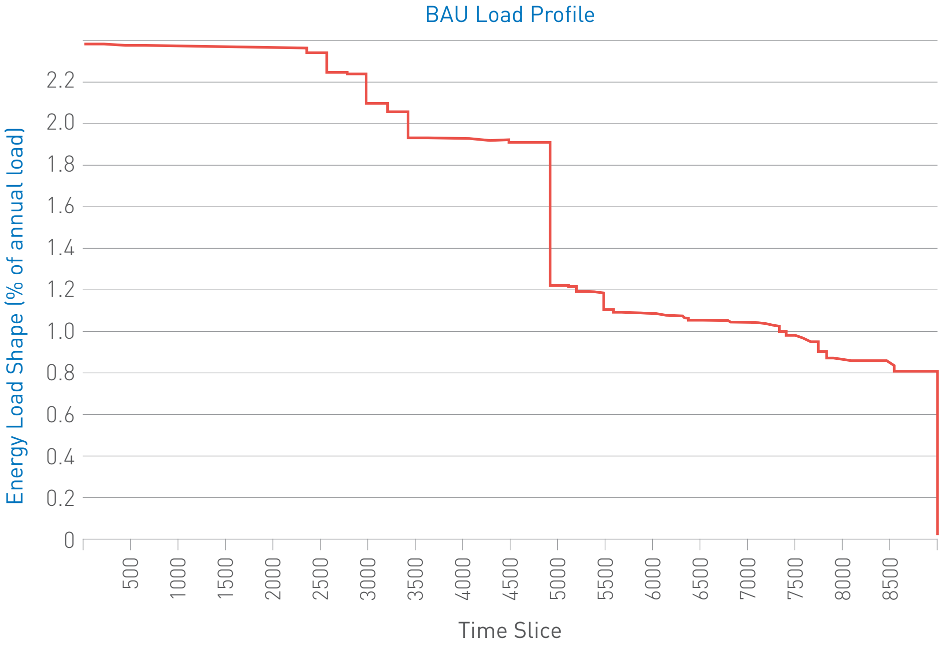
[59] This applies in the situation where demand is so low that it is below the output of the units that are first in the merit order, such as coal and renewables. Suppose demand is 10% below output. Ordinarily, LEAP would reduce the output of all units that are first in the merit order proportionately - by 10% each - so that output matches demand. However, for the analysis presented here, LEAP has been told to reduce the output of renewables so that output does not exceed demand. The output of coal is unaffected - that is, it runs at minimum capacity in all situations.

Figure 16 **Annual load profile**



As this is an averaging approach, it will naturally smoothen out some of the peaks and troughs of electricity demand. As a consequence, this would cause the LEAP model to underestimate capacity requirements. In order to avoid this, we have included the 'peak hour' in the load curve. This is the hour in which demand was greatest in our dataset. We then calculate the quantity of this amount of load as a percentage of annual demand and include it as an additional 1-hour time slice. The value of the load and the additional hour are subtracted from the slice in which the peak hour occurred. When assessing the effects of energy storage, we assume that the energy storage units are operating at full capacity during this hour and deduct the quantity of storage from the demand in the peak hour. The capacity of storage in this calculation is de-rated by the ratio of 2014 capacity to 2020 capacity to account for the fact that 640 MW of storage in 2020 is a smaller proportion of the grid than the same amount of storage in 2014.

We assess the potential effect of the installed hydro pumped storage capacity[60] and flatten the demand curve accordingly. This is done using an Excel-based model, which assumes that storage both charges and discharges for a period of four hours per day and shifts this quantity of energy from the highest to the lowest levels of the demand. As explained earlier, this reduces the need for reserve capacity and might also reduce the need to operate environmentally unfriendly plants lower down the merit order. It is also assumed that the energy storage units are operating at full capacity during the peak hour.

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[60] Localized battery storage is treated as increasing the capacity credit of rooftop PV and to avoid double counting, is assumed not to affect the demand curve.

6.1.2.9 Fuels and emissions

The power sector uses the same calorific values and emissions factors as used elsewhere in the model. This provision extends to refuse-derived fuel (RDF), which is used as a mitigation measure.

6.1.2.10 Transmission and distribution

Transmission losses have been set at 4.2%, as per historical IEC data. This does not change in the BAU or mitigation scenarios

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6.1.3 Mitigation

The previous section included the data used to project emissions in a Business As Usual situation with no further action to reduce emissions. In this section, we look at possible options for reducing emissions from the electricity sector.

Those options are of two broad types: installing new capacity which produces less carbon dioxide emissions than what would be installed under BAU, and using the existing capacity in a different way that reduces emissions.

Whilst most of the measures in the first category involve new renewable generation capacity, we also consider replacement of Project D and/ or Orot Rabin 1-4 with a new CCGT. In the second category are measures such as changing the merit order to run gas units more and coal units less, and the use of Refuse-Derived Fuel (RDF) for co-firing in coal stations.

The 'ambitious target' scenario described a situation in which the deployment of all measures reaches the technical potential for that measure. For the purpose of this report, the "technical potential" of mitigation technologies would be better considered as the maximum reasonable level of deployment for that technology.

The 'conservative target' scenario describes a more targeted package of measures that sees some power sector generation technologies excluded and others deployed in more limited quantities. These decisions were taken on the basis of cost and advice received from stakeholders.

The key difference between the scenarios is that less renewable capacity is installed in the "conservative" scenario, in accordance with the feedback received from the working group. Detailed figures are in Table 67 and Table 68, but in summary in the "conservative" scenario:

- Not all potential for solar PV is installed
- CSP Parabolic Trough with storage is not installed beyond BAU capacity
- No new CSP Solar Tower with storage is installed beyond BAU capacity
- Less CSP Hybrid is installed
- Less onshore wind, and no offshore wind, is installed

In the rest of this section, we describe the mitigation options in more detail. We start by looking at the measures that involve building new capacity, before describing those that involve using existing capacity differently.

For the majority of mitigation measures that involved installing new, low-emission capacity, the abatement cost analysis was conducted by calculating the levelised cost of electricity generation for each generation technology, compared with the levelised cost of generation from the reference technology. With the exception of new capacity that replaces specific existing or planned capacity, the reference technology was assumed to be natural-gas based OCGT.

The levelised costs (NIS / kWh) of each technology were calculated based on the following methodology:
1. CAPEX costs were annualized, based on the lifetime of the technology and the discount rate of 4%
2. Total annual OPEX costs were calculated based on fixed OPEX and as well as variable OPEX multiplied by annual electricity generation, based on the assumed load factor
3. Annual fuel costs were calculated based on the cost of fuel, the efficiency of the power plant, and the annual electricity generation. Externalities were also taken into account.
4. The levelised cost of electricity generation is calculated as the sum of annualised CAPEX costs, total annual OPEX costs and annual fuel costs, divided by annual electricity generation
5. In calculating the levelised cost of renewable technologies, two additional parameters were taken into account:
   - Capacity Credits: The capacity credit reflects the level at which a given technology counts towards the total capacity at peak load, for the purpose of maintaining the reserve margin. Essentially, this means that a technology with a capacity credit of less than 100% can only partially be depended during peak consumption, and therefore does not full replace conventional installed capacity. By example, if a technology only has a capacity credit of 20%, that it only replaces 20% of a conventional plant - and as such, the remaining 80% capacity must still be installed - leading to both additional CAPEX and fixed OPEX costs. As such, the annualized CAPEX and fixed annual costs of the remaining required conventional capacity were added onto the renewable energy costs in calculating the levelised cost of generation. In order to maintain consistency in the analysis, the levelised cost of renewable generation is compared to conventional units with the same capacity and load factor.
   - Storage: Costs of storage were also taken into account in calculating the levelised costs of renewable energy technologies. For hydro-pumped storage, in accordance with the PUA, the following was assumed:
     - Ground-based PV without localised storage would require hydro-pumped storage at 20% of the rated PV capacity
     - Wind would require hydro-pumped storage at 4% of the rated wind capacity

- As per the data provided by the PUA, whilst the hydro-pumped storage is required to facilitate renewable energy capacity, it will then perform primarily as a peak-shaving plant, replacing OCGT capacity. Hence, only the cost differential between hydro-pumped storage and OCGT were attributed to the relevant renewable technologies.
- Every 1MW of PV with localised storage was accompanied by 2MWh of localized battery storage
- Finally, it should be noted that the abatement renewable uptake is assumed to take place between 2021 - 2030. As such, 2025 costs have been used in the analysis.

6.1.3.1 Additional capacity in mitigation scenarios

Table 66 describes the key characteristics of those mitigation technologies that were not described in preceding sections. In most cases, the PUA was the source for performance characteristics whereas international data were generally used for costs. The technical potentials for individual technologies were selected on the basis of a review of published literature regarding various levels of renewable uptake in Israel, manufacturer data, and data provided by the Ministry of Energy, as well input from stakeholders, the power sector work team and the MoEP. While these figures are treated as the maximum technical potential for the purpose of this report, in reality they are more a reflection of the team's best assessment of the maximum reasonable uptake for these technologies by 2030. These are shown in Table 65 below.

Table 65 Maximum reasonable uptake for technologies by 2030

Plant Type	Uptake (MW)
Solar PV (Ground)	5,200
Solar PV (Rooftop)	3,400
CSP Solar Tower	500
CSP Parabolic Trough	500
CSP Hybrid (NG)	1,000
CSP Hybrid (Biomass)	300
Biogas	132
New biomass	5
Onshore Wind	1,000
Offshore Wind	50
Water Pipe Hydro	5
Wave	50

In addition to these measures involving the deployment of additional capacity, one mitigation measure was the deployment of a natural gas CCGT unit in place of the coal-fired Orot Rabin 1-4 units. For the purpose of the analysis this is assumed to occur in 2018. The details of this and other non-renewable mitigation options are described in the next section, after data on renewables.

Table 66 Key characteristics of renewable technologies

Plant Type	Efficiency	Load Factor	Capacity credit
Solar PV (Ground)	-	21	17[61]
Solar PV (Rooftop)	-	20	85[62]
CSP Solar Tower	-	43	85
CSP Parabolic Trough[63]	-	47	85
CSP Hybrid (NG)	59.4	85	100
CSP Hybrid (Biomass)	33	85	100
Biogas	30	85	100
Biomass	30	80	100
Onshore Wind	-	35	25
Offshore Wind	-	35	25
Water Pipe Hydro	-	84	100
Wave	-	19	19

For the characteristics in the table above, offshore wind is assumed to be similar to onshore wind, as is biomass to biogas and water pipe hydro to micro and small hydro. Efficiencies and load factor of natural gas and biomass CSP are from manufacturer data, while capacity credit is from Ministry of Energy data. The efficiency in LEAP refers to the fuel efficiency exclusively, as this is the only meaningful quantity as far as the results are concerned (the efficiency of these plants with solar has no impact). This is also relevant to CSP hybrids that also use combustible fuels.

Table 67 demonstrates the generation capacity by type in the 'ambitious target' scenario. It should be noted that the exogenous capacity additions are such that there are no endogenous capacity additions. This is because the reserve margin is met on the basis of exogenous capacity alone. In other words, because of the combination of the reduction in electricity demand from energy efficiency measures and the increase in the level of renewable generation, there is no need for new thermal power plants, including Project D. This of course means that the abatement option of replacing Project D with a CCGT is not used.

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[61] Assumed to be 20% with localized storage (capacity credit = 85%), 80% without (capacity credit = 0)
[62] Assumed to be 100% with localized storage
[63] Figures quoted are for Parabolic Trough with Storage

Table 67 Capacity in selected years for ‘ambitious target’ scenario (MW)

Plant Type	2015	2020	2025	2030
IEC Coal	2,825	3,400	3,400	3,400
Orot Rabin 1-4	1,440	-	-	-
IEC NG Steam Generator	1,622	1,340	228	-
IEC Diesel Gas Turbine	542	542	542	542
IEC NG Gas Turbine	1,028	1,028	1,028	1,028
IEC Jet Gas Turbine	504	504	504	504
IEC CCGT E	995	995	995	660
IEC CCGT F	4,083	5,523	5,523	5,523
IEC Project D				
IPP CCGT F	2,320	3,368	3,368	3,368
IPP OCGT NG	-	-	-	-
IPP OCGT HFO	28	-	-	-
IPP Cogeneration CCGT F	561	827	827	827
IPP Cogeneration OCGT	109	165	165	165
IPP Cogeneration NG Steam Generator	212	212	212	212
IPP Cogeneration Diesel Turbine	48	48	48	48
Micro and Small Hydro	7	7	7	7
Solar PV (Ground)	445	1,723	3,462	5,200
Solar PV (Rooftop)	291	1,127	2,263	3,400
CSP Solar Tower	-	131	316	500
CSP Parabolic Trough	-	131	316	500
CSP Hybrid (NG)	-	-	500	1,000
CSP Hybrid (Biomass)	-	-	150	300
Biogas and biomass	27	45	128	137
Onshore Wind	6	435	718	1,000
Offshore Wind	-	-	25	50
Water Pipe Hydro	-	-	3	5
Wave	-	-	25	50
Pumped hydro storage	0	640	940	1,240
Total (excluding energy storage)	**17,093**	**21,551**	**24,751**	**28,426**
Total (including energy storage)	**17,093**	**22,191**	**25,691**	**29,666**

Table 68 demonstrates the generation capacity by type in the ‘conservative target’ scenario. As above, there are no endogenous capacity additions in this scenario.

Table 68 Capacity in selected years for 'conservative target' scenario (MW)

Plant Type	2015	2020	2025	2030
IEC Coal	2,825	3,400	3,400	3,400
Orot Rabin 1-4	1,440	-	-	-
IEC NG Steam Generator	1,622	1,340	228	-
IEC Diesel Gas Turbine	542	542	542	542
IEC NG Gas Turbine	1,028	1,028	1,028	1,028
IEC Jet Gas Turbine	504	504	504	504
IEC CCGT E	995	995	995	660
IEC CCGT F	4,083	5,523	5,523	5,523
IEC Project D	-	-	-	-
IPP CCGT F	2,320	3,368	3,368	3,368
IPP OCGT NG	-	-	-	-
IPP OCGT HFO	28	-	-	-
IPP Cogeneration CCGT F	561	827	827	827
IPP Cogeneration OCGT	109	165	165	165
IPP Cogeneration NG Steam Generator	212	212	212	212
IPP Cogeneration Diesel Turbine	48	48	48	48
Micro and Small Hydro	7	7	7	7
Solar PV (Ground)	445	1,723	3,149	4,574
Solar PV (Rooftop)	291	1,127	2,059	2,991
CSP Solar Tower	-	131	131	131
CSP Parabolic Trough	-	131	131	131
CSP Hybrid (NG)	-	-	200	400
CSP Hybrid (Biomass)	-	-	60	120
Biogas and biomass	27	45	128	137
Onshore Wind	6	435	618	800
Offshore Wind	-	-	-	-
Water Pipe Hydro	-	-	3	5
Wave	-	-	25	50
Pumped hydro storage	0	640	940	940
Total (excluding energy storage)	**17,093**	**21,551**	**23,349**	**25,622**
Total (including energy storage)	**17,093**	**22,191**	**24,289**	**26,562**

Cost data is included for the MACC analysis. Plant costs are described by capital cost, fixed operation and maintenance (O&M) costs and variable O&M costs. In the model these are expressed in $/kW capacity or $/kWh generation. Steam generator costs (including Project D) are from Ministry of Energy modelling assumptions whereas other thermal plant costs are from PUA data, as are costs for CSP parabolic trough and solar tower as well as biogas and pumped hydro storage.

Costs for solar PV panels and lithium-ion batteries are taken from Bloomberg data. It is assumed that ground-based capacity is all utility grade (above 50 kW) and that rooftop capacity is 80% utility grade, 10% commercial grade (10-50 kW) and 10% small-scale panels (up to 10 kW). Additionally, solar PV fixed operating costs are assumed to be 2% of capital costs, as per the PUA. Costs for on- and off-shore wind turbines are from the UK Department of Energy and Climate Change (DECC), and International Renewable Energy Agency (IRENA) costs are used for biomass and CSP parabolic trough without storage. Costs for CSP NG/biomass and water pipe hydro are from manufacturer data (with a 10% conservative factor applied to CSP hybrids).

Fuel costs are from Ministry of Energy forecasts and PUA assumptions. They do not change over our modelling horizon in line with these projections. Operational and maintenance costs for all generation capacity types in 2015 are included in Appendix 4.

It should also be noted that when building new renewable capacity, additional storage capacity was also built.

The costs of the storage are shown below. Pumped hydro costs are sourced from the PUA, while battery costs are sourced from Bloomberg.

Table 69 Costs of storage

Storage type	Capital cost ($/kW – 2025 costs)	Fixed annual operating cost ($/KW)
Pumped hydro[64]	1,600	25
Localized battery storage ($/kWh)	400	-

Some cost reductions are assumed over the modelled period. Cost reductions for renewable technologies are largely forecast on the basis of UK government predictions for international renewable costs[65]. Solar PV cost forecasts from Bloomberg contain inbuilt reductions, as do wind capital cost forecasts from UK DECC. Based on IRENA data, it is assumed that biomass capital costs fall by 10% by 2025 and that CSP costs fall by 32.5% in the same period; cost reductions for these technologies were projected forward to 2030 in a linear manner. As a conservative estimate, it was assumed that CSP hybrid costs fall by 2% per annum - less than the 3.25% per annum reduction assumed by IRENA for standard CSP.

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[64] Costs are shown as the net costs relative to a new OCGT

[65] https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/223940/DECC_Electricity_Generation_Costs_for_publication_-_24_07_13.pdf

Table 70 Changes in costs for renewable capacity

Plant Type	Capital Cost ($/kW) (2015)	Capital Cost ($/kW) (2020)	Capital Cost ($/kW) (2025)	Capital Cost ($/kW) (2030)
Micro and Small Hydro	7407	7407	7407	7407
Solar PV (Ground)	1393	1088	922	817
Solar PV (Rooftop)	1513	1185	1010	901
CSP Solar Tower with storage	6739	5729	4720	3710
CSP Parabolic Trough with storage	8253	7017	5780	4544
CSP Hybrid (NG)	5775	5198	4620	4043
CSP Hybrid (Biomass)	5941	5347	4753	4159
Biogas	4500	4500	4500	4500
Biomass	2871	2727	2584	2440
Onshore Wind	1991	1946	1900	1855
Offshore Wind	3705	3274	2843	2412
Water Pipe Hydro	5000	5000	5000	5000
Wave	6800	6800	6800	6800

Non-renewable capacity

In addition to the renewable capacity considered above, two options for building new CCGTs, in place of existing or planned capacity, were also considered.

The first was the option of replacing Orot Rabin 1-4 with a new CCGT. Under the BAU scenario, Orot Rabin 1-4 was assumed to continue to 2035, and have scrubbers fitted in 2019 (assumed to cost 3,100,000 NIS - source: Ministry of Finance). The alternative was to build a new CCGT, which is assumed to be of Type F - assumptions on cost and efficiency are as set out elsewhere in this report. The load factor of the units was assumed to be the same in both cases i.e. 54.6%. This is based on Orot Rabin being 'must run' from 01 December until 15 March and 01 June until 15 September, which is 212 days per year, combined with a 6% EFOR[66].

The second option was the replacement of Project D with a new CCGT of Type F. Cost assumptions are set out in Annex 3. However, as will be seen in the next section, in the mitigation scenarios Project D is not needed, and so this mitigation option was not relevant and therefore not used.

6.1.3.2 Other measures - using existing capacity differently

There are two additional measures considered in the mitigation scenarios, which are the substitution of some coal with refuse-derived fuel (RDF) and a modification of the merit order, in order to give priority to combined cycle natural gas over coal. In this option, CCGT plants are dispatched to full capacity before ramping up coal units to full capacity. Coal minimum capacity remains "must-run".

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[66] Source: PUA

The cost of this measure was calculated based solely on the variable generation costs of CCGT versus coal power plants - i.e. variable OPEX, fuel costs, and externalities, given that this measure pertains to the manner in which existing units are operated, and therefore CAPEX and fixed OPEX costs are not impacted.

The RDF substitution measure replaces 3% of coal used in coal-fired power plants with RDF. This figure was chosen on the basis of the waste modelling results (see section 7.2). Given scarcity, the industrial sector was the preferred destination for RDF as the substitution in that sector achieves a greater mitigation per unit of RDF and so is preferable as a mitigation measure. The comparison here is between a standard IEC Coal Steam Generator using 100% coal for fuel and the same generator using 97% coal and 3% RDF. The cost of RDF is assumed to be 90% of that of coal on an energy basis[67]. Externalities, as set out below are taken into account in calculating the net cost/ benefit, as for other abatement measures.

6.1.3.3 Externalities

The externality costs of combusting fossil fuel have been included in our analysis. These are sourced from the Ministry of Environmental Protection and are shown below.

It should be noted that the coal externality costs assume that all coal units are equipped with scrubbers; although this is not currently the case, it is assumed that this will more accurately reflect the situation in Israel in a few years' time.

Table 71 Externality costs in NIS per kWh

Pollutant	Coal	Natural Gas
SOx	0.026004	0.000788
NOx	0.01505988	0.006845
PM10	0.00393666	0.000562
Total	**0.04500054**	**0.00819578**

The mitigation measures above were analysed and levelised costs calculated as in section 2.4. This gives the following assessment of potential mitigation by measure. Cost effective measures are shown in italics.

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[67] Source: IEC

Table 72 Mitigation measures and potential

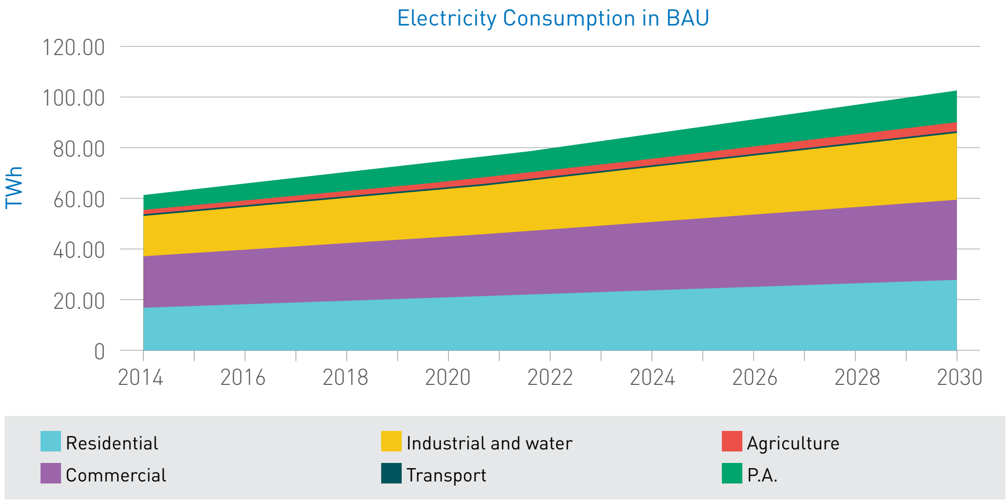
Option	Abatement potential in millions of tonnes of CO_2 per year in 2030
Project D replaced with new CCGT	0.70
RDF co-firing in coal units	0.46
Solar PV Ground	3.05
Solar PV rooftop	1.88
CSP (Hybrid biomass)	1.06
CSP (Hybrid gas)	2.41
Onshore Wind	0.82
Water Pipe Hydro	0.02
Merit order switch	6.14
Orot Rabin 1-4 replaced with CCGT	3.37
CSP (Solar Tower with Storage)	0.65
CSP (parabolic trough with storage)	0.71
Biogas	0.31
New Biomass	0.02
Offshore Wind	0.07
Wave	0.04

6.2 RESULTS

6.2.1 BAU scenario

Our analysis shows significant growth in electricity demand from residential buildings in the business-as-usual scenario. The total expected BAU electricity consumption (see Figure 17) closely matches the Ministry of Energy forecast of 94.5 TWh in 2030.

Figure 17 BAU electricity consumption[68]



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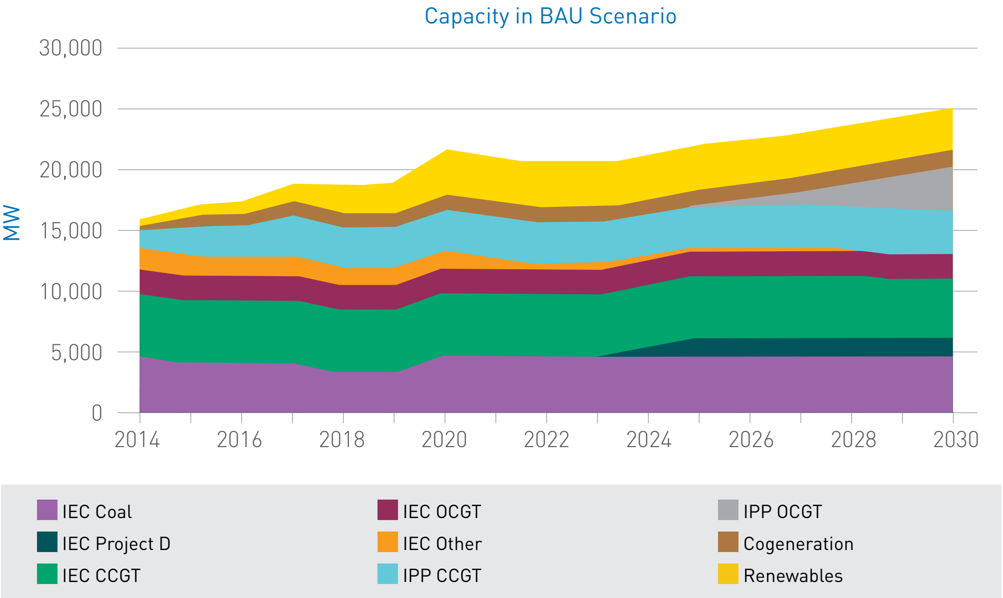
[68] PA consumption based on Ministry of Energy economic models, assuming 1.9% growth in GDP per capita.

In the BAU scenario, generation capacity increases significantly to 2020 and then continues to increase at a slower rate towards 2030. Project D is built in 2024 and 2025 to maintain reserve margin; see Figure 18.

Figure 18 **BAU gerneration capacity**



There are 300 MW of pumped hydro storage built in 2018 and a further 340 MW in 2020, giving a total pumped hydro storage capacity of 640 MW in the BAU scenario. This is not shown on the above graph.

Table 73 Capacity before and after capacity credit in 2030 (MW)

Capacity type	Capacity	Capacity Value
Coal Steam Generator	4840.00	4840.00
NG CCGT	8111.00	7299.90
NG OCGT	4728.00	4255.20
Cogeneration	1252.00	1126.80
Wind	435.00	108.75
Solar PV	2850.10	988.98
Solar CSP	262.00	156.86
Other Renewable	51.60	51.60
Other	2570.00	2465.40
Total	25099.70	21293.49

After accounting for the peak-shaving effects of energy storage[69], the peak power requirements in the BAU scenario in 2030 are 17.8 GW. This tallies well with the capacity in the BAU scenario, after taking account of the capacity credits (21.3 GW), assuming a reserve margin of 20%.

Table 74 Fuel mix for power generation in BAU

Fuels	2015	2020	2025	2030
Natural Gas	52.29%	45.42%	53.69%	60.27%
Diesel	0.03%	0.03%	0.02%	0.02%
Coal Bituminous	45.09%	44.12%	37.44%	32.12%
Biogas and biomass	0.32%	0.46%	0.39%	0.33%
Wind	0.03%	1.83%	1.55%	1.33%
Solar	2.15%	8.07%	6.85%	5.88%
Hydro	0.08%	0.07%	0.06%	0.05%
Total	100.00%	100.00%	100.00%	100.00%

Table 75 Percentage of total generation from the different renewable types (BAU)

Renewable Type	% of total generation in 2025	% of total generation in 2030
Solar	6.85%	5.88%
of which PV	5.18%	4.44%
of which CSP	1.67%	1.43%
Wind	1.55%	1.33%
Hydro	0.06%	0.05%
Biogas and biomass	0.39%	0.33%
Total	8.85%	7.59%

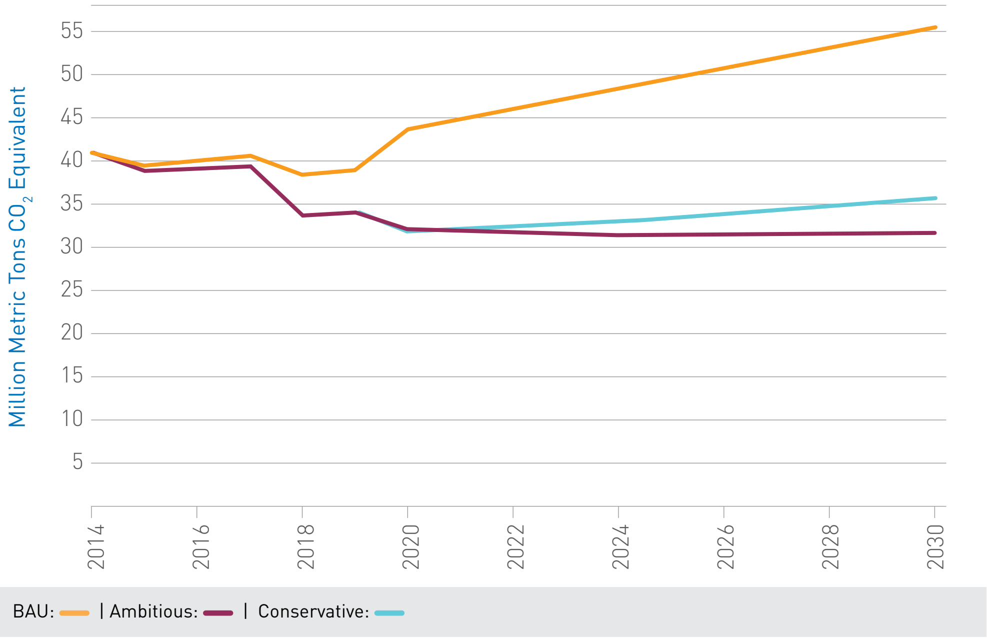
---

[69] The load curve incorporates the peak-shaving effects of hydro pumped storage and thus LEAP will consequently generate this figure after taking account of energy storage

6.2.2 Mitigation

Figure 19 shows that emissions in the power sector can be reduced by 35.6% below BAU by 2030 through a selection of the measures shown in the abatement curve below (the 'conservative target' scenario), or 42.6% through the introduction of all the measures in the abatement curve (the 'ambitious target' scenario). Figure 21 is the corresponding MACC.

Figure 19 **Mitigation potential in the power sector**

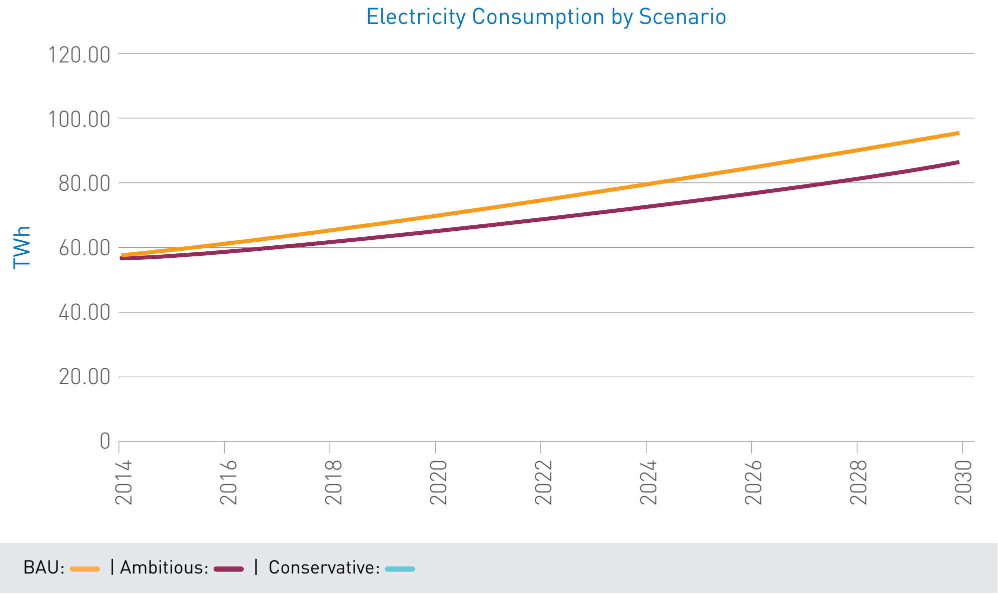


In the conservative scenario energy efficiency measures account for 16.2% of the emissions abated in the power sector, with the other 83.8% coming from power sector measures. Any additional GHG abatement in the ambitious scenario is mainly a consequence of additional power sector measures.

Table 76 Generation capacity in conservative scenario (MW)

Category	2015	2020	2025	2030
Coal	4265.0	3400.0	3400.0	3400.0
NG	10930.0	13458.0	12346.0	11783.0
Other Thermal	1122.0	1094.0	1094.0	1094.0
Renewable	775.7	3598.7	6509.1	9345.4
Pumped hydro storage	0.0	640.0	940.0	940.0
Sum (excluding storage)	17092.7	21550.7	23349.1	25622.4
Sum (including storage)	17092.7	22190.7	24289.1	26562.4

Figure 20 Electricity consumption across scenarios



Key differences between the BAU and the mitigation scenarios are the increase in deployment of renewable capacity in the latter and the consequential fall in required thermal capacity. Project D is not required in either mitigation scenario due to additional renewable generation capacity and energy efficiency measures.

Table 77 Generation capacity in ambitious scenario (MW)

Category	2015	2020	2025	2030
Coal	4265.0	3400.0	3400.0	3400.0
NG	10930.0	13458.0	12346.0	11783.0
Other Thermal	1122.0	1094.0	1094.0	1094.0
Renewable	775.7	3598.7	7910.7	12148.6
Pumped hydro storage	0.0	640.0	940.0	1240.0
Sum (excluding storage)	17092.7	21550.7	24750.65	28425.6
Sum (including storage)	17092.7	22190.7	25690.7	29665.6

Note that the Orot Rabin 1-4 units are also phased out in the mitigation scenarios. The main difference between the ambitious and conservative scenarios is the level of renewable deployment. Note that these tables do not include energy storage.

Table 78

Capacity in conservative and ambitious scenarios, before and after capacity credits

Conservative	Capacity	Capacity Value
Coal Steam Generator	3400.0	3400.0
NG CCGT	9551.0	8595.9
NG OCGT	1028.0	925.2
Cogeneration	1252.0	1126.8
Wind	800.0	200.0
Solar PV	7564.8	3119.6
Solar CSP	782.0	676.9
Other Renewable	198.6	158.1
Other	1046.0	941.4
Total	25622.4	19143.9

Ambitious	Capacity	Capacity Value
Coal Steam Generator	3400.00	3400.00
NG CCGT	9551.00	8595.90
NG OCGT	1028.00	925.20
Cogeneration	1252.00	1126.80
Wind	1050.00	262.50
Solar PV	8600.00	4140.60
Solar CSP	2300.00	2084.16
Other Renewable	198.60	158.10
Other	1046.00	941.40
Total	28425.60	21634.66

In the conservative scenario, the peak power requirements are 15.6 GW, whereas the requirements in the ambitious scenario are 15.2 GW, again taking account of the effects of energy storage in both cases. After taking account of capacity credit, the capacity is higher than the capacity that would be required to meet the reserve margin. The capacity after capacity credit is 19.1 GW in the conservative scenario and 21.6 GW in the ambitious scenario.

Table 79

Generation mix in conservative scenario

Fuels	2015	2020	2025	2030
Natural Gas	51.24%	72.21%	67.10%	64.59%
Diesel	0.03%	0.03%	0.03%	0.02%
Coal Bituminous	46.08%	16.15%	14.12%	12.26%
Biogas	0.33%	0.49%	1.19%	1.09%
Wind	0.03%	1.95%	2.42%	2.72%
Solar	2.19%	8.61%	14.30%	18.31%
Hydro	0.08%	0.07%	0.14%	0.19%
Refuse Derived Fuel	-	0.50%	0.44%	0.38%
Biomass	-	-	0.26%	0.45%
Total	**100.00%**	**100.00%**	**100.00%**	**100.00%**
of which renewable	2.6%	11.1%	18.3%	22.8%

Table 80 Generation mix in ambitious scenario

Fuels	2015	2020	2025	2030
Natural Gas	51.24%	72.20%	61.19%	54.31%
Diesel	0.03%	0.03%	0.03%	0.02%
Coal Bituminous	46.09%	16.15%	14.12%	12.26%
Biogas	0.33%	0.49%	1.19%	1.09%
Wind	0.03%	1.95%	2.91%	3.57%
Solar	2.19%	8.61%	19.37%	27.11%
Hydro	0.08%	0.07%	0.14%	0.19%
Refuse Derived Fuel	-	0.50%	0.44%	0.38%
Biomass	-	-	0.61%	1.06%
Total	**100.00%**	**100.00%**	**100.00%**	**100.00%**
of which renewable	2.6%	11.1%	24.2%	33.0%

The following table shows the split of electricity generation that is IEC, IPP cogeneration and IPP thermal plants in 2025 and 2030.

Table 81 Electricity generation in 2025 and 2030

Source	Output in 2025	Output in 2030
IEC	46.2%	44.3%
IPP Thermal	22.2%	20.6%
IPP Cogeneration	12.4%	10.8%
Other	19.2%	24.3%
Sum	100.0%	100.0%

The percentage of total abatement[70] that is cost-effective is 91.5%:

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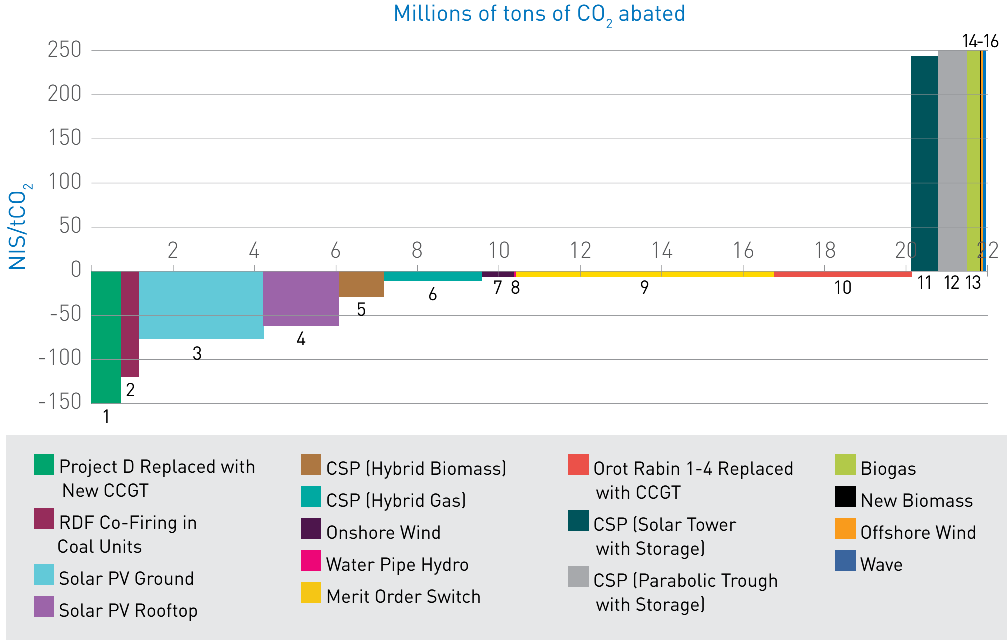
[70] Excluding the substitution of a new CCGT for Project D, as this is not applicable in the mitigation scenarios

Figure 21 Marginal abatement cost curve for the power sector for 2030, including externalities and costs of storage



The MACC is driven by the levelised cost of generation for each technology. These are listed below:

Table 82 Levelised costs for different generation technologies (NIS / MWh)

Technology	Levelised cost	Levelised cost of counterfactual (OCGT unless stated)
Wave	1,246	337
Offshore Wind	618	269
Onshore Wind	266	269
New Biomass	497	221
Biogas	389	218
CSP (parabolic trough with storage)	400	247
CSP (Solar Tower with Storage)	369	254
CSP (Hybrid gas)	215	218
CSP (Hybrid biomass)	204	218
Solar PV rooftop	303	333
Solar PV Ground	289	326
Water Pipe Hydro	216	219
Orot Rabin 1-4 replaced with CCGT	222	221[71]
Project D replaced with new CCGT	213	270[72]
RDF co-firing in coal units	223	224[73]
Merit Order Switch (operate CCGT instead of Coal, variable costs only)	143	145

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[71] Counterfactual in this case is continuation of Orot Rabin with the fitting of scrubbers
[72] Counterfactual is Project D
[73] Counterfactual is 100% coal fue

6.2.3 Observations

Steadily increasing demand for electricity is the strongest driver of emissions in the power sector. In the BAU scenario this leads to a stable trend towards 2030 - that is, the rate of growth in capacity is relatively constant to 2030.

Within the power sector, use of coal is an important factor behind the changes in emissions. This is revealed by the fall in emissions in the years between 2018 and 2020, when some coal units are closed for extended maintenance. This leads to a relatively large reduction in emissions as natural gas units are called upon to meet supply.

Along these lines, one of the most effective mitigation options is the merit order switch. As a cost-effective measure, the analysis reveals this to be a highly attractive mitigation option. The same is true of the replacement of Orot Rabin 1-4 with CCGT units.

In line with international experience, solar PV is a cost-effective mitigation option, whether ground- or roof-mounted. Hybrid concentrated solar power (CSP) are cost-effective, whether using natural gas or biomass as a secondary fuel. Traditional CSP units are not at all cost-effective, however, because of their high capital cost. The cost of localised storage will prove to be an important factor in the feasibility of solar power as a mainstay in the Israeli power sector, given the importance of energy security.

This analysis includes the cost of both localised storage and centrally located pumped hydro units in the cost of solar and wind generation capacity. These technologies are both forecast to be very affordable despite the additional system costs incurred by added energy storage.

The analysis reveals that onshore wind is narrowly feasible, from an economic perspective, whereas offshore wind has limited potential and is fairly expensive.

RDF is a highly effective mitigation option. The analysis only includes a 3% substitution of RDF for coal, due to limitations on the availability of waste as per the results of the waste sector model; should sufficient waste be available for 10% replacement (as per the total technical potential as provided by the PUA) then this could become a major mitigation option.

07

WASTE SECTOR

7.1 METHODOLOGY

7.1.1 BAU

Historically Israel had hundreds of small landfills, many of which were not properly managed. In 1993, a Government decision promoted reorganisation of the landfills, and smaller landfills were closed and 14 large regulated landfills were opened. These landfills are all required to have active landfill gas (LFG) capture and flaring equipment installed, which must be activated when the methane concentration crosses a certain threshold.

Production of electricity from LFG is incentivised via feed in tariffs and three currently operating landfills (Dudaim, Evron and Chagal-Talia) produce electricity and sell it to the grid. Together they have approximately 6 MW of generating capacity. Hiriya and Teenim landfills also transfer captured LFG to industrial plants for steam generation.

Emissions from disposal of waste to landfill are currently estimated in the GHG inventory on the basis of methane emissions per tonne of waste disposed of to landfill. However the CBS is planning to move to a more accurate first order decay (FOD) model to estimate emissions from landfill and this approach is therefore used for the projections for this report. The Intergovernmental Panel on Climate Change (IPCC) model provided as part of the IPCC 2006 GHG inventory guidelines has been used. This requires the quantity of waste disposed to landfill, waste composition data and methane recovery rates at landfills, for both historic years (1950 to present) as well as future years. The climate for regions where most landfills are located is assumed to be "tropical dry". More detailed information on the model can be found on 3.32 of the IPCC 2006 guidelines on solid waste disposal [74].

7.1.1.1 Waste deposited to landfill

Municipal waste generated per capita[75] is assumed to be as shown in Table 83, and waste compositions are shown in Table 84. Waste composition is assumed to change linearly between the years for which data is provided and is assumed to be unchanged between 1950 and 1975, and to remain unchanged from 2013 to 2030. Total waste generated is calculated by combining historical population data and population forecasts (from CBS) with waste generated[76] per capita for 1950 to 2004. For the period 2004 to 2013 total amounts of waste generated are available directly from data from CBS.

Information on the quantity of waste landfilled between 2004 and 2013 is available from landfill levy data. For some years (2004, 2005 and 2007), quantities of waste landfilled are greater than waste generated, and so for these years the quantity of waste deposited in landfills is based on the landfill levy data on quantities. By 2013, 81% of waste generated is disposed of to landfill. Prior to 2004, it is assumed that all waste went to landfill.

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[74] http://www.ipcc-nggip.iges.or.jp/public/2006gl/pdf/5_Volume5/V5_3_Ch3_SWDS.pdf.

[75] Assumed to be household, yard and commercial waste.

[76] This may be due to data inaccuracies or additional sources of waste (e.g. industrial waste may be landfilled).

Looking forward, quantities of waste disposed of to landfill, and the composition of that waste, are estimated by subtracting the following four components from the quantities of waste generated:

1. Food and garden waste going to planned composting and anaerobic digestion facilities. This is based on a list of recycling facilities (provided by MoEP solid waste division, which are already approved and budgeted)[77]
2. Recyclables separated from dry waste at transfer stations (data provided by MoEP)
3. Waste (mainly fractions with a high calorific value such as wood, plastic, textiles, cardboard and paper) going to the planned RDF facility at Hiriya
4. Recycling of packaging waste due to implementation of the Packaging Act. Packaging waste is assumed to make up 23% of total waste, and 60% recycling is achieved.
5. This results in the quantities of waste going to different treatment options, as shown in Table 85

Table 83 Waste generated per capita

Year	2012 kg/capita/day	2020 kt CO_2 e
1950 to 2003	Rises linearly from 1 kg per capita per day to 2004 value	Assumption provided by MoEP's solid waste division
2004 to 2013	1.59 rising to 1.69 kg per capita	CBS (data from Tables 27.16 and 27.17 of the Statistical Abstract of Israel on Solid Household Waste, Commercial and Yard waste)
2014 to 2030	1.7 kg per capita	Assumption provided by MoEP's solid waste division

Table 84 Waste composition

Year	1975	1983	1986	1995	2005	2013
Paper and cardboard	16.86%	17.33%	21.05%	23.95%	25.02%	24.40%
Textiles	3.52%	3.90%	3.60%	3.61%	3.86%	4.40%
Processed wood	-	-	-	-	0.87%	1.60%
Organic non-food (garden waste, etc.)	-	-	-	5.66%	3.39%	2.30%
Organic - food	64.82%	60.40%	49.16%	37.81%	36.35%	34.40%
Nappies	-	-	-	4.29%	5.04%	5.50%

Source: MoEP

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[77] See Appendix 5 for a list of the facilities.

Table 85 Waste composition

		2014	2020	2025	2030
Population	thousands	8,224	9,117	9,845	10,620
Waste per capita	kg/capita/day	1.7	1.7	1.7	1.7
Waste generated	kt	5,103	5,657	6,109	6,590
Of which		-	-	-	-
Organic waste	kt	1,873	2,076	2,242	2,418
Dry recyclables	kt	2,470	2,738	2,957	3,189
Waste management		-	-	-	-
Waste to organic treatment facilities	kt	341	1,899	1,899	1,899
Recycling packaging waste	kt	587	781	843	909
Recycling other	kt	35	221	234	234
RDF production	kt	-	183	183	183
Landfill	kt	4,139	2,574	2,950	3,365

7.1.1.2 Landfill characteristics

Prior to 2000, landfill sites are assumed to be poorly managed and to have a Methane Correction Factor (MCF) in the model of 0.6 (assumption provided by MoEP). Since 2000, sites have been managed better, and from 2004 onwards, the MCF for all sites is assumed to be 1.0. Between 2000 and 2004 a linear transition between poorly managed and better managed sites is assumed.

Data on methane captured at active landfill sites for the period is available from MoEP, and from the closed Hiriya landfill from monitoring for Clean Development Mechanism purposes. In 2013, total methane captured was 7.8 kt, or 5% of methane generated. Recovery rates for active landfills are assumed to continue at current rates; capture at the closed Hiriya landfill has already begun to decline and is assumed to continue to decline, falling to around two-thirds of current levels by 2020 and 40% of current levels in 2030[78].

Using the above methodology and data gives an estimate of methane emissions from solid waste disposal in 2012 of 156 $ktCH_4$ (3,276 $ktCO_2$ e) compared to the current estimate in the inventory of 214 $ktCH_4$. The estimate made here is lower due to the change to a more complex, time dependent model for methane generation in landfill. The revised estimate presented here is 4% of total national emissions in 2012.

7.1.1.3 Emissions from waste water

Emissions from waste water in 2012 were 986 $ktCO_2e$, which is 1% of total emissions. Emissions from household waste water are estimated on the basis of population, estimates of biochemical oxygen demand (BOD) per day generated, and protein consumed per day.

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[78] Estimates of gas recovered are based on expected decline in gas production assuming that the site received waste every year it was operational i.e. from 1954 to 1998, and the fraction of gas produced which is recovered remains constant at current levels.

All domestic waste water is assumed to go to the sewer system. Future emissions of domestic waste water are estimated based on the growth in population. Future industrial waste water emissions are estimated assuming that waste water volumes increase in line with GDP growth.

Table 86 Emissions from waste water (2012)

Source of waste water	kt CO_2 eq
Household waste water (CH_4)	136
Household waste water (N_2O)	247
Industrial waste water (CH_4)	603
Total	986

Source: Data from CBS

7.1.2 Mitigation

Israel has already taken or is currently implementing a number of actions in the waste sector which will reduce greenhouse gas emissions and these are included in the baseline scenario:

- Methane capture and recovery at landfill sites
- Aggressive program to reduce landfilling, based on:
  - Separation of Municipal Solid Waste at the source as well as at transfer stations for recycling
  - Composting and anaerobic digestion (AD) of organic food and garden waste
  - Introducing extended producer responsibility legislation ("producer pays"), such as the Packaging Law requiring recycling of 60% of packaging waste.
  - Production of RDF for use as a fuel

Overall, these measures are expected to lead to a reduction in the percentage of waste going to landfill to 44% by 2018, although after this the increase in waste generated outstrips the growth in facilities for recycling and composting/AD so that by 2030, 51% of waste is going to landfill.

Additional mitigation measures which could be considered are described below.

7.1.2.1 Improved capture and oxidation of landfill gas

Efficient capture and combustion of landfill gas, either through flaring or using to generate electricity or heat, is typically one of the most cost-effective options which can be implemented in the waste sector. While legislation is in place to require this in Israel, the data provided indicates that only 5% of landfill gas generated is actually being captured, suggesting that there is considerable scope to increase this.

It is assumed that:

- Landfill gas recovery and combustion is most viable at the new larger regulated landfills. The FOD model used to estimate total emissions of landfill was rerun for only the new larger landfills[79], to estimate quantities of landfill gas generated now, and into the future in these landfills.
- Any of the new landfill sites which reach capacity and close are replaced with a new, large, regulated landfill site; similarly additional landfill capacity is assumed to be added as required.
- The average landfill gas capture rates at sites could be raised from current levels (6 kt of methane per year or 4% of landfill gas generated) to 50%. Higher rates of landfill gas capture can be achieved (e.g. up to 70% in modern landfills) but a conservative estimate has been used, as the actual capture rate which can be achieved at a site is influenced by specific aspects of the landfill design, and e.g. whether gas recovery infrastructure was installed at the time of construction or is retrofitted.
- Landfill gas captured is burnt in a gas engine to generate electricity which is exported to the grid. Raising the landfill gas capture rate to an average of 50% would allow installation of about another 40 MW of gas engines[80]. Landfill gas can also be exported and used to produce heat, but this requires that a suitable heat user is located close to the site, so may not be viable at all sites.

It is estimated that implementation of this measure would reduce methane emissions from landfills by 76.5 kt CH_4 in 2020 and 77.1 kt CH_4 (1.6 Mt CO_2) in 2030.

As this measure generates electricity, it is also included as a mitigation measure in the power sector. Costs were sourced from the PUA.

7.1.2.2 Additional composting and anaerobic digestion facilities

While existing planned plants have the capacity to deal with organic waste arising up to 2020, by 2025, the modelling of waste arising done to support the calculation of landfill emissions suggests there would be sufficient organic waste in the waste stream from 2025 onwards to support additional facilities.

It is assumed that:

- The additional plant built are anaerobic digestion plant utilising food waste as a feedstock and generating electricity from the biogas produced
- The capture rate for organic waste is 90%. This means that 260 kt of food waste is available as a feedstock in 2030[81].
- This could support 8 MW of generation (based on typical biogas yields from food waste)[82]; it is likely that this would be comprised of several smaller plant.

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[79] This was done by only modelling waste deposited from 2000 onwards.

[80] It is assumed that each MW of gas engine installed would combust 1655 tonnes of methane per year if it ran at full load and availability

[81] This is based on quantities of food waste arisings which could be collected, after allowing for food waste going to currently planned and constructed facilities which are allowed for in the BAU scenario

[82] Based on 0.03 Mw of generating capacity per kt per annum of food waste input

It is estimated that every kilotonne of food waste diverted away from landfill prevents the emission of at least 0.02 kt CH_4 from a landfill site[83]. This reduction in emissions occurs over a number of years as the methane generated as the food waste decomposed in a landfill would occur over a number of years. The value of 0.02 kt CH_4 methane saving per kt food waste is thus the cumulative saving in methane emissions from landfill over the next 20 years. It assumes that the mitigation measure described above (increased capture of landfill gas) has already been implemented.

Assuming that half of the new AD capacity was operational by 2026, then the actual reduction in landfill emissions in 2030 which could be achieved through this measure is 2.3 kt CH_4 (47.3 kt CO_2 eq).

As this measure generates electricity, it is also included as a mitigation measure in the power sector and its cost-effectiveness is calculated there, based on the costs of an AD plant and gas engine.

7.1.2.3 Additional Refused-Derived Fuel (RDF) production facilities

The planned Hiriya plant will produce 180 kt of RDF from residual waste, which will be used as a fuel in the cement industry. Construction of this plant and diversion of waste from landfill to this plant is allowed for in the BAU scenario. However, even after construction of this plant, and of planned recycling and AD and composting facilities, large amounts of residual waste are still projected to be landfilled in the future (2.3 Mt in 2002, 2.5 Mt in 2025 and 2.7 Mt in 2030). There is therefore the potential to construct more RDF plants in the future. Assuming that these are similar to the planned plant, which takes in 540 kt of residual waste to produce 180 kt of RDF, it is estimated that a further 1.9 Mt of residual waste could be diverted to new RDF plant, producing an additional 650 kt of RDF. It is assumed that this is used as fuel in cement sector.

7.2 RESULTS

7.2.1 BAU

In the BAU scenario emissions are forecast to increase by 16% between 2014 and 2030, from 4.3Mt CO_2e to 5.0 Mt CO_2e (see Figure 22). This is mainly due to an increase in emissions from waste water treatment, due to increasing levels of water requiring treatment due to an increasing population. Emissions from solid waste disposal (landfilling of waste) remain relatively constant, as the increase in waste generated due to an increasing population is largely offset by the diversion of organic waste from landfill into planned composting and anaerobic digestion (AD) facilities and a facility producing refuse derived fuel (RDF).

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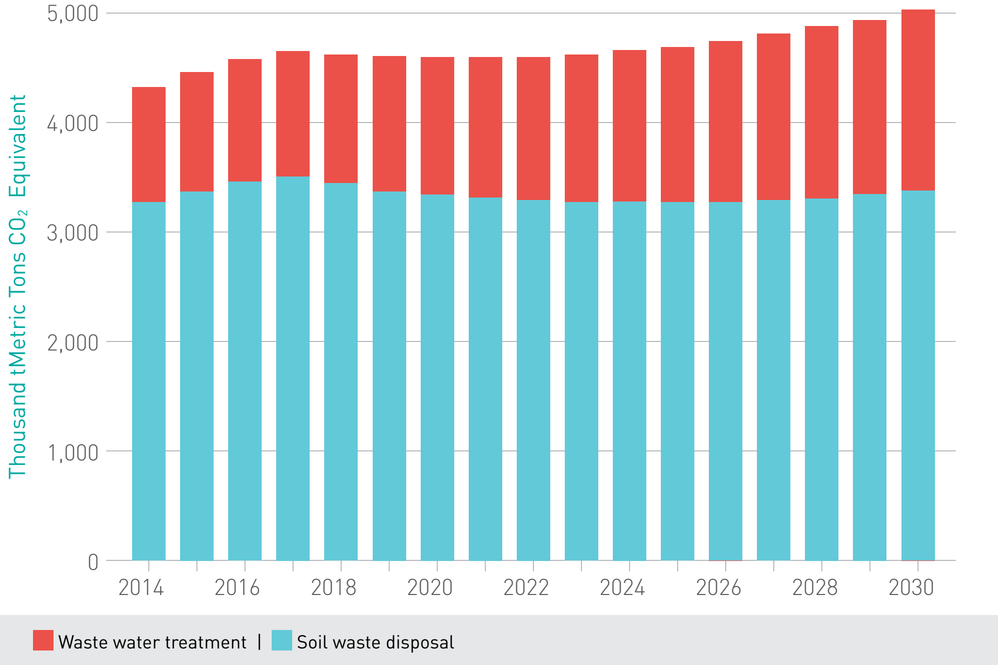
[83] This value was calculated by estimating emissions from disposal of a tonne of food waste in the same IPCC FOD model used to estimate total landfill emissions.

Figure 22 **BAU emissions from waste**



7.2.2 Mitigation

The emissions savings in 2030 from the three waste mitigation options identified are shown in Table 87. Implementing recovery and combustion of landfill gas (to generate electricity) reduces the emissions associated with landfilling organic waste, as well as providing a low carbon source of electricity. It is assumed that overall 50% of landfill gas emissions can be recovered and combusted. The savings shown in Table 87 are those associated with reducing emissions from the landfill site itself; emission savings associated with using this electricity to replace electricity based on fossil fuel generation are accounted for in the power sector MACC. Emissions savings associated with anaerobic digestion of food waste, and production of biogas which is then used to generate electricity are treated similarly i.e. the table shows only emissions savings from avoiding landfilling of the waste. Savings are shown for each option if it was to be the only option implemented and the savings which would be achieved if all options are implemented. Savings from landfill gas recovery are reduced when AD and RDF are implemented as less organic waste goes to landfill, so less landfill gas is generated and is available for recovery. Savings from AD and RDF production are reduced as the amount of landfill gas production which is avoided is reduced if landfill gas recovery is in place. Overall total estimated savings in 2030 are 1.6 Mt CO_2e, which would reduce emissions in 2030 to about two-thirds of their levels in the BAU scenario.

The cost-effectiveness of these recovery of landfill gas and use of food waste in AD plants is not reported here, as the costs of electricity generation from these sources is included in the power sector. Therefore, a MACC for this sector was not included.

Table 87 Emissions savings from waste mitigation options in 2030

Measure	Saving if implemented in isolation (kt CO_2e)	Saving when implemented with other waste measures (kt CO_2e)
Recovery of landfill gas and use for electricity generation	1619	1117
Waste diverted from landfill to RDF production	958	498
Food waste to AD plant for biogas production	47.3	23.7
Total potential emissions savings		**1638**

7.2.3 Observations

Emissions in the waste sector can be significantly reduced through the use of these three measures, all of which are based on technology already in place in Israel. Increased use of landfill gas recovery and utilisation of the biogas for electricity (or heat generation) could generate substantial savings, and is typically a very cost-effective measure, which is widely implemented in countries with regulated landfills. Savings from the introduction of AD plants for food waste are relatively small, as a large number of such plants are already proposed, and have been included in the BAU scenario. The quantities of waste which are landfilled in the BAU scenario, as well as once these measures are implemented, are shown in Table 88. For comparison, it is estimated that in 2014, of 5,103 kt of waste generated 81% was landfilled.

Table 88 Quantities of waste generated and landfilled in 2030

	kt	% landfilled
Waste generated	6,590	
Landfilled in BAU	3,365	51%
Conservative scenario		
Organic waste to AD plants	260	
Residual waste to RDF plant	1,944	
Landfilled in conservative scenario	1,161	18%

08

AGRICULTURE, FORESTRY & LAND USE

8.1 METHODOLOGY

8.1.1 BAU

In 2012 non-energy related emissions from agriculture were 1,900 kt CO_2 eq and accounted for 2.3% of national emissions. The forestry sector led to removals of 514 kt of CO_2.

Emissions from agriculture predominantly arise from enteric fermentation (39%) and direct emissions from soil (37%) - see Table 89. Enteric fermentation emissions are emissions from ruminant livestock, and in Israel, come from dairy cows (55%), other cattle (30%) and sheep (13%) and goats. Direct emissions of N_2O from soils arise mainly from use of nitrogenous fertilisers (27%), manures spread on fields (25%), incorporation of crop residues into fields (20%) and from cultivation of mineral soils (15%). More minor sources are manure deposited on the fields during grazing, and compost and sludge spread to fields.

Table 89 Agricultural emissions 2012

IPCC category	Source of emissions	CH_4 kt CO_2e	N_2O kt CO_2e	Total kt CO_2e	Share
3A1	Enteric fermentation	736		736	39%
3A2	Manure management	58	136	194	10%
3C4	Soil direct emissions		706	706	37%
3C5	Soil indirect emissions		222	222	12%
3C6	Indirect emissions from manure management		42	42	2%
	Total	794	1106	1900	100%

Source: Data from CBS

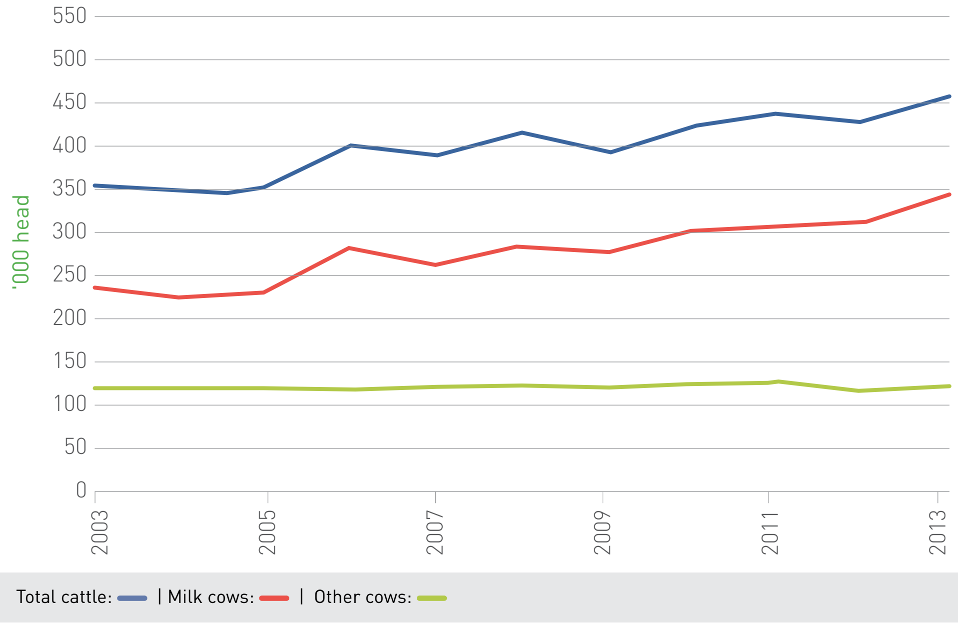
Key categories for projecting forward are thus, enteric fermentation (focussing on cattle) and emissions from soils caused by fertiliser applications, manure management and incorporation of crop residues.

It should be noted that emissions from agriculture can be quite variable on a year on year basis, due to variability in climate leading to changes in harvests.

8.1.1.1 Emissions from enteric fermentation

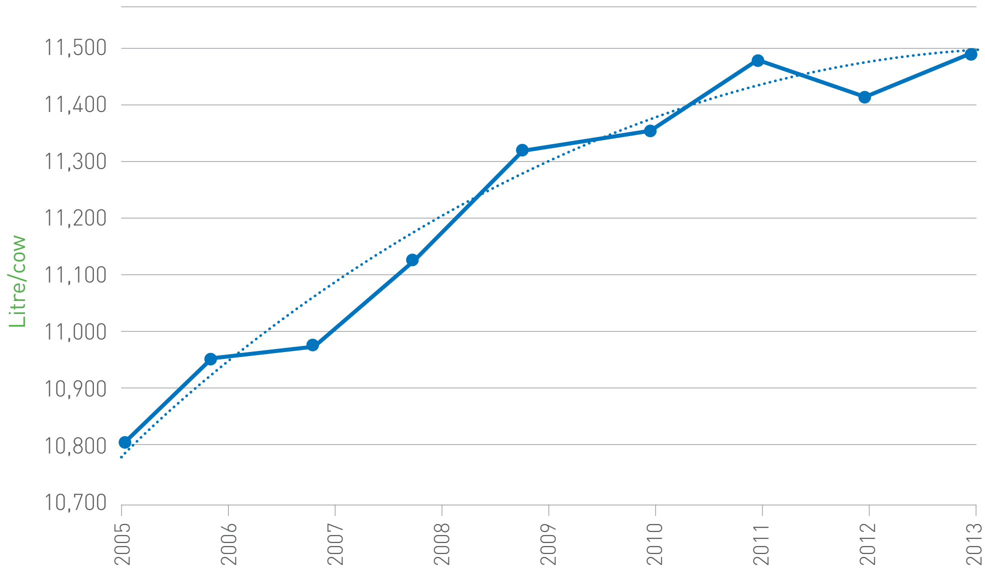
As can be seen from Figure 23, while the number of milk cows has remained approximately constant over the period 2003 to 2013, the number of other cows has increased, showing an average annual growth rate over the period of 3.7%. Enteric emissions from cattle are also affected by the gross energy intake of the cattle, which for dairy cattle is typically related to milk yield. This has increased in the past (Figure 24) but appears to be plateauing; using 3 year average figures, the latest rate of increase is only 0.3%. Emissions factors currently used in the GHG inventory for Israel for enteric emissions from dairy cows, and other cattle, are calculated to reflect Israel specific conditions.

Figure 23 Cattle numbers (2003 to 2013)



Source: CBS. Data is estimated for 2010 to 2013.

Figure 24 Milk yield



Source: Data from CBS

Based on this data the following assumptions (see Table 90) were made to forecast emissions from enteric fermentation.

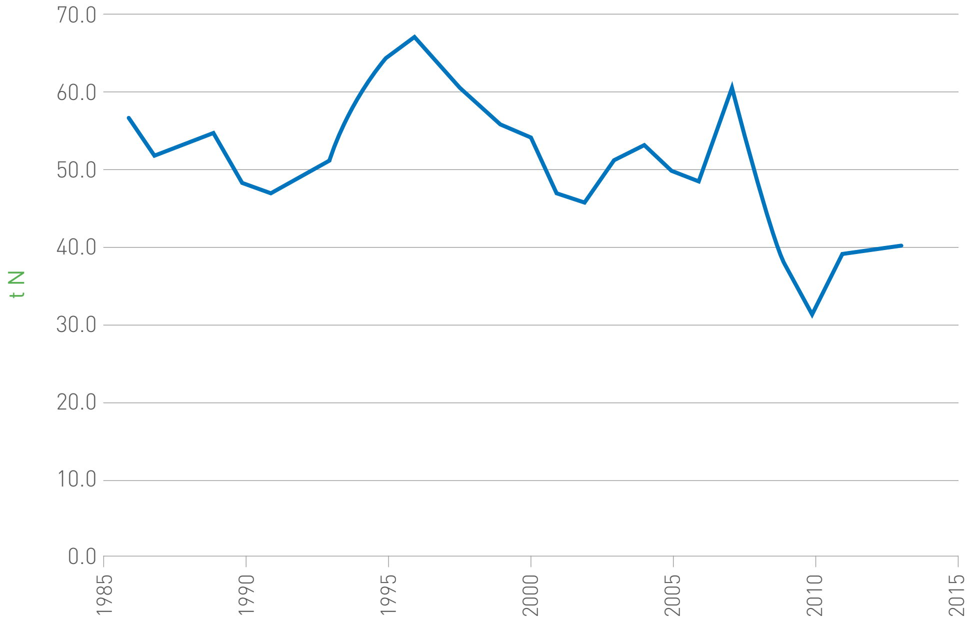
Table 90 Proposed projection of parameters for enteric fermentation

Category	Number of animals	Emission factor
Dairy cattle	Kept constant	Increases at 0.3% (on basis of recent milk yield increases) to 2020 and then remains constant
Other cattle	Increases at 4% p.a. to 2030 (based on recent rate of growth)	Kept constant to 2030
Other ruminants[84]	Kept constant to 2030	Kept constant to 2030

8.1.1.2 Emissions from soils

Emissions of N_2O from soils (both direct and indirect) are mainly the result of nitrogen applied to the soil, either as nitrogenous fertilisers, in sludge or compost, or manure - either spread directly or from grazing animals, or from crop residues incorporated into the soil. The quantities of chemical nitrogenous fertiliser used shows considerable fluctuation year on year (see Figure 25), but is generally decreasing and this may be related to a small downward trend in the area devoted to field crops. Trends in the amount of compost and sludge applied to the soil are not available.

Figure 25 Annual applications of nitrogenous fertiliser



Source; Statistical Abstract of Israel, 2014 (CBS)

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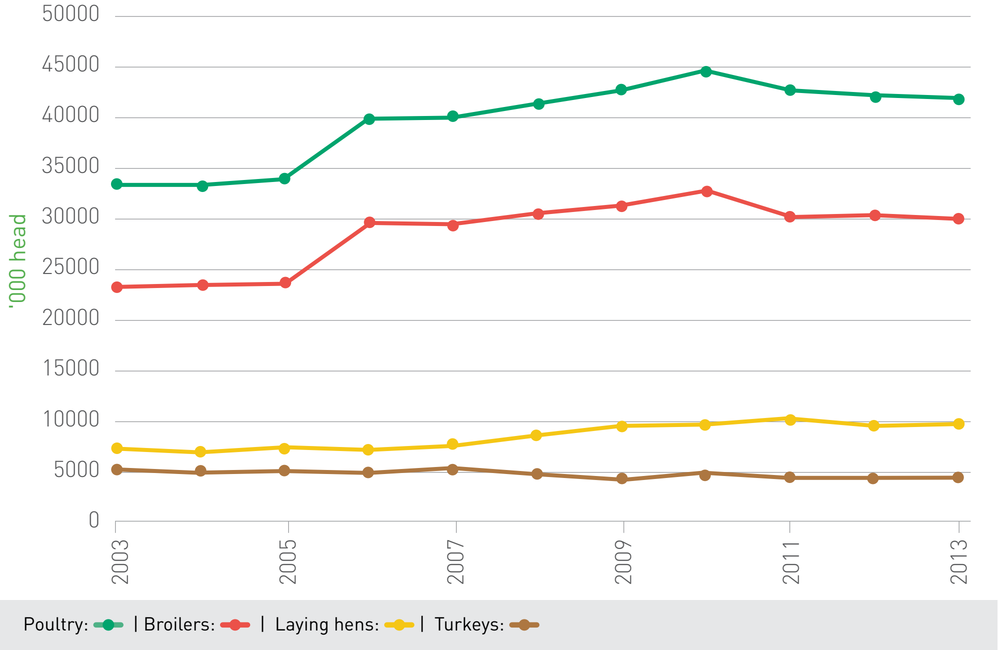
[84] As other ruminants account for only a small proportion of enteric fermentation emissions, a simplifying assumption was made that the number of other ruminants would remain constant until 2030.

No specific changes are expected in the agricultural sector, in terms of changes to crops grown etc. It was therefore assumed that future emissions from the application of fertiliser to the soil are held constant. Similarly applications of sludge and compost are assumed to remain unchanged in the future.

Emissions from manure applied to land (either spread or from grazing animals) arise predominantly from cattle manure and poultry manure. Assumptions about changes in cattle population were discussed above. Poultry numbers (Figure 26) generally rose in the period 2003 to 2010, but have subsequently declined again. The number of poultry has been assumed to remain constant at 2012 levels until 2030. Similarly other categories of livestock whose manure is responsible for only minor N_2O emissions have been assumed to remain constant.

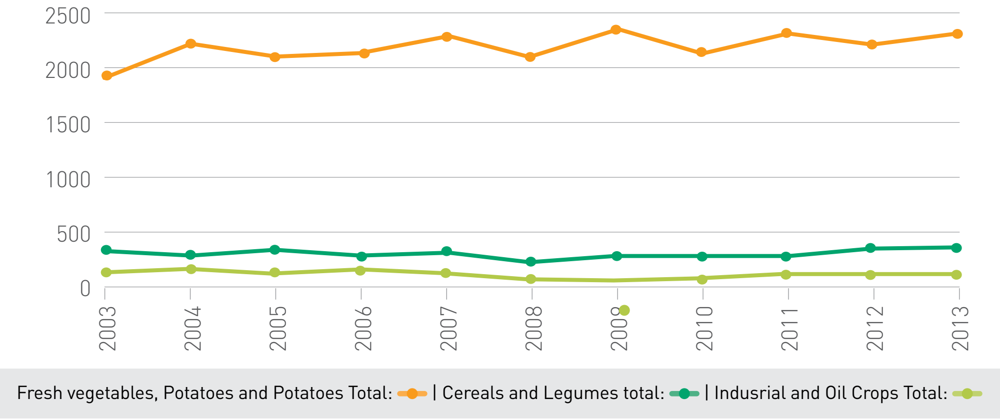
Figure 26 Poultry population



Source; Statistical Abstract of Israel, 2014 (CBS)

The incorporation of crop residues into the soil also leads to N_2O emissions. While no direct historical data is available on the quantity of residues incorporated into the soil, historical production data indicates that the quantity of field crops and vegetables produced in the period 2003 to 2013 was relatively constant (Figure 27). Emissions from this source are therefore assumed to be constant at 2012 levels from 2012 to 2030.

Figure 27 Crop production



Source; Statistical Abstract of Israel, 2014 (CBS)

Proposed assumptions for sources of emissions from soils are summarised below in Table 91.

Table 91 Assumptions for emissions from soils out to 2030

IPCC category	Source of emissions	kt CO_2e	%	Assumption
3C4	Synthetic fertilisers - direct	189	19%	Constant from 2012 to 2030
3C5	Synthetic fertilisers - indirect	61	6%	Constant from 2012 to 2030
3C4	Compost - direct[85]	33	3%	Constant from 2012 to 2030
3C5	Compost - indirect	14	1%	Constant from 2012 to 2030
3C4	Sludge - direct	8	1%	Constant from 2012 to 2030
3C5	Sludge - indirect	3	0%	Constant from 2012 to 2030
3C4	Crop residues - direct	139	14%	Constant from 2012 to 2030
3C5	Crop residues - indirect	56	6%	Constant from 2012 to 2030
3C4	Manure spread on the field - direct	175	18%	Portion from other cattle increases at rate of 4% p.a. as for enteric emissions projection; remainder is constant from 2012 to 2030
3C5	Manure spread on the field - indirect	74	8%	Portion from other cattle increases at rate of 4% p.a. as for enteric emissions projection; remainder is constant from 2012 to 2030
3C4	Manure field grazing - direct	48	5%	Portion from other cattle increases at rate of 4% p.a. as for enteric emissions projection; remainder is constant from 2012 to 2030
3C5	Manure field grazing - indirect	13	1%	Portion from other cattle increases at rate of 4% p.a. as for enteric emissions projection; remainder is constant from 2012 to 2030
3C4	Agricultural land	6	1%	Constant from 2012 to 2030
3C4	Mineral soils	108	11%	Constant from 2012 to 2030
3C6	Manure management - indirect	42	4%	Portion from other cattle increases at rate of 4% p.a. as for enteric emissions projection; remainder is constant from 2012 to 2030
	Total	969.727	100%	

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[85] Given the increase in the number of composting and AD facilities in the waste sector, it is possible that compost spread to land may increase. However this is highly dependent on the quality of the compost produced, and some compost form such facilities may only be suitable or land restoration activities. It has therefore been assumed that quantities of compost applied to soils remains constant to 2030. Any underestimation of future emissions introduced by this assumption will be small as total emissions from compost applications are only 4% of total agricultural emissions.

8.1.1.3 Emissions from manure management

Emissions from manure management are driven by quantities of 1) manure produced which is related to animal numbers and the quantity of manure excreted daily (which is in turn related to diet and size of animal), and 2) to the way that manure is managed. Factors that are important to controlling emissions are whether animals are housed inside and manures stored in dry or liquid form. As far as could be established no changes are expected in the way livestock are housed, or changes in manure management practices, so the only changes forecast in emissions from manure management will be driven by changes to the number of livestock discussed above.

8.1.1.4 Emissions from forestry

Emissions from forestry are the net sum of carbon uptake due to biomass growth in forests, and carbon losses due to removal of harvested biomass from forests. No information was found to suggest that either afforestation or harvest rates are forecast to change in the period to 2030, therefore net emissions from this source are assumed to remain constant at 2012 levels (a net uptake of 514 ktCO$_2$ per year).

8.1.2 Mitigation

A number of mitigation measures have been suggested both internationally and within Israel for use in the Agricultural and Forestry Sector. Table 92 below lists these along with comments on whether they are appropriate for further consideration in Israel.

Table 92 Potential mitigation options for inclusion in MACC curves

Source	Option	Comment
Enteric fermentation	Changes to diet, and use of vaccine to reduce methanisation in the gut	A number of dietary improvements have been suggested which could theoretically help to reduce enteric emissions. They offer the most potential where livestock diets are not currently well optimised. For herds where nutrition is already well managed, reductions in GHG emissions are likely to be more marginal, and require a detailed understanding of current diet before the potential impact can be assessed. The development and use of a vaccine to reduce methanisation in the gut has also been suggested as a possible option for reducing enteric emissions. However the effectiveness of this option is likely to decline over time, and this has not been adopted as a mitigation option yet.
Manure management	Improved manure management systems, and use of biogas digesters for management of slurries	Anaerobic digestion of slurries rather than storage in lagoons or pits, can reduce methane emissions as well as produce electricity, helping to reduce emissions from the power sector. Applicability of this option will depend on number of farms using liquid manure management systems, and there is a minimum size threshold for these systems.
N$_2$O from managed soils from synthetic fertilisers	Fertiliser use: type, dose, placement, timing, adjuvants	A variety of precision farming options can help to reduce quantities of nitrogen applied, as can the use of nitrification inhibitors.
Afforestation	Increase in afforested area to increase carbon uptake	This is not a suitable option for Israel as largest areas of suitable land are not available. In addition the carbon sequestered could be released if forest areas are not maintained.

Two measures were deemed most appropriate in Israel and were taken forward for assessment and inclusion in the mitigation scenarios - use of nitrification inhibitors and anaerobic digestion of animal wastes. Key assumptions used to assess mitigation potential and cost-effectiveness are detailed below.

8.1.2.1 Use of Nitrification Inhibitors

There has been much recent research on these which has shown them to be quite effective in reducing GHG emissions. For example Misselbrook et al., (2014) concluded that the nitrification inhibitor dicyandiamide (DCD) could reduce N_2O emissions from UK agriculture by 20%. They cited an abatement estimate of 50% for New Zealand. Zaman et al., (2008) reported that nitrification inhibitors reduced N_2O emissions following application of urea by 38%.

The efficiency of nitrification inhibitors is likely to be less in Israel as the persistence of nitrification inhibitors in soil is reduced under warm and wet conditions. Although Israel is generally drier than the UK or NZ, significant areas of crops are irrigated.

The cost-effectiveness of using nitrification inhibitors can be very poor. Schulte and Donnellan (2012) carried out a Marginal Abatement Cost Curve (MACC) analysis of GHG abatement options for Irish Agriculture and concluded that the use of nitrification inhibitors was cost-prohibitive. Similarly Adler et al (2013) who looked at the use of nitrification inhibitors to reduce emissions from dairy farming in New Zealand also found that it was not a cost-effective option.

The cost of using nitrification inhibitors has also been considered in the UK (SAC, 2008) and in France (INRA, 2013). These two studies found a cost-effectiveness of 1071 and 291 NIS/t CO_2 e respectively. In the case of the UK, it was estimated that use of the inhibitors could reduce emissions of N_2O from soils by 2.8 % and in the case of France by 5.1%. As there is no direct assessment of the effectiveness of using nitrification inhibitors in Israel, a conservative approach is taken in using the results to these studies to estimate the cost-effectiveness and mitigation potential of their use. Cost-effectiveness is taken as the higher cost from the two studies (i.e. 1071 NIS/t CO_2 e) and the mitigation potential is taken as 2.8% of agricultural soil emissions. It is assumed that nitrification inhibitors could be introduced from 2019 (thus allowing for time to demonstrate their efficiency) reaching full implementation potential by 2023. This gives emissions reduction of 2.1 kt CO_2 e in 2020 and 5.3 kt CO_2 e in 2025 and in 2030.

8.1.2.2 Anaerobic digestion of animal wastes

The anaerobic digestion (AD) of animal excreta produces biogas which can then be burnt to produce electricity and/or heat. This not only reduces GHG emissions by avoiding the use of fossil fuels for heat and electricity production, but also reduces emissions by avoiding emissions from the storage of excreta. The GHG savings are greatest for wastes which would have otherwise been stored anaerobically for some time, leading to substantial methane emissions; savings from using manures in solid form, which might otherwise have been spread daily, are much smaller.

Typically a minimum number of livestock are required on a farm for an on-farm small-scale AD plant to be viable; even with larger centralised plant, a certain size of farm is required to make transport of the slurry to the plant on a regular basis viable. In the case of swine, livestock are concentrated in 20 large farms (Dov et al, 2014), so it is assumed that all swine excreta could be used for biogas production. Similarly the dairy industry has intensive production, mainly in large scale units, with 56% of cattle in 185 co-operative farms, with an average of 330 cows per farm[86]. It is therefore assumed that at least 50% of cattle excreta could be available for biogas production. Finally it is assumed that a significant proportion of poultry is kept in large farms, so that 50% of poultry excreta could also be available. It is estimated that these manures would provide enough feedstock for 34MW of biogas generation in anaerobic digestion plant.

While information on the type of manure management system used by livestock type is available from CBS as used for the GHG inventory compilation, it is not known if type of manure management system varies by farm size. It is therefore assumed that the fraction of excreta diverted to AD systems for biogas production is the same for all manure management systems. This reduces emissions from manure management by 1445 t CH_4 per year; allowing for 1% leakage of biogas from AD plants (equivalent to 619 t CH_4), the net emissions reduction would be 827 t CH_4, (17 kt CO_2 e). It is assumed that AD plant could be constructed after 2020, with all in place by 2025.

8.2 RESULTS

8.2.1 BAU

In the BAU scenario emissions from agriculture are forecast to increase by 16% between 2014 and 2030 (see Figure 28) from 1.9 to 2.25 Mt CO_2 e. This is due to the projected increase in non-dairy cattle numbers which increases emissions from enteric fermentation, manure management and soils (due to increases in the amount of manures spread to land). Forestry is a carbon sink, absorbing 0.5 Mt of CO_2 every year. This means that net emissions from the AFOLU sector are 1.74 Mt CO_2 e in 2030.

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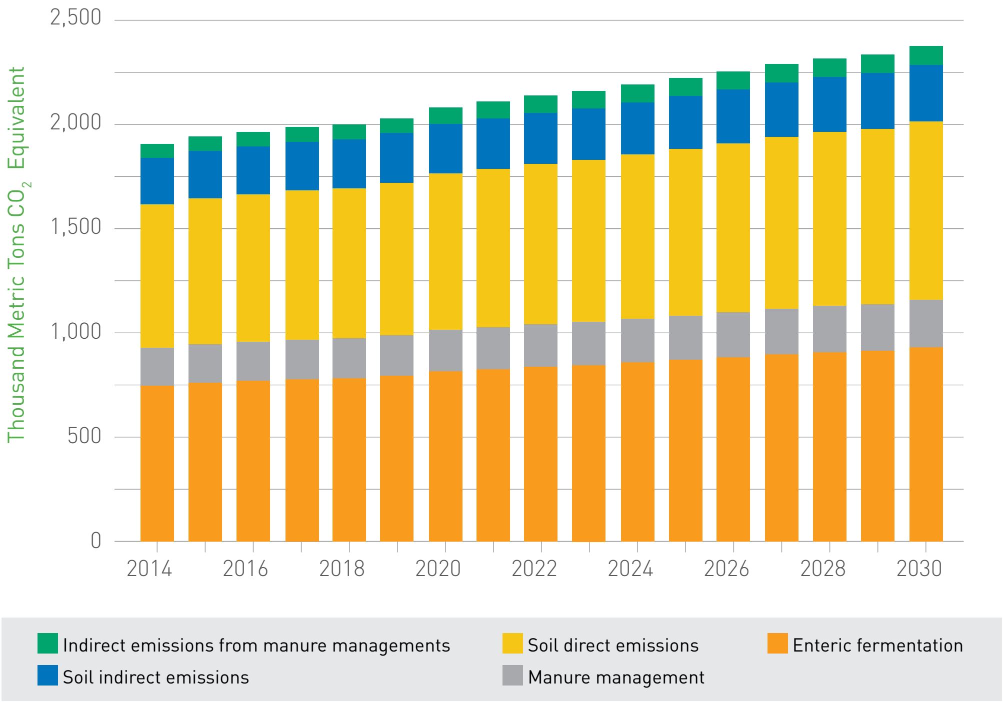
[86] Data from Israeli Herdbook Report, 2005 reported in presentation 'Advanced technologies allows small. Dairy farms in Israel to be competitive' by I. Flamenbaum, Ministry of Agriculture & Rural Development Extension Service, Cattle Division.

Figure 28 **BAU emissions from agriculture**

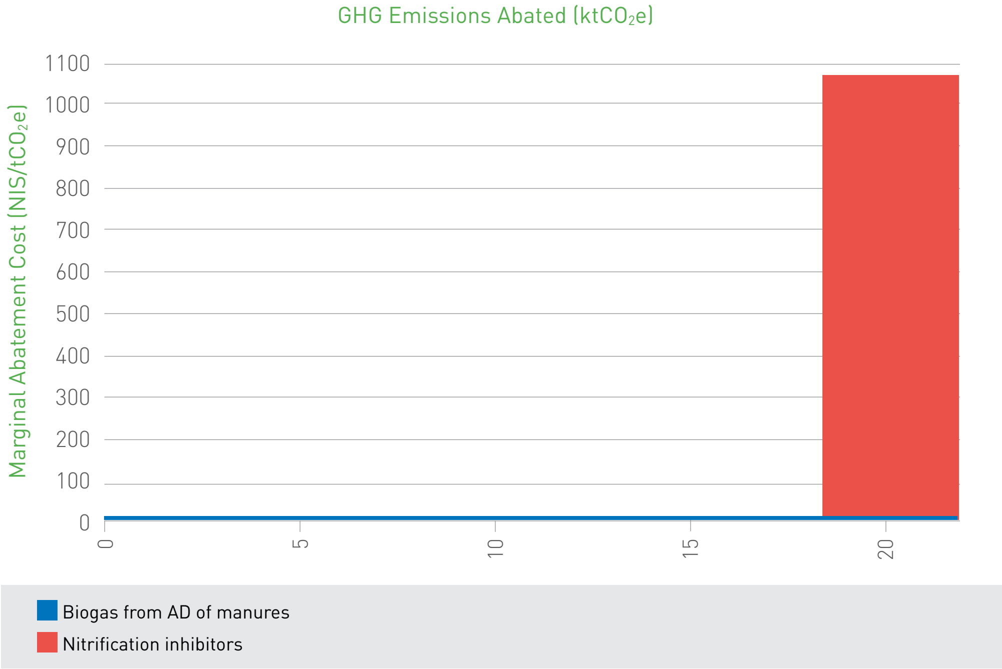


8.2.2 Mitigation

Two mitigation measures were evaluated, the use of nitrification inhibitors to reduce N_2O emissions from soils, and the use of AD plant to digest manures and produce biogas for electricity generation. Emissions savings from AD are treated in the same way as in the waste sector, i.e. only emissions savings achieved from putting animal wastes into the AD plant, rather than treating in other ways are included in the MACC, and savings from the 'carbon-free' electricity generation are included in the power sector MACC. As in the waste sector analysis, the cost of biogas generation from manures is not reported here, as the costs of electricity generation from these sources is included in the power sector.

In total, the measures on the MACC are estimated to deliver 23 ktCO_2e of savings in 2025 and in 2030 (see Figure 29).

Figure 29 Marginal abatement costs in the agricultural sector



8.2.3 Observations

Mitigation measures identified in the agricultural sector deliver very small savings, and are projected to reduce agricultural emissions in 2030 by only 1%, although the production of biogas from manures, will also lead to additional emissions savings in the power sector. The cost-effectiveness of nitrification inhibitors is very poor, at over 1000 NIS/t CO_2e (see Figure 29).

09

OTHER NON-ENERGY SECTORS

9.1 INDUSTRIAL PROCESS EMISSIONS

9.1.1 BAU

9.1.1.1 Clinker production

Carbon dioxide is emitted during the production of clinker by Israel's sole cement manufacturer, Nesher Cement Enterprises. Future emissions are estimated assuming that cement production grows as assumed in the industry sector projections for pet coke consumption. The emissions factor (CO_2 per t clinker produced) is as used in the GHG inventory produced by the CBS.

9.1.1.2 Lime production

Carbon dioxide emissions from lime production are estimated by CBS on the basis of lime production figures. Data from 2010 to 2013 for lime production were provided by the Ministry of Economy and show an upward trend in lime production, with an average increase of 1% year on year. Emissions are therefore forecast forward on the basis of a 1% per annum increase in emissions from 2013 to 2030, using the same emissions factor as used by CBS for the GHG inventory.

9.1.1.3 Soda ash use

Soda ash use is a very minor source of emissions. Estimates of CO_2 emissions from soda ash use are calculated by CBS on the basis of soda ash imported into the country. Import data is available for the period 2010 to 2013. For the period 2014 to 2030, emissions are assumed to be constant at 2013 levels.

9.1.1.4 Nitric acid production

There are 5 nitric acid production lines at the Haifa chemicals and fertiliser production plant, all of which have had N_2O abatement measures installed as part of CDM projects. Data on emissions is available from the CDM registry, although the last full year for which data from all 5 lines is registered is 2010. For 2010 emissions as reported in the CDM registry data are 0.84 kt of N_2O compared to 2.5 kt reported in the GHG inventory for 2010. One of the main uses for nitric acid is fertiliser production; fertiliser consumption in agriculture is assumed to remain constant in projections of agricultural emissions, so production of nitric acid is assumed to remain constant here. It is assumed that abatement measures installed as part of CDM projects continue to operate. The value of 0.84 kt of N_2O is used for 2010 emissions.

9.1.2 Mitigation

The replacement of clinker with fly ash in the cement sector is considered as a mitigation option in the industry sector. The reduction in the quantities of clinker, produces both energy savings and process emissions savings. These have both been taken account of in the industry sector evaluation of this measure, and it is therefore not considered further here.

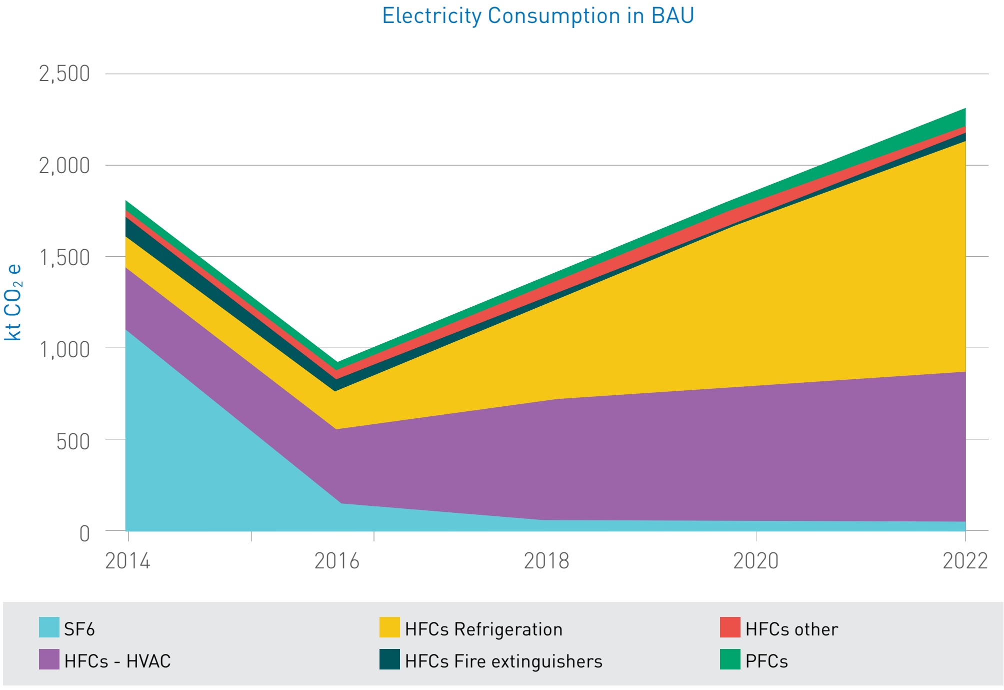
9.2 F-GASES

9.2.1 BAU

Consumption of F-gases is estimated by the CBS based data on the imported quantities of each gas from customs, as well as the largest commercial group that imports F-Gases. An assumption is made that imported quantities in a given year are equal to emissions in that year; this is highly conservative as equipment charged with F-gases has an average lifetime of several years and in many cases leakage rates are small. The end use of F-gases is broken down using two sources of data: 1) estimates provided by the importers, and 2) direct consumption data received from very large consumers, of which there are a very limited number. The remainder not accounted for is assumed to go to the general market, and to be used primarily for HVAC and refrigeration. The breakdown between HVAC and refrigeration, and market sector (residential, commercial/public and industrial) is based on local and international estimates.

Historic trends in the use of F-gases are shown in Figure 30; in 2012, F gas emissions were 2.8% of national GHG emissions. Emissions of PFCs arise from semiconductor manufacture and account for 0.1% of total GHG emissions. SF_6 is mainly used in switch gear in the electricity industry, with a small use in semiconductor manufacture. The large fall in SF_6 emissions in 2009, was due to the magnesium industry switching from SF6 to HFC134a (which has a much lower GWP) as a cover gas.

Figure 30 **Historical emissions of F gasesis disposed of to landfill. Prior to 2004, it is assumed that all waste went to landfill**



Source: CBS

HFC emissions are shown in more detail in Figure 31. Emissions of HFCs have risen sharply in the past few years as they are used to replace HCFCs, which as a signatory to the Montreal Protocol, Israel is committed to phasing out:

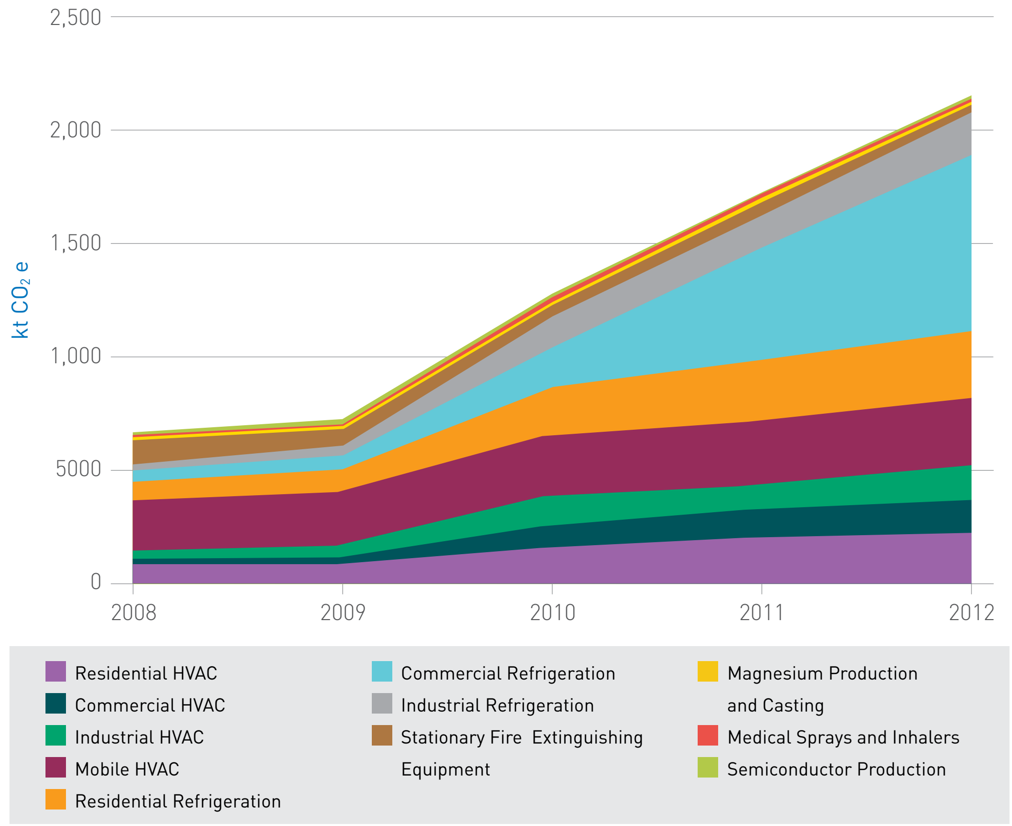
Starting in 2010, consumption was reduced to 25% of Montreal Protocol Baseline Use of 329 ton ODP and was therefore limited to no more than 82.25 ton ODP per annum, through the end of 2014.

Starting in 2015, consumption will be reduced to 10% of Montreal Protocol Baseline Use or 33 ton ODP per annum, through the end of 2019

Starting in 2020, consumption will be reduced to 0.5% of the Montreal Protocol Baseline Use for use in preexisting machinery

From 2030 onwards, HCFCs will be completely prohibited[87].

Figure 31 Historical emissions of HFCs



It should be noted that for the refrigeration, HVAC sectors and fire extinguisher sectors, the assumption that emissions in a year are equal to consumption provides an estimate of potential rather than actual emissions. In reality some of the gases imported will be used to charge refrigeration and HVAC systems, and a bank of HFCs is built up in devices.

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[87] Ministry of Economy, Environment & Sustainable Development Administration

Typically refrigeration and HVAC systems have an initial charge of refrigerant gas, at which point there may be some losses. After this, losses typically occur as leakage which can range from minimal for hermetically sealed systems such as found in domestic refrigerators to up to 10% p.a. for commercial and industrial systems, from servicing when gas may be vented and the system then refilled and at disposal. In the long run however, generally speaking, gases which are imported will eventually be emitted.

In projecting emissions for this sector, it is necessary to take account of two effects: the continuing transitioning out of HCFCs to HFCs (for relevant uses) and the growth in emissions due to growth in the end use sector.

For sectors where HCFCs were in use (refrigeration, HVAC, stationary fire extinguishing equipment and medical sprays) the reduction in HCFC use required in each year is calculated by linearly interpolating between the years for which reductions are specified in the Montreal Protocol Commitments. It is assumed that the rate of decline in HCFC use is identical in each sector[88]. Thus in 2012 HCFC use in each of the sectors has been reduced by 81% from the baseline use[89]. It is then assumed that the consumption (and hence emissions) of HFCs in the sector in 2012 was the amount necessary to replace the quantity of HCFCs which deliver an 81% reduction in HCFC use in 2012. This approach to estimating HFC emissions avoids the need to know on a tonne for tonne basis the quantity of HFC needed to replace a tonne of HCFC. This quantity is then prorated for other years on the basis of the HCFC reduction which is required in that year. This gives HFC emissions which are a result of transitioning out of HCFCs, based on demand in 2012. To this, must be added the HFC use and emissions which result from growth in the sector. This was calculated by choosing the most appropriate driver for the sector as shown in Table 93.

Table 93 Drivers used to estimate growth in emissions

Source	Driver
SF6	GDP
HFCs Residential HVAC	Number of households
HFCs Commercial/public HVAC	Commercial/public floor space
HFCs Industrial HVAC	GDP
HFCs Mobile HVAC	Number of passenger cars
HFCs Residential Refrigeration	Number of households
HFCs Commercial/public Refrigeration	GDP
HFCs Industrial Refrigeration	GDP
HFCs Stationary Fire Extinguishing Equipment	GDP
HFCs Magnesium Production and Casting	GDP
HFCs Medical Sprays and Inhalers	Population
HFCs Semiconductor Production	GDP
PFCs Semiconductor Production	GDP

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[88] This assumes a smooth transition from HCFCs to HFC, with users planning for their phase out, and potentially transitioning out of HCFCs before the final cut-off date, particularly e.g. if equipment needs replacing anyway as it has reached its end of life. In reality, the transition pattern may show much higher rates of transition closer to the cut off date.

[89] Derived by linearly interpolated between the reductions required from the base line use in 2010 and 2015 (75% and 90% respectively).

This gives projected emissions in 2030 (Table 94) of 4,978 ktCO_2 e, an increase of 259% from 2012. Of this increase, approximately 20% is due to continued phase out of HCFCs and their replacement by HFCs, and the remainder is due to growth in the end use sectors

Table 94 Projected F gas emissions (kt CO_2 e)

Source	2012	2015	2020	2025	2030
SF6	70	59	71	84	99
HFCs Residential HVAC	149	249	298	322	348
HFCs Commercial/public HVAC	108	203	265	318	381
HFCs Industrial HVAC	130	187	245	291	346
HFCs Mobile HVAC	266	385	510	625	765
HFCs Residential Refrigeration	215	344	411	445	481
HFCs Commercial/public Refrigeration	178	975	1275	1517	1800
HFCs Industrial Refrigeration	133	233	305	362	430
HFCs Stationary Fire Extinguishing Equipment	57	59	78	92	110
HFCs Magnesium Production and Casting	13	3	3	4	5
HFCs Medical Sprays and Inhalers	21	28	30	31	31
HFCs Semiconductor Production	13	8	9	11	13
PFCs Semiconductor Production	38	101	120	143	169
Total	**1388**	**2834**	**3620**	**4245**	**4978**

9.2.2 Mitigation

The key emitting sectors are HVAC, with mobile air conditioning becoming an increasingly important source of emissions and refrigeration, with emissions dominated by refrigeration in the commercial/public sector. Options for reducing emissions in these sectors include:

- The use of alternatives to HFCs, e.g. using hydrocarbons as the fluid in domestic refrigerators, CO_2 in commercial refrigeration units, and ammonia in industrial units
- Using lower GWP refrigerants, these include lower GWP HFCs and also more recently developed very low GWP hydrofluroolefins (HFOs)
- Introducing practices to minimise leakage, recovery of vented fluids during servicing and recovery of fluids at end of life.

As an example, implementation of these types of measures in the EU has been achieved through the MAC Directive on air conditioning systems used in small motor vehicles, and the 'F-gas Regulation' which covered all other key applications in which F-gases are used. Both these pieces of legislation were implemented in 2006.

The MAC Directive prohibited the use of F-gases with a global warming potential of more than 150 in all new cars and vans produced from 2017. The F-gas Regulation implemented two main courses of action:

- Improving the prevention of leaks
- Setting limits from 2015, phased down over time, on the volume of HFCs which could be placed on the market

In 2015, a new F-gas Regulation came in to force which strengthened this by

- Limiting sales of HFCs to 20% of their 2014 levels by 2030,
- Banning the use of F gases in many types of equipment where less harmful alternatives are widely available
- Preventing emissions of F-gases from existing equipment by requiring checks, proper servicing and recovery of the gases at the end of the equipment's life.

Similar packages of these types of measures should also be applicable in Israel.

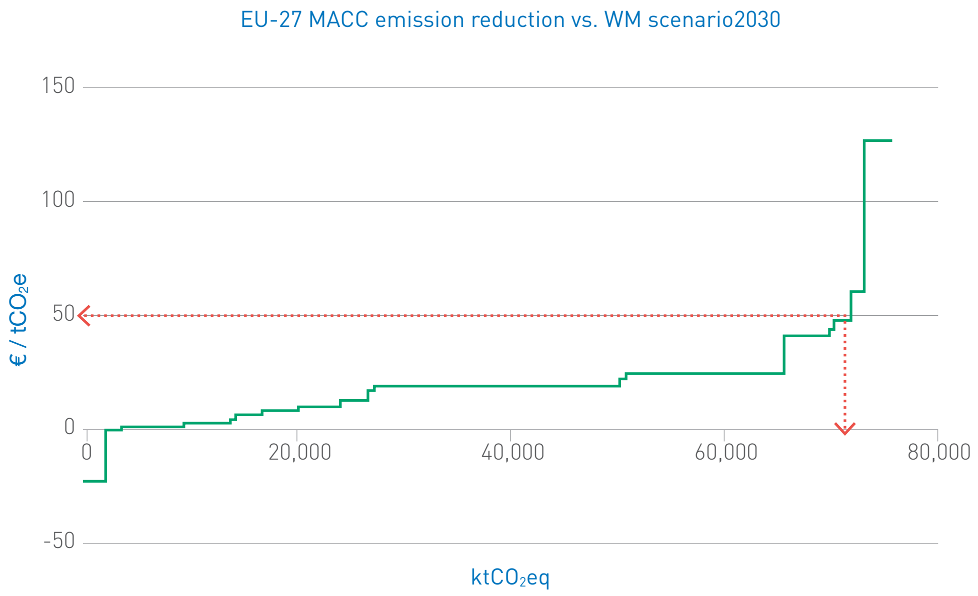
A full individual assessment of each of the individual measures which could be applied in each of the source sectors would have very large data requirements. The assessment would require a large amount of data on number of refrigeration and HVAC plant in each sector, current gas leakage rates, and more information on the actual HFCs used in each type of application, and would need a detailed country specific study.

Information on the average cost of measures can be obtained from the impact assessment which was carried out to assess options for the new F gas regulation for the EU (EC, 2012). This used detailed information on F gas use in the EU, and the cost of individual abatement measures to calculate an average abatement cost for reductions achieved under a range of policy instruments, (voluntary agreements, bans and phase down of F gas use). This gave an average cost of 16 to 17 £/t CO_2 (in 2010 prices), and estimated that reductions of about 70% of current emissions could be achieved at a marginal abatement cost of less than €50/t; see Figure 32.

Assuming that the cost of refrigerants and HVAC and refrigeration systems in Israel is broadly similar to that in Europe, it is proposed to use these average abatement costs.

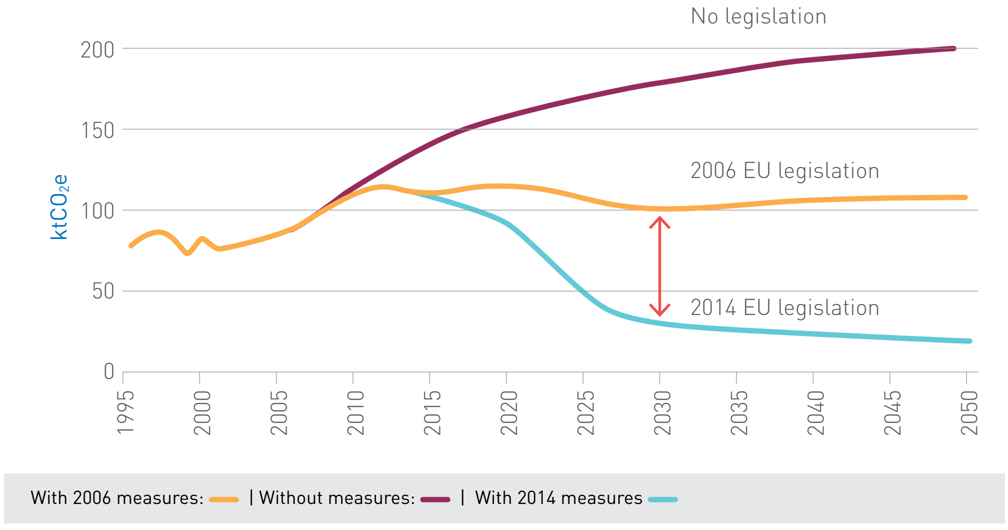
HFCs were introduced into the EU from the late 1990s as the phase out of HCFCs began much earlier there. The significant phase down in HFC use - to 20% of 2014 levels by 2030, is in part achievable due to action in this area since 2006 at the EU level, which has driven consideration and development of alternative refrigerant systems and use of low GWP refrigerants. Reductions which could reasonably be achieved in Israel by 2020 and 2030 are likely to be much lower than this. It is proposed that achievable reductions might be closer to those forecast to result from the earlier EU legislation (Figure 33). On this basis it is considered that as a minimum, in the refrigeration and HVAC sectors emissions reductions of 10% of BAU emissions could be achieved by 2020, 15% by 2025 and 30% by 2030. Given that this assumes that the abatement measures will achieve the lower level of reductions, using the average abatement cost of 16£ therefore was deemed reasonable

Figure 32 Marginal Abatement Cost Curve for F gas emissions in EU



Source: EC ,2012

Figure 33 Predicted impacts of EU legislation on F Gas emissions



Source: EC, 2014

9.3 FUGITIVE EMISSIONS

9.3.1 BAU

Fugitive emissions from oil refining and natural gas production, transmission and distribution are not currently estimated in the GHG inventory. However gas production and distribution are expected to increase significantly to 2030, so an estimate of current and future emissions should be included in national emissions projections.

As fugitive emissions from these sectors have yet to be characterised in Israel, a simple approach, applying Tier 1 emission factors from the IPCC 2006 guidelines to current and projected gas production, and gas use, and to quantities of oil refined has been applied.

Current and future natural gas production are based on forecasts of gas use made in the BAU energy projections for the power, industrial and transport sectors.

Quantities of oil refined in 2012 are taken from the CBS energy balance for 2012. It is proposed to assume that there is no expansion of capacity of existing refineries and that no new refineries are built between 2012 and 2030.

The emissions factors used are shown in Table 95. These have been taken from Table 4.2.4 of IPCC 2006 Guidelines and are for developed countries. Fugitive emissions can depend on a number of factors and for some activities a range is given for the emissions factor. In these cases the mid-point of the range has been taken. While it is understood that the gas field developments and the gas distribution networks have been developed to modern standards, and emission factors might thus be at the lower end of the range, good practice in inventory compilation is where uncertainty is high to take a conservative approach to estimating emissions.

Application of the emissions factors in Table 4.2.4 of IPCC 2006 Guidelines to the projections of gas use and refinery production gives the emissions projections shown in Table 95.

Table 95 Projected fugitive emissions

Source of fugitive emissions	2012 kt CO_2 e	2020 kt CO_2 e	2030 kt CO_2 e
Gas production	118	1287	1562
Gas transmission and distribution	85	401	595
Oil refining	6	6	6
Total	209	1694	2163
As % of total GHGs	0.3%	2.0%	2.6%

9.3.2 Mitigation

In the long list of mitigation measures initially circulated for comment, three mitigation options were assessed as relevant for fugitive emissions, all based on improving gas distribution infrastructure:

- Improved compressor maintenance, sealing
- Improved distribution pipeline maintenance
- Improved pipeline planning - shorter distances, fewer compression stations.

The project team decided that these were not to be taken forward for further analysis in the MACC as:

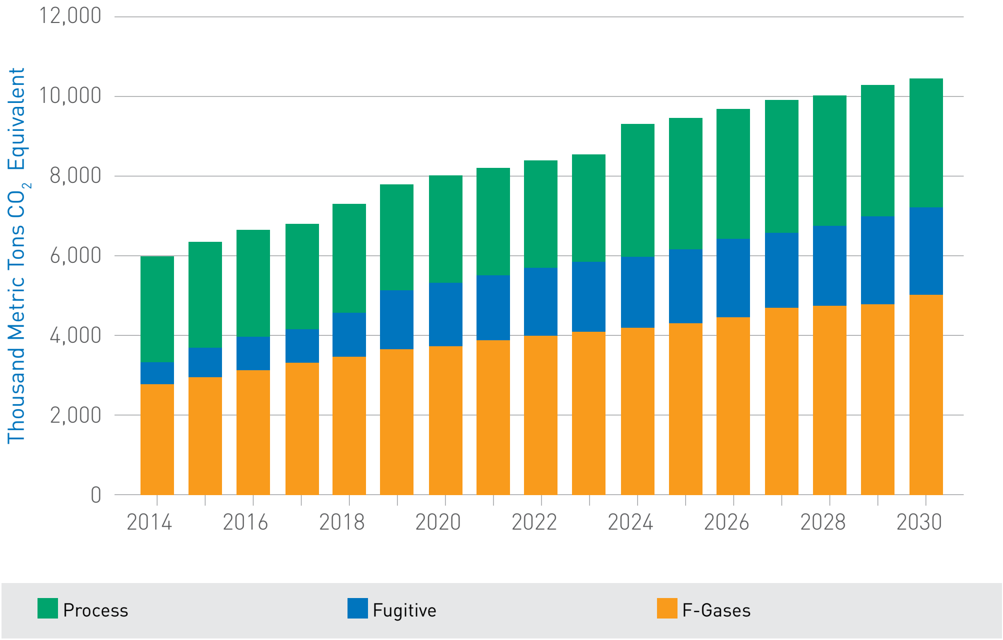
- The mitigation potential of these options is likely to be quite small, both because the source emissions are relatively small and because given that the infrastructure in place is new, it is likely to already be meeting quite high standards.
- An estimate of the abatement potential will be very difficult as we are relying on average 'default' emissions factors to characterise the losses, and this is based on gas throughput, rather than pipeline length and number of compressor stations, which would be the case for a more detailed approach. The emissions from this source would need to be more accurately characterised before a realistic estimate of potential reductions could be made.

9.4 RESULTS

9.4.1 BAU

Emissions from other sectors are projected to rise substantially, from 6.0 Mt CO_2e in 2014, to 10.4 Mt CO_2e in 2030. The largest contribution to this rise is emission of fluorinated gases which are forecast to almost double over this period, as their use increases as HCFCs (for which they are a replacement) are phased out. Fugitive emissions from natural gas production and transmission almost triple as quantities of gas produced and used rise over this period, and also contribute substantially to the increase in emissions. Process emissions (from cement, lime, soda ash and nitric acid production) show only a moderate increase, as only cement and lime production are forecast to increase over this period, and at a relatively slow rate.

Figure 34 **BAU emissions of GHGs from industrial process, fugitive and F-gases**

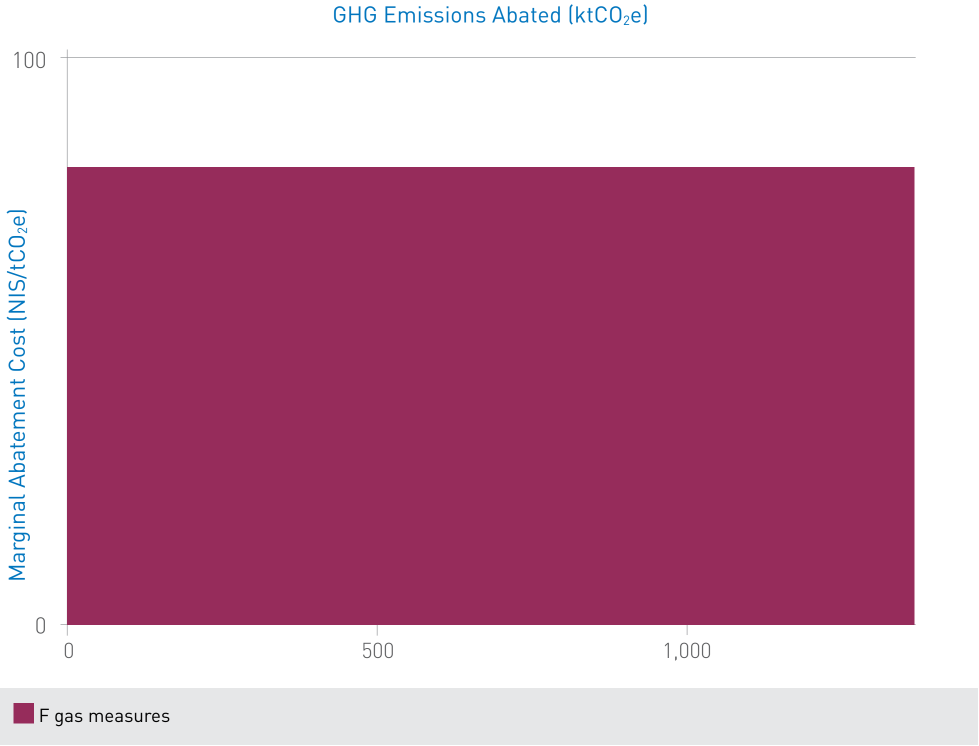


9.4.2 Mitigation

Two mitigation options were evaluated for these sectors: 1) the use of PFA in the cement sector and 2) measures to reduce emissions of fluorinated gases in the refrigeration and HVAC sector. The impact of the former is discussed in the industry section and would reduce process emissions from the cement sector by 0.295 Mt CO_2e. Measures to reduce emissions of F gases could reduce emissions by 0.6 Mt CO_2e in 2025, and by 1.4 MtCO_2e in 2030. This is equivalent to a 27% reduction in BAU emissions from F gases in 2030.

As the cost-effectiveness of the use of PFA in the cement sector has already been evaluated in the industry sector MACC, it is shown as zero in this MACC.

Figure 35 Marginal abatement costs in “other” sectors



9.4.3 Observations

Emissions of fluorinated gases are set to rise substantially to 2030, from 2.7 $MtCO_2e$ in 2014 to 5.0 $MtCO_2e$ in 2030, but this growth can be substantially reduced by the introduction of a variety of measures to reduce their emissions, principally in the refrigeration and heating and air conditioning sector. These include banning the use of high GWP HFCs and encouraging the use of lower GWP gases; reducing leakage from systems in operation and at servicing and recovery of gases at the end of equipment lifetime. These measures could reduce emissions by 0.6 $MtCO_2$ e in 2025 and 1.4 $MtCO_2$ e in 2030.

10

NATIONAL-LEVEL RESULTS

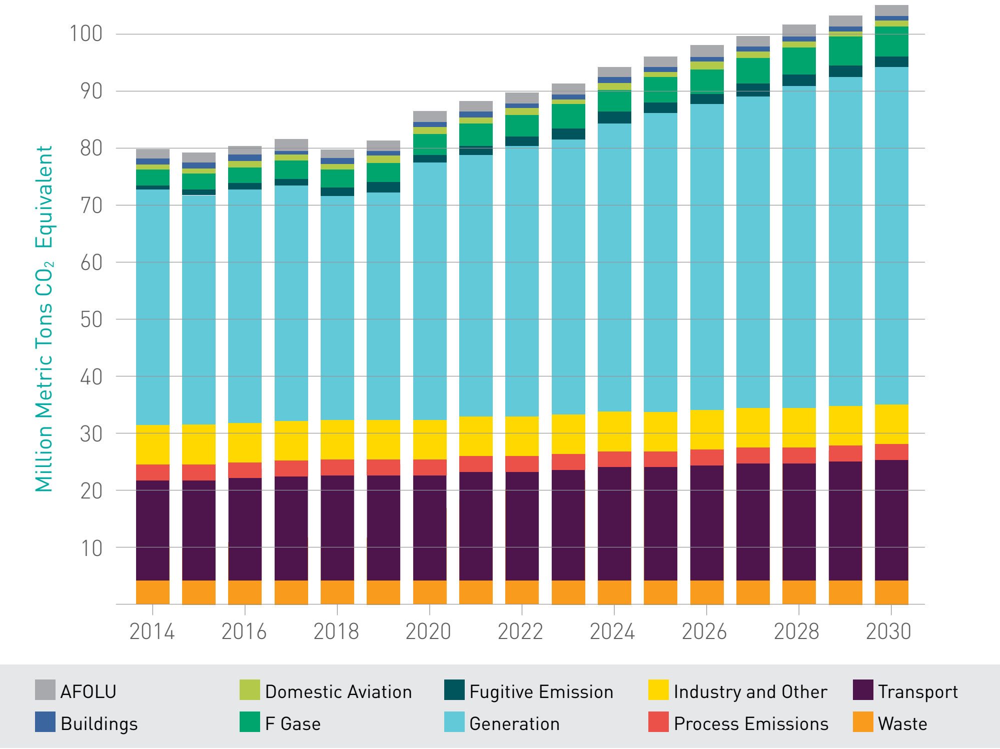
10.1 BUSINESS-AS-USUAL (BAU)

Under a 'business-as-usual' (BAU) scenario, GHG emissions in Israel will increase by 27.05% from 2012 levels by 2030, with total GHG emissions in 2030 expected to be 105.5 Mt CO_2e (9.95 tCO_2e per capita). Total GHG emissions in 2025 are projected to be 96.4 Mt CO_2e (9.8 tCO_2e per capita).

10.1.1. GHG emission results

Figure 36 below shows total emissions out to 2030 under the BAU scenario, split by sector on a source basis. This means that emissions from electricity consumption in the building and industry sectors for example are assigned to the power sector and that the emissions for buildings and industry shown in the graph are only for direct emissions from combustion.

Figure 36 GHG emissions (Mt CO2e) to 2030 under 'business-as-usual'[90]



As can be seen in Figure 36 above, the power sector continues to be the dominant source of GHG emissions in Israel, accounting for 52.5% of total emissions in 2030, followed by the transport sector, which is projected to account for 20.6% of GHG emissions.

All sectors continue to show a rise in direct emissions, with the exception of direct combustion emissions from buildings, which fall by 11.2% due to continued trends away from fuel use in the residential and commercial sectors.

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[90] AFOLU' = agriculture, forestry and other land use. 'F Gases' = fluorinated gases.

Emissions in the power sector are expected to decrease slightly through 2019, due to a combination of increased uptake of renewables as well as planned shut-downs of coal-fired power plants for major maintenance, before increasing significantly in the coming decade, driven by growth in electricity consumption, which is expected to increase by 68% relative to 2012 levels, to 96.02 TWh in 2030.

10.1.2 Other results

10.1.2.1 Trends in electricity consumption

In the BAU scenario (see Figure 37), total electricity consumption in 2030 is 96.02 TWh, driven by growth in consumption in all sectors, with commercial and public buildings accounting for 32.1% of total electricity consumption in 2030, followed by residential buildings, which account for 27.1%, and the industrial and water sectors, which together account for 24.9%.

Figure 37 Electricity consumption by sector in 2030

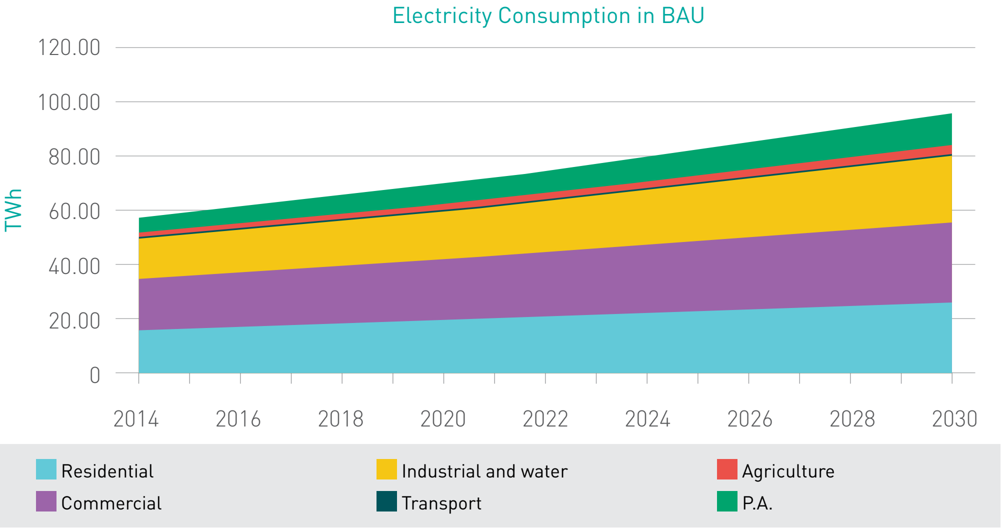

Table 96 Electricity consumption by sector for key years[91]

Electricity Consumption (TWh)	2015	2020	2025	2030
Residential	16.76	19.28	22.49	26.00
Commercial/public	19.10	22.69	26.59	30.84
Industrial and Water	15.63	18.03	20.83	23.93
Transport	0.10	0.20	0.27	0.36
Agriculture	2.20	2.50	2.90	3.30
P.A.	5.50	7.20	9.30	11.60
Total	**59.30**	**69.90**	**82.39**	**96.02**

It should be noted that the forecast for electricity consumption was found to closely match the official Ministry of Energy forecasts:

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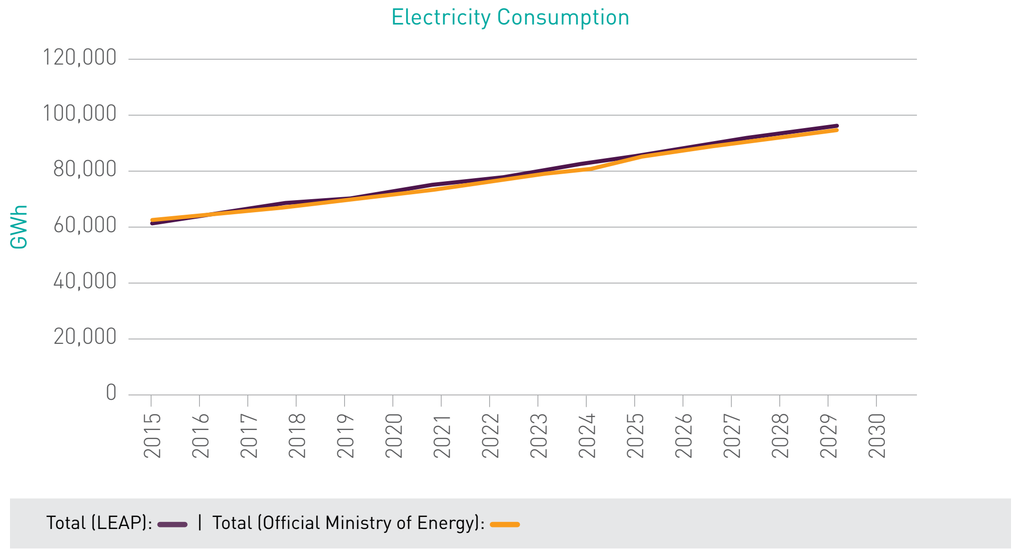
[91] Note that the figures in this table do not return the percentages quoted in the text above exactly due to rounding.

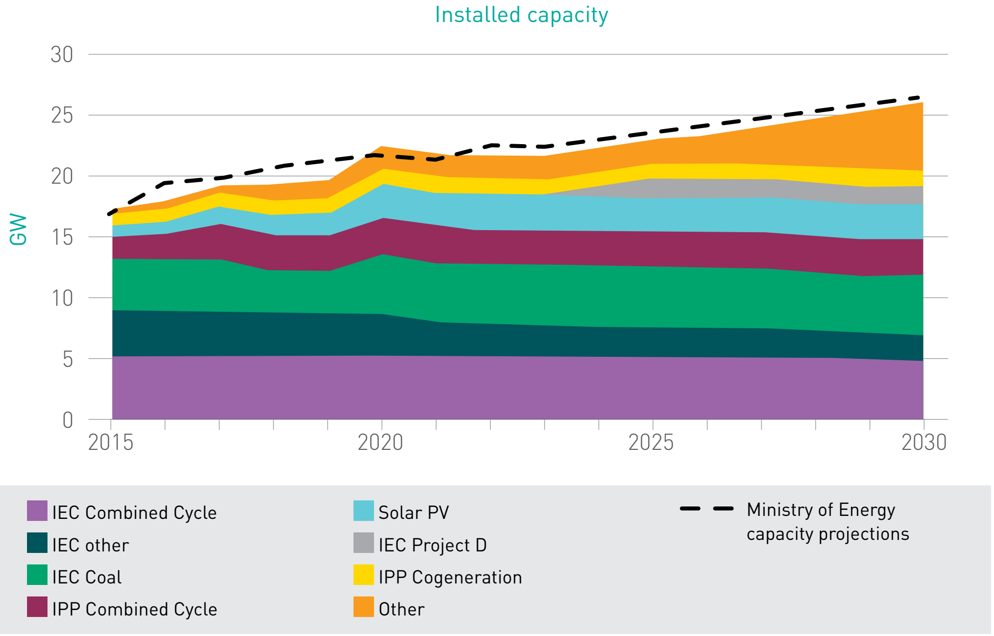
Figure 38 BAU electricity consumption compared to Ministry of Energy forecast



10.1.2.2 Electricity generation (the power sector)

Under the BAU scenario (see Figure 39), generation capacity grows to 2030, again closely matching Ministry of Energy forecasts:

Figure 39 Generation capacity (MW) to 2030 under the BAU scenario



Existing and planned conventional power generation capacity was found to be sufficient to meet the increasing demand through 2024, at which point a new dual-fuel power plant with a capacity of 1,524 MW (Project D) is required[92]. In all, it is expected that the increase in electricity consumption will require an additional 5,200 MW[93] of conventional power generation capacity beyond the current and planned power stations:

Table 97 Generation capacity to 2030 under the BAU scenario (MW)

BAU	2015	2020	2025	2030
Coal	4,265	4,840	4,840	4,840
NG	10,930	12,018	12,530	15,567
Other Thermal	1,122	1,094	1,094	1,094
Renewable	776	3,590	3,599	3,599
Total	17,093	21,551	22,063	25,100

Natural gas is expected to be the dominant fuel for power generation, comprising nearly 61% of the generation fuel mix in 2030. Renewables will peak at 10% in 2020 before declining to 7.5% in 2030. The percentage falls because the amount of renewable capacity remains constant whilst generation increases to match rising demand, in line with the BAU assumptions:

Table 98 Percentage of electricity generation from different fuels in select years

BAU	2015	2020	2025	2030
Coal	45%	44%	37%	32%
Natural Gas	52%	46%	54%	60%
Other Fossil*	0%	0%	0%	0%
Renewable**	3%	10%	9%	8%

*This is included to indicate that other fuels are used (in negligible quantities).
**Including biomass

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[92] This plant will be built, in the BAU scenario, in two equal units - one in 2024 and the other in 2025

[93] Required capacity additions. The growth in total capacity is more limited, as some of the capacity additions are offset by planned decommissioning of existing units.

Coal consumption in 2030 is 12.13 million tons, and economy-wide natural gas consumption is 15.86 billion cubic metres (BCM), 79% of which is consumed in the power sector. Coal consumption remains largely constant until 2030 but its share of the power sector energy consumption declines significantly. This reflects the trend in coal-fired generation capacity. By contrast, the substantial rise in natural gas consumption is strongly driven by an expansion of combined cycle turbines and other natural gas-fired capacity.

Table 99 Economy-wide consumption of key fuels in the BAU scenario

Fuel	2015	2020	2025	2030
Coal (million tons)	10.52	12.13	12.13	12.13
Natural gas (BCM)	8.94	9.45	12.68	15.86
Natural gas (cumulative BCM from 2015)	8.94	59.49	116.01	188.92

10.1.2.3 Other Results

In the transport sector, GHG emissions are expected to grow by 15% by 2030.

Passenger cars will continue to be the dominant emission source, accounting for approximately 50% of total transport GHG emissions. Passenger car use is expected to increase by approximately 46%, reaching more than 55 billion vehicle kilometres travelled nationwide in 2030.

Petroleum-based fuels will remain the dominant fuel for overland travel, accounting for 97.1% of total fuel consumed, the result of limited uptake of electric and CNG vehicles.

Additional noteworthy results from the BAU projections include:

- The current waste recycling facilities, as well as planned facilities that have already been budgeted and approved, are expected to be sufficient to reduce the percentage of municipal solid waste that is landfilled from the current 80% to approximately 50% in 2030.
- HFC emissions are expected to increase by 268% by 2030, due in large part to the gases' suitability as a replacement for HCFCs phased out in accordance with the Montreal Protocol.

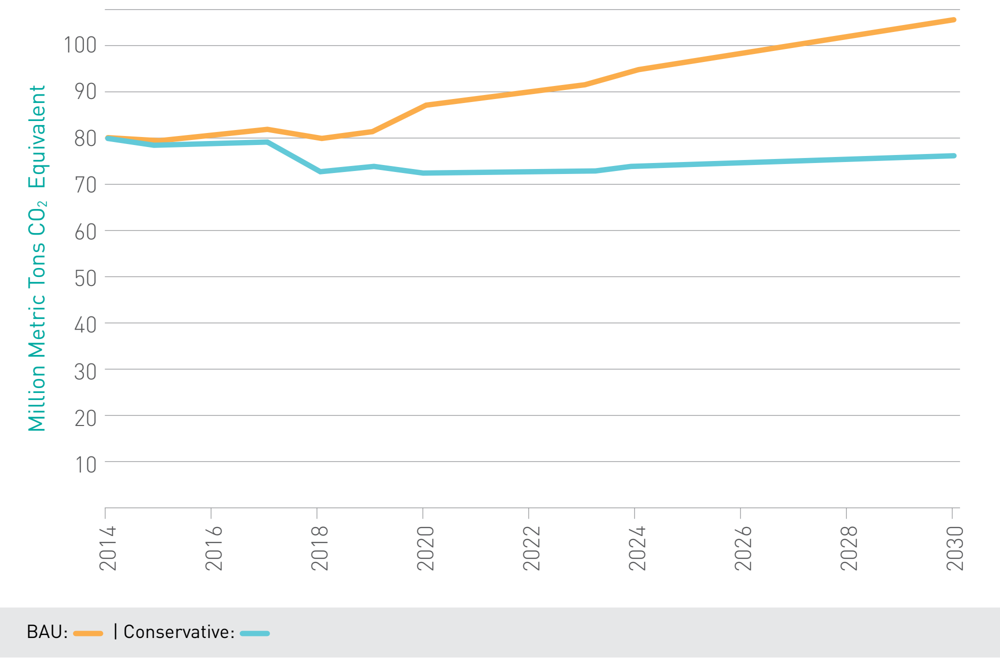
10.2 Mitigation scenario results

In the conservative target scenario, GHG emissions are expected to be reduced below BAU emissions by 23.0% in 2025 and 27.7% in 2030, to a level of 76.3 $MtCO_2e$ in 2030 (7.2 tCO_2e per capita).

This would mean GHG emissions would be 74.2 Mt CO_2e in 2025 (7.5 tCO_2e per capita) and 76.3 Mt CO_2e in 2030 (7.2 t CO_2e per capita), as compared to 105.5 Mt CO_2e (9.95 tCO_2e per capita) in the BAU scenario in 2030.

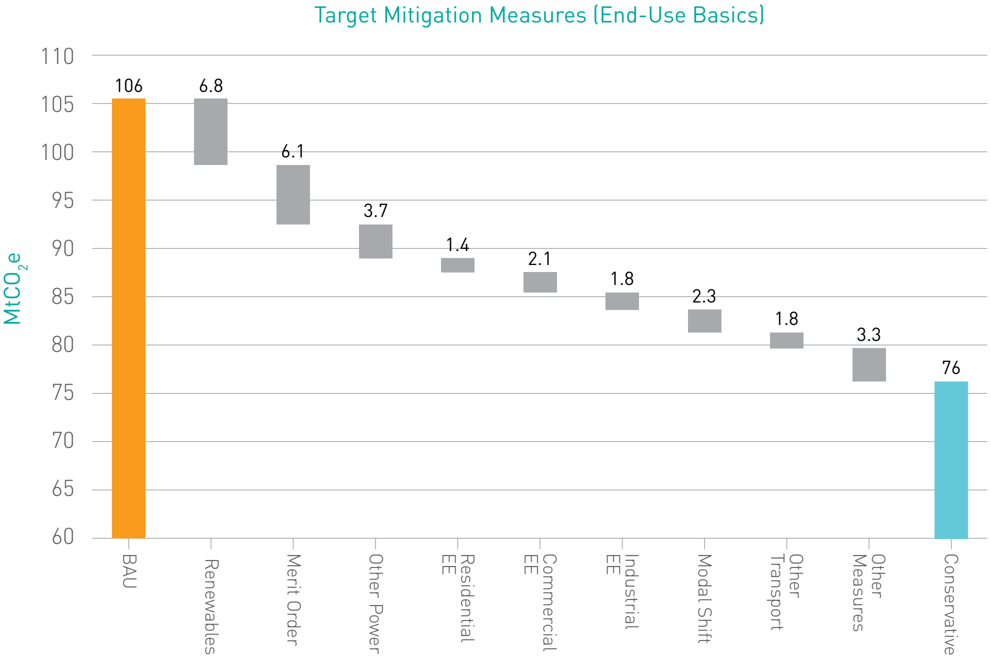
It should be noted that this represents a growth in absolute emissions of 6% relative to historical 2005 levels, but an absolute emission reduction of 8.1% relative to 2012 levels:

Figure 40 GHG emissions (Mt CO_2e) to 2030 under the BAU scenario and the 'conservative target' scenario



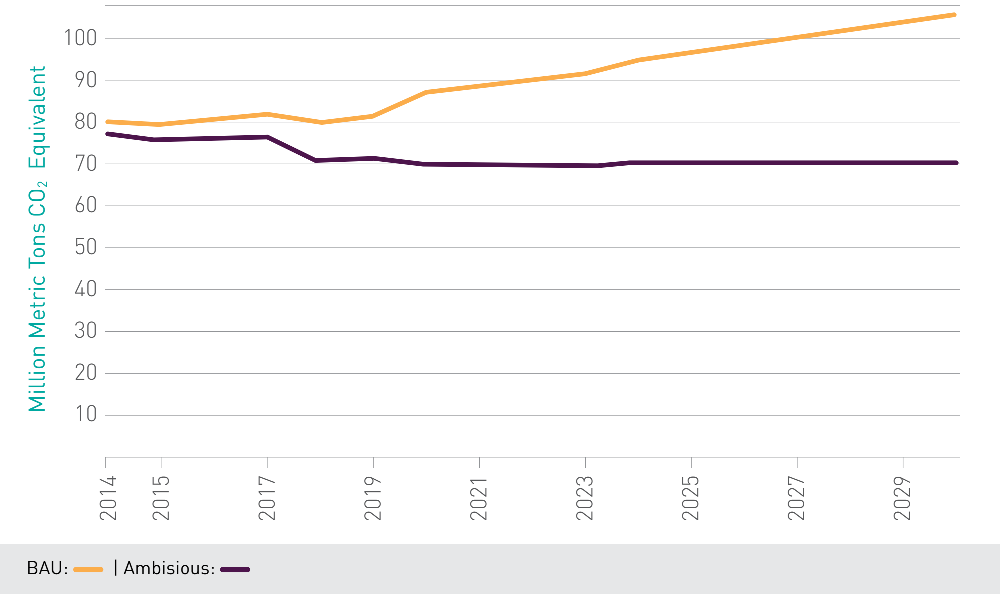
This emission reduction is achieved primarily by key power sector measures renewable energy (6.8 $MtCO_2e$, or 23% of the total reduction) and changes to the merit order (6.1 $MtCO_2e$, or 21% of the total reduction), energy efficiency measures (5.3 $MtCO_2e$, or 18% of the total reduction), and increased use of public transport as well as walking/cycling (2.3 $MtCO_2e$, or 8% of the total reduction)

Figure 41 Split of emissions reductions from different categories in the 'conservative target' scenario



Through implementation of all technically feasible abatement measures in Israel (the 'ambitious target scenario'), GHG emissions could be reduced below 'business-as-usual' emissions by 25.0% in 2025 and 31.4% in 2030. This would mean GHG emissions would be 72.3 $MtCO_2e$ in 2025 (7.3 t CO_2e per capita) and 72.2 $MtCO_2e$ in 2030 (6.8 tCO_2e per capita), as compared to 105.5 $MtCO_2e$ (9.95 tCO_2e per capita) in the BAU scenario in 2030.

Figure 42 GHG emissions (Mt CO_2e) to 2030 under the BAU scenario and the 'ambitious target' scenario



The emissions reductions for each sector in 2025 and 2030 are set out in Table 100 below. It should be noted that this is on a source basis, meaning for instance that emission reductions from energy efficiency measures in buildings that reduce electricity consumption are allocated to the power sector.

Table 100

GHG reductions (Mt CO_2e) by sector in 2025 and 2030 in the 'conservative' and 'ambitious target' scenarios

Sector	'conservative target'		'ambitious target'	
Year	2025	2030	2025	2030
Residential	0.02	0.02	0.02	0.02
Commercial/public	0.00	0.00	0.00	0.00
Transport	2.98	5.06	2.98	5.06
Industry	0.49	0.74	0.49	0.74
Power	16.10	19.74	18.06	23.59
Non-Energy	2.56	3.71	2.56	3.71
Total	**22.15**	**29.27**	**24.11**	**33.12**

10.2.1 Electricity and Energy Consumption

Total energy efficiency potential in Israeli electricity consumption is estimated at 18-22% relative to expected BAU levels, in line with similar targets in advanced countries. Implementation of the efficiency potential in all sectors excluding transport[94] will yield a 20% reduction in electricity consumption, or 16.8 TWh. This reduction will yield a total Israeli electricity consumption, including transport, of 67.6 TWh in 2030; electricity consumption including the Palestinian Authority will be 79.2 TWh.

Implementation solely of the efficiency measures that were assessed in-depth and included in the conservative target scenario, in all sectors excluding transport and agriculture, are expected to reduce electricity consumption in these sectors by approximately 15% in both the conservative and ambitious target scenarios (some 12 TWh). This is expected to yield a total Israeli electricity consumption, in all sectors, of 74.8 TWh (86.4 TWh including the Palestinian Authority).

The BAU scenario, electro-intensity grows by 18.8% in the residential sector, 20.2% in the commercial/public sector and falls 8.8% in the industrial and water sectors. In the 'ambitious' and 'conservative' scenarios, these figures have fallen to 5.7% and 2.5% increases in the residential and commercial/public sectors and a 25.0% decrease in the industrial and water sectors.

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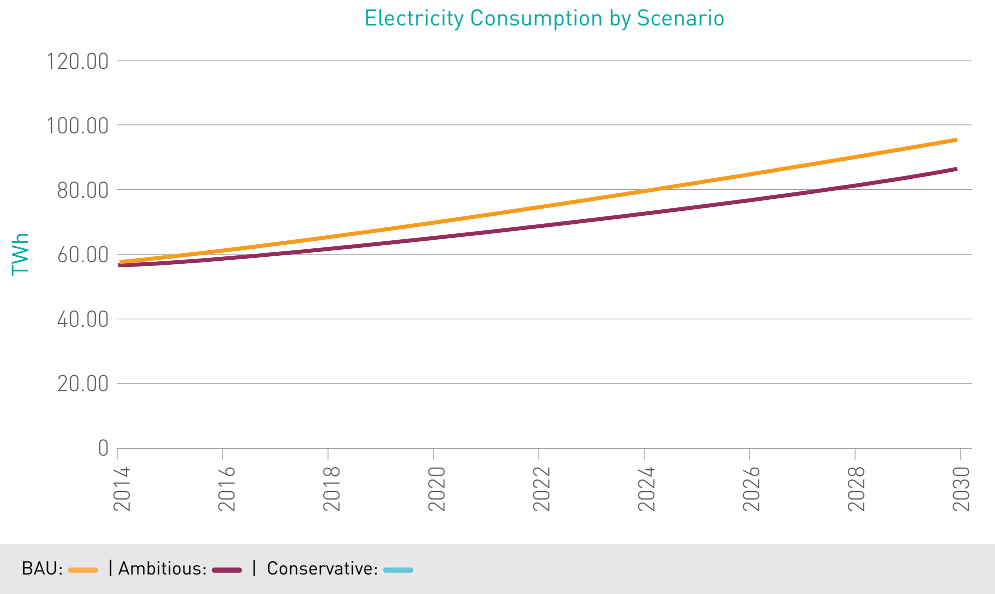
[94] This includes the residential sector, commercial/public, industry and water, and agriculture

Figure 43 Electricity consumption across scenarios, based on analysed measures only



In addition, in the conservative target scenario:

- Total primary energy consumption is reduced by 26.5% relative to BAU levels.
- Uptake of small scale cogeneration and additional fuel switching to natural gas in industry will reduce total HFO consumption in Israel by 73% relative to current levels.

10.2.2 Power generation

Due to the electric efficiency measures, in conjunction with added renewable energy capacity, in both the conservative target scenario and the ambitious target scenario, the power sector will not require the construction of the 5,200 GW additional conventional capacity required in the BAU scenario, including Project D:

Table 101 Generation capacity in conservative scenario (MW)

Category	2015	2020	2025	2030
Coal	4265.0	3400.0	3400.0	3400.0
NG	10930.0	13458.0	12346.0	11783.0
Other Thermal	1122.0	1094.0	1094.0	1094.0
Renewable	775.7	3598.7	6509.1	9345.4
Total	17092.7	21550.7	23349.1	25622.4

Table 102

Generation capacity in ambitious scenario (MW)

Category	2015	2020	2025	2030
Coal	4265.0	3400.0	3400.0	3400.0
NG	10930.0	13458.0	12346.0	11783.0
Other Thermal	1122.0	1094.0	1094.0	1094.0
Renewable	775.7	3598.7	7910.7	12148.6
Total	17092.7	21550.7	24750.65	28425.6

Note that the Orot Rabin 1-4 units are also phased out in the mitigation scenarios. The main difference between the ambitious and conservative scenarios is the level of renewable deployment. Note that these tables do not include energy storage.

By 2030, renewable energy technologies will account for 22.8% of total electricity generation in the conservative target scenario, and 33.0% of electricity generation in the ambitious target scenario.

In both scenarios the share of natural gas in the fuel mix will increase slightly, despite the increased renewable uptake, due to other power sector measures (primarily the merit order switch):

Table 103

Electricity generation by fuel type in the mitigation scenarios

Conservative	2015	2020	2025	2030
Coal	46.1%	16.1%	14.1%	12.3%
Natural Gas	51.2%	72.2%	67.1%	64.6%
Other Fossil	0.0%	0.0%	0.0%	0.0%
Renewable	2.6%	11.1%	18.3%	22.8%
RDF	0.0%	0.5%	0.4%	0.4%
Ambitious	2015	2020	2025	2030
Coal	46.1%	16.2%	14.1%	12.3%
Natural Gas	51.2%	72.2%	61.2%	54.3%
Other Fossil	0.0%	0.0%	0.0%	0.0%
Renewable	2.6%	11.1%	24.2%	33.0%
RDF	0.0%	0.5%	0.4%	0.4%

10.2.3 Transport Sector

In the transport sector, private vehicle use is reduced by 25% relative to BAU levels due to construction of advanced mass transit systems in Israel's metropolitan areas.

Due to this measure, along with uptake of alternative-fuelled vehicles (such as CNG and electric vehicles) as well as more efficient conventional vehicles, the share of petroleum-based fuels used for overland transport is expected to fall from 97.1% in the BAU scenario to 74.2% in the conservative target scenario.

10.2.4 Other Key Findings

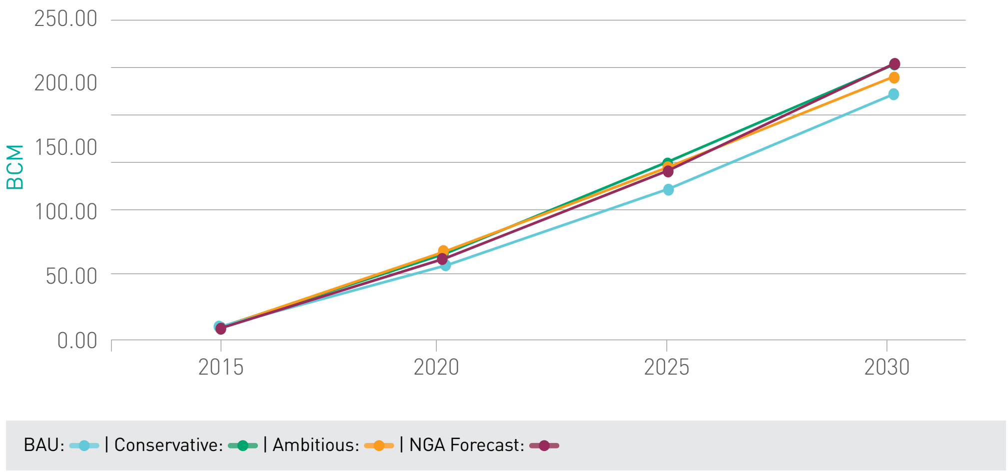
Natural gas consumption in the conservative scenario increases from 8.7 BCM in 2015 to 16.8 BCM in 2030 - 5.8% greater than the expected 2030 consumption under the BAU scenario (15.9 BCM). This modest increase is driven by opposing trends: consumption in the power sector declines by 5.6% (0.7 BCM) relative to the BAU, while consumption in transport and industry increases relative to BAU levels by 550% (1.1 BCM) and 16% (0.5 BCM), respectively:

Table 104 Natural Gas Consumption in 2030 (BCM)

Sector	2030 - BAU	2030 - Conservative	2030 - Ambitious	2030 - NGA forecast
Transport	0.2	1.3	1.3	1.9
Industry	3.1	3.6	3.6	3.9
Generation	12.6	11.9	10.1	12.1
Total	**15.9**	**16.8**	**15**	**17.9**

- Cumulative natural gas consumption over the period 2015-2030 closely matches the Natural Gas Authority forecasts in all scenarios, indicating that meeting the natural gas demand in both the BAU and the conservative target scenario will require not only the development of the Leviathan reserve, but according to the PUA will also necessitate the construction of an additional natural gas pipeline:

Figure 44 **Cumulative natural gas consumption by scenario**



- Coal consumption in both mitigation scenarios in 2030 is 4.4 million tons (63% below BAU):

Table 105 Coal consumption in key years, by scenario (million tons)

Scenario	2015	2020	2025	2030
BAU	10.5	12.1	12.1	12.1
Conservative	10.5	4.4	4.4	4.4
Ambitious	10.5	4.4	4.4	4.4

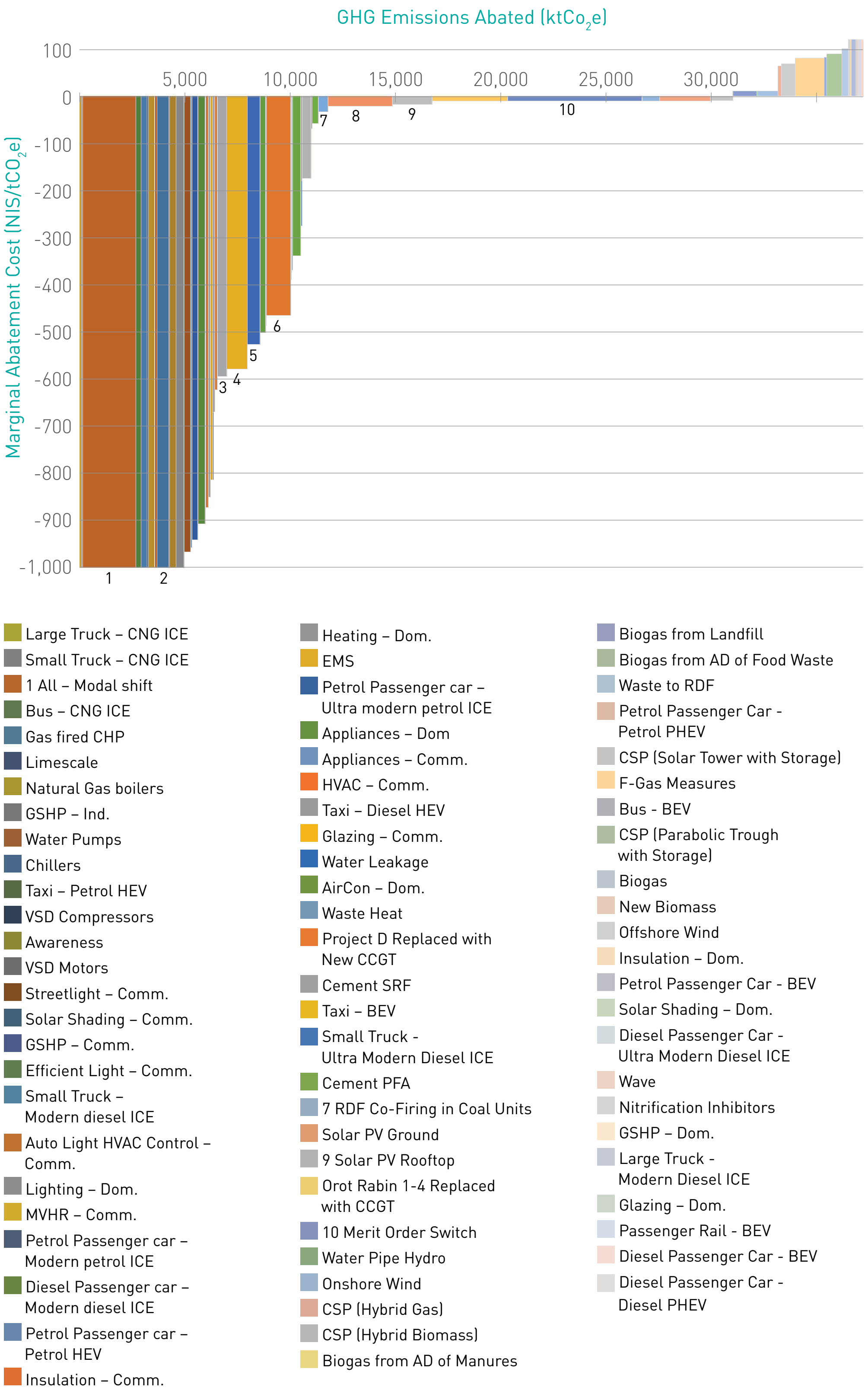
- The percentage of municipal solid waste that is landfilled in 2030 is reduced from approximately 50% in the BAU scenario to 18%.
- HFC emissions are reduced by 30% relative to BAU levels.

10.3 Abatement costs and economic impacts

Of the total GHG emission reduction potential that was assessed, approximately 80% was found to be cost-effective, without taking into account the cost of carbon (i.e., assuming a carbon cost of 0 NIS). These measures are represented by measures displayed below the x-axis on the MACC.

It should be noted that whilst the emission reduction potential presented in the MACC does account for interactions within each sector (for instance, the cumulative impacts of several measures that influence HVAC consumption in buildings), it does not account for interactions between the various sectors (most importantly, between electricity consumption and emissions from power generation). Therefore, the total abatement potential presented in the MACC represents an overestimation of the economy-wide abatement potential. Nonetheless, these interactions were accounted for by the LEAP model and are reflected in the target recommendation.

Figure 45 Economy-wide marginal abatement cost curve[95]



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[95] Note: Axes cut-off before full range of cost-effectiveness is shown. As such, several measures appear to have the same cost-effectiveness but this is a result of restricting the axes ranges.

As can be seen from Figure 45, the abatement measures vary considerably both in terms of emissions reduction potential (width of the measures on the horizontal axis) and cost effectiveness (height on the vertical axis). Among the cost-effective measures, those with the highest abatement potential include:

Table 106 Top 10 cost-effective measures in terms of reduction potential

Measure Name	Abatement potential in 2030 (ktCO$_2$e)	Cost-effectiveness (NIS/tCO$_2$e)
Merit Order Switch	6,136	5-
Solar PV Ground	3,052	22-
All - Modal shift	2,535	4291-
Solar PV rooftop	1,882	17-
HVAC - Commercial	1,170	467-
Energy management systems	984	580-
Petrol Passenger car - Ultra modern petrol ICE	599	528-
Chillers – industry	543	1069-
RDF co-firing in coal units	461	33-
Heating - domestic	442	596-
Total	**15,253**	

The analysis found that replacement of the Orot Rabin units 1-4 with a natural gas-fired combined cycle power plant could yield a significant emission reduction of 3,585 ktCO$_2$e, and would also be cost effective at NIS -11 per tCO$_2$e.

The measures implemented under the 'conservative target' scenario to 2025 will deliver a discounted net benefit to the Israel economy of around 133 NIS billion by 2025 over their lifetime, which increases to 218 NIS billion when considering all measures implemented to 2030.

As such the energy saving (and any operational cost saving) benefits associated with the measures considered (valued at 457 NIS billion for measures implemented to 2030) outweigh any additional investment or operating costs (valued at 239 NIS billion for measures implemented to 2030). These figures estimate the impacts over the full lifetime of the measures put in place, discounted to 2015. Note this does not include any valuation of the GHG emissions savings achieved by these measures.

The present value of the total gross economic benefits associated with meeting the conservative target are estimated at NIS 457 billion over the full lifetime of the measures, with present value of the total economic costs estimated at NIS 239 billion. As such, implementation of the conservative target is expected to yield a cumulative net economic benefit of approximately NIS 218 billion.

The net cost of measures varies across sectors. Measures delivered in the transport sector to 2030 are estimated to deliver the greatest net benefit of 159 NIS billion over their lifetime, and in particular, a large proportion of this is achieved through modal shift.

Large net benefits are also achieved through energy efficiency measures which yield a net benefit of NIS 56 billion: NIS 28 billion in industry, NIS 21 billion in commercial and public buildings, and NIS 7 billion in residential buildings.

Again these estimates do not include a valuation of the GHG emissions benefits achieved through the measures included in the 'conservative target' scenario.

Table 107 Economic impact of conservative target (Billion NIS, discounted to 2015)

Abatement Measure Category	Benefits	Costs	Net Benefits
Energy Efficiency	79.9	24.3	55.6
Renewable Energy	28.2	26.7	1.5
Merit Order Switch	4.0	3.1	0.9
Other Power Sector Measures	3.8	2.8	1.0
Modal Shift (Public Transport, walking/cycling)	305.1	155.8	149.3
Other Transport Measures	35.5	25.8	9.7
Other Measures	0.00	0.5	(0.5)
Total	**456.6**	**239.1**	**217.5**

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CONCLUSIONS & POLICY RECOMMENDATIONS

photograph: Knesset Spokesperson's Office

Based on the analysis conducted in this study, and in accordance with the conservative target, **the Government of Israel can adopt an economical GHG reduction target of 7.2 tCO_2e per capita for 2030, and an interim target of 7.5 tCO_2e per capita in 2025**.

Meeting this target is expected to **yield significant economic benefits for the country, estimated at NIS 218 billion**.

In formulating the policy framework required to meet this target, the implementation of the following key measures is recommended:

- Adoption of an energy efficiency target to reduce electricity consumption on the order of 18-20% by 2030.
- Adoption of a renewable energy target on the order of 22-23% of electricity generation in 2030.
- Adoption of a national target to reduce private vehicle use by 25% relative to BAU levels, by 2030.
- Adoption of policies to account for externality costs in the daily management and long-term planning of the power generation system. Externality costs can be accounted for in the management of the power generation system through implementation of a pollution levy, which is expected to yield a change in the power plant merit order (as assessed in this study) as well as generate significant government income that will enable promotion of energy efficiency, assistance to low income households as well as the middle class, and improved competiveness in Israeli industry.
- Establishment of a mechanism to approve renewable energy quotas whilst minimizing economic costs, through a market mechanism based on bidding for tariffs. This mechanism shall account for, among other things, the economic benefits of various generation technologies, including benefits from reduction of air pollution and greenhouse gases.
- Establishment of a national energy efficiency fund to promote and catalyze private investment in energy efficiency and GHG reductions; such funds can be used to target investments in low-income households as well as SMEs.
- Implementation of additional national energy efficiency measures, including provisions for the IEC and IPPs to carry out energy efficiency projects amongst consumers. These provisions could be linked to a mechanism for evaluating the 'value of the saved kWh'. Additionally, provisions should also be made in order to enable energy efficiency improvements to be financed by the power producer whilst allowing consumers to repay the loan via their electric bill.
- Adoption of the Israel Green Building Standard 5281 as a mandatory standard for new buildings, in a graduated manner and whilst taking into account socio-economic factors. Economic tools can be implemented to provide incentives and assistance in meeting this standard, through the national energy efficiency fund.

APPENDICES

Appendices

Appendix 1	Acknowledgements
Appendix 2	Glossary
Appendix 3	Transport sector data
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Appendix 5	BAU waste facilities
Appendix 6	CBS Emission Factors

Appendix 1 - Acknowledgments

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Appendix 2 - Glossary

Acronyms

BAU	Business as usual
CSP PT	Concentrated solar power – parabolic trough
CSP ST	Concentrated solar power – solar tower
CCGT	Combined cycle gas turbine
DECC	Department of Energy and Climate Change (UK)
GIS	Geographic information systems
GWh	Gigawatt hour
HFO	Heavy fuel oil
ICE	Internal combustion engine
IEC	Israel Electric Corporation
IPP	Independent power producers
IRENA	International Renewable Energy Agency
LPG	Liquefied petroleum gas
MW	Megawatt
NEC	National Economic Council
OCGT	Open cycle gas turbine
PUA	Public Utilities Authority
RDF	Refuse-derived fuel
Solar PV	Solar photovoltaic
VKM	Vehicle kilometres

Appendix 3 - Transport sector data

STOCK DATA

Israeli road transport vehicle stock (CBS, 2013 data projected out to 2030)

Stock	2013	2014	2020	2025	2030
Passenger car	2,338,687	2,394,344	2,736,235	3,061,827	3,426,161
Taxi	19,821	20,277	23,075	25,729	28,688
Minibus	14,238	14,537	16,369	18,087	19,987
Bus	16,917	17,272	19,449	21,491	23,747
Motorcycle	121,218	123,885	140,238	155,664	172,787
Small Truck	256,659	262,562	298,796	333,157	371,470
Large Truck	78,419	80,223	91,293	101,792	113,498
Passenger rail*	116	166	267	267	267
Freight rail*	197	232	439	439	439
e-Bike**	130,000	130,000	143,710	154,726	166,240
Walk or cycle**	8,119,060	8,119,060	8,975,339	9,663,331	10,382,422

*Growth rate assumed
**Growth rate assumed based on growth of Israeli population

FUEL EFFICIENCY

Fuel efficiency data (Alternative units)

Fuel efficiency (Alternative units)	Units	2013	2014	2020	2025	2030
Passenger car - Petrol	Km/L	11.20	11.38	12.60	13.39	14.18
Passenger car - Diesel	Km/L	16.00	16.25	18.00	19.13	20.25
Passenger car - Petrol hybrid	Km/L	14.40	14.63	16.20	17.21	18.23
Passenger car - Diesel hybrid	Km/L	17.76	18.04	19.98	21.23	22.48
Passenger car - Electricity	Km/kWh	3.50	3.54	3.83	4.00	4.17
Passenger car - LPG	Km/L	8.03	8.16	9.04	9.60	10.17
Motorbike – Petrol	Km/L	20.38	20.38	20.89	23.65	26.25
Motorbike – Electricity	Km/kWh	6.37	6.34	6.87	7.16	7.46
Taxi – Petrol	Km/L	11.20	11.38	12.60	13.39	14.18
Taxi – Diesel	Km/L	16.00	16.25	18.00	19.13	20.25
Taxi – Diesel hybrid	Km/L	17.76	18.04	19.98	21.23	22.48
Taxi – Electricity	Km/kWh	3.50	3.54	3.83	4.00	4.17
Taxi – LPG	Km/L	8.03	8.16	9.04	9.60	10.17
Bus – Diesel	Km/L	1.40	1.40	1.42	1.45	1.48
Bus – CNG	Km/Kg	1.85	1.85	1.87	1.91	1.96
Minibus – Diesel	Km/L	6.72	6.77	7.15	7.31	7.48
Minibus – Hybrid diesel	Km/L	7.39	7.45	7.87	8.04	8.22
Truck ←3.5t – Petrol	Km/L	6.40	6.50	7.20	7.50	7.80
Truck ←3.5t – Diesel	Km/L	8.78	8.85	9.35	9.78	10.20
Truck ←3.5t – Hybrid diesel	Km/L	11.17	11.46	13.50	14.25	15.00

Fuel efficiency (Alternative units)	Units	2013	2014	2020	2025	2030
Truck →3.5t – Petrol	Km/L	2.14	2.15	2.38	2.53	2.68
Truck →3.5t – Diesel	Km/L	3.06	3.08	3.18	3.24	3.30
Truck →3.5t – CNG	Km/Kg	3.09	3.09	3.36	3.48	3.60
Passenger rail – Diesel	Km/L	0.16	0.16	0.17	0.17	0.18
Passenger rail – Elec	Km/kWh	0.04	0.04	0.05	0.05	0.05
Freight rail – Diesel	Km/L	0.14	0.14	0.14	0.14	0.15
Freight rail – Elec	Km/kWh	0.04	0.04	0.04	0.04	0.04
Light rail and Metro	Km/kWh	0.10	0.10	0.10	0.10	0.10
e-Bike	Km/kWh	17.50	17.68	17.68	17.68	17.68

Fuel efficiency data (pkm/tkm units)*

Fuel efficiency (pkm/tkm units)	Units	2013	2014	2020	2025	2030
Passenger car - Petrol	gCO$_2$/pkm	217.40	214.05	193.24	181.88	171.77
Passenger car - Diesel	gCO$_2$/pkm	150.64	148.33	133.91	126.03	119.03
Passenger car - Petrol hybrid	gCO$_2$/pkm	169.09	166.49	150.30	141.46	133.60
Passenger car - Diesel hybrid	gCO$_2$/pkm	135.71	133.63	120.64	113.54	107.23
Passenger car - Electricity	gCO$_2$/pkm	132.85	131.28	121.29	116.24	111.59
Passenger car - LPG	gCO$_2$/pkm	100.62	99.07	89.44	84.17	79.50
Motorbike – Petrol	gCO$_2$/pkm	141.98	141.98	138.49	122.35	110.22
Motorbike – Electricity	gCO$_2$/pkm	86.76	87.08	80.46	77.10	74.02
Taxi – Petrol	gCO$_2$/pkm	104.35	102.75	92.76	87.30	82.45
Taxi – Diesel	gCO$_2$/pkm	72.31	71.20	64.27	60.49	57.13
Taxi – Diesel hybrid	gCO$_2$/pkm	65.14	64.14	57.91	54.50	51.47
Taxi – Electricity	gCO$_2$/pkm	63.77	63.02	58.22	55.80	53.56
Taxi – LPG	gCO$_2$/pkm	48.30	47.55	42.93	40.40	38.16
Bus – Diesel	gCO$_2$/pkm	83.49	83.49	82.44	80.73	78.89
Bus – CNG	gCO$_2$/pkm	63.46	63.46	62.67	61.37	59.97
Minibus – Diesel	gCO$_2$/pkm	53.83	53.40	50.57	49.44	48.37
Minibus – Hybrid diesel	gCO$_2$/pkm	48.93	48.54	45.97	44.95	43.97
Truck ←3.5t – Petrol	gCO$_2$/tkm	992.47	977.20	882.19	846.91	814.33
Truck ←3.5t – Diesel	gCO$_2$/tkm	715.87	710.14	672.48	643.25	616.44
Truck ←3.5t – Hybrid diesel	gCO$_2$/tkm	563.08	548.75	465.76	441.24	419.18
Truck →3.5t – Petrol	gCO$_2$/tkm	184.33	183.43	165.60	155.86	147.20
Truck →3.5t – Diesel	gCO$_2$/tkm	127.73	127.11	122.91	120.64	118.44
Truck →3.5t – CNG	gCO$_2$/tkm	126.70	126.70	116.52	112.50	108.75
Passenger rail – Diesel	gCO$_2$/pkm	69.35	68.66	66.72	65.40	64.11
Passenger rail – Elec	gCO$_2$/pkm	49.86	49.36	47.97	47.02	46.09
Freight rail – Diesel	gCO$_2$/tkm	32.95	32.62	31.70	31.07	30.46
Freight rail – Elec	gCO$_2$/tkm	23.69	23.45	22.79	22.34	21.90
Light rail and Metro	gCO$_2$/pkm	135.60	134.26	134.26	134.26	134.26
e-Bike	gCO$_2$/pkm	31.56	31.25	31.25	31.25	31.25

*Load factors used to calculate the above are below

Assumed load factors

Load Factor (persons or tonnage per vehicle)	Load	Value	Source
Passenger car	Persons	1.20	McKinsey (2009)
Motorbike	Persons	1.01	Estimate
Taxi	Persons	2.50	Estimate
Bus	Persons	24.70	McKinsey (2009)
Minibus	Persons	8.00	Estimate
Truck ←3.5t	Tonnes	0.46	UK value (DECC Conversion Factors 2014)
Truck →3.5t	Tonnes	7.40	UK value (DECC Conversion Factors 2014)
Passenger rail	Persons	255.50	Based on vkm and pkm data from CBS in 2013
Freight rail	Tonnes	649.70	Based on vkm and tkm data from CBS in 2013
Light rail and Metro	Persons	40.00	Estimate
E-bike	Persons	1.01	Estimate

Assumed BAU efficiency scenario improvement (% reduction from 2013 MJ/km values)

Fuel efficiency improvement (%)	2013	2014	2020	2025	2030
Passenger car - Petrol	100%	98%	89%	84%	79%
Passenger car - Diesel	100%	98%	89%	84%	79%
Passenger car - Petrol hybrid	100%	98%	89%	84%	79%
Passenger car - Diesel hybrid	100%	98%	89%	84%	79%
Passenger car - Electricity	100%	99%	91%	88%	84%
Passenger car - LPG	100%	98%	89%	84%	79%
Motorbike – Petrol	100%	100%	98%	86%	78%
Motorbike – Electricity	100%	100%	93%	89%	85%
Taxi – Petrol	100%	98%	89%	84%	79%
Taxi – Diesel	100%	98%	89%	84%	79%
Taxi – Diesel hybrid	100%	98%	89%	84%	79%
Taxi – Electricity	100%	99%	91%	88%	84%
Taxi – LPG	100%	98%	89%	84%	79%
Bus – Diesel	100%	100%	99%	97%	94%
Bus – CNG	100%	100%	99%	97%	94%
Minibus – Diesel	100%	99%	94%	92%	90%
Minibus – Hybrid diesel	100%	99%	94%	92%	90%
Truck ←3.5t – Petrol	100%	98%	89%	85%	82%
Truck ←3.5t – Diesel	100%	99%	94%	90%	86%
Truck ←3.5t – Hybrid diesel	100%	97%	83%	78%	74%
Truck →3.5t – Petrol	100%	100%	90%	85%	80%
Truck →3.5t – Diesel	100%	100%	96%	94%	93%
Truck →3.5t – CNG	100%	100%	92%	89%	86%
Passenger rail – Diesel	100%	99%	90%	94%	92%
Passenger rail – Elec	100%	99%	90%	94%	92%
Freight rail – Diesel	100%	99%	90%	94%	92%
Freight rail – Elec	100%	99%	90%	94%	92%

Fuel efficiency improvement (%)	2013	2014	2020	2025	2030
Light rail and Metro	100%	99%	99%	99%	99%
e-Bike	100%	99%	99%	99%	99%

Lifetime age used in MACC analysis

Mode	Powertrain Types	Lifetime age
Passenger car	Petrol PHEV	14
Passenger car	Diesel PHEV	14
Passenger car	BEV	14
Passenger car	Petrol HEV	14
Passenger car	Diesel HEV	14
Passenger car	Modern petrol	14
Passenger car	Ultra-modern petrol	14
Passenger car	Modern diesel	14
Passenger car	Ultra-modern diesel	14
Taxi	Petrol HEV	5
Taxi	Diesel HEV	5
Taxi	BEV	5
Bus	BEV	15
Bus	CNG ICE	15
Small Truck	Modern diesel	12
Small Truck	Ultra-modern diesel	12
Small Truck	CNG ICE	12
Small Truck	Diesel HEV	12
Large Truck	CNG ICE	9
Large Truck	Modern diesel	9

FUEL USE AND EMISSIONS RESULTS

Detailed transport fuel use by mode (BAU)

Fuel use by mode (PJ)	2015	2020	2025	2030
Passenger Car	110.4	112.0	116.3	120.9
Taxi	3.8	3.8	4.0	4.2
Bus	25.5	27.8	30.1	32.6
Minibus	4.0	4.2	4.5	4.9
Motorcycle	1.5	1.6	1.5	1.6
Small Truck	26.6	27.9	29.6	31.4
Large Truck	36.8	40.1	44.0	48.2
Passenger rail	2.3	3.7	3.6	3.6
Freight rail	0.5	0.9	0.9	0.9
Ebike	0.1	0.1	0.1	0.1
Shipping	0.0	0.0	0.0	0.0
Aviation	13.9	15.4	15.1	15.0
Walk/Cycle	-	-	-	-
Total	**225.4**	**237.4**	**249.9**	**263.3**

Detailed transport emissions by mode (BAU)

Emissions by mode (kt CO_2)	2015	2020	2025	2030
Passenger Car	9,800	9,902	10,240	10,566
Taxi	299	305	318	334
Bus	2,034	2,206	2,370	2,563
Minibus	316	333	359	389
Motorcycle	130	141	138	138
Small Truck	2,156	2,248	2,376	2,503
Large Truck	2,936	3,179	3,482	3,813
Passenger rail	170	278	272	267
Freight rail	42	72	71	69
Ebike	-	-	-	-
Shipping	-	-	-	-
Aviation	1,019	1,124	1,108	1,100
Walk/Cycle	-	-	-	-
Total	**18,903**	**19,786**	**20,735**	**21,742**

Transport emissions use by fuel (BAU)

Emissions by fuel(kt CO_2)	2015	2020	2025	2030
Gasoline	9,891	9,701	9,708	9,426
Diesel	7,962	8,762	9,528	10,793
CNG	31	198	391	423
Jet Fuel	1,019	1,124	1,108	1,100
Total	**18,903**	**19,786**	**20,735**	**21,742**

MACC RESULTS WITHOUT EXTERNALITY COSTS

This section shows abatement potential and costs but excluding the external costs associated with the abatement measures. Externalities are applied to factor in positive or negative benefits to each measure, out with the bounds of GHG reduction potential. Externality costs take into account such factors as;

- Air quality
- Noise
- Safety and
- Congestion.

Assumptions were made on the external costs of all measures investigated however in the analysis below, these have been excluded. You will notice that measures become less cost effective without externalities factored in as external benefits (such as those listed above).

MACC results without externality costs included

Technology	2030		2025	
	kt CO_2	Annual cost (NIS) per t CO_2	ktCO_2	Annual cost (NIS) per tCO_2
Large Truck - CNG ICE	90.28	-6271.00	46.81	-5676.88
Small Truck - CNG ICE	56.29	-6310.09	36.93	-5228.22
Bus - CNG ICE	244.29	-2957.03	116.54	-2550.32
Taxi - Petrol HEV	48.93	-1041.28	27.33	-800.01
Small Truck - Modern diesel ICE	28.96	-811.94	25.13	-708.46
Petrol Passenger car - Modern petrol ICE	46.48	-783.14	138.89	-668.94
Petrol Passenger car - Ultra modern petrol ICE	598.53	-518.29	333.71	-418.80
Petrol Passenger car - Petrol HEV	57.13	-655.69	76.45	-305.67
Small Truck - Ultra modern diesel ICE	41.58	-41.18	25.91	30.19
Taxi - Diesel HEV	12.43	-188.67	6.53	218.85
Taxi - BEV	17.90	-29.30	12.74	428.41
Diesel Passenger car - Ultra modern diesel ICE	32.96	499.83	18.37	526.90
Petrol Passenger car - Petrol PHEV	173.73	75.69	145.93	666.05
Bus - BEV	124.54	110.67	79.39	690.87
Petrol Passenger car - BEV	206.56	343.17	98.75	1590.75
Large Truck - Modern diesel ICE	18.98	1560.12	17.32	1626.45
Passenger rail - BEV	96.78	2776.92	80.79	1711.44
All - Modal shift	2535.31	4478.20	1162.26	4728.88
Diesel Passenger car - BEV	110.77	3296.86	53.86	5204.57
Diesel Passenger car - Diesel PHEV	7.57	5262.53	9.79	5779.80

Appendix 4 - Power sector data

Costs for all generation capacity (2015) (O - operation; M - maintenance)

Plant Type	Capital Cost ($/kW)	Fixed O&M ($//kW)	Variable O&M ($/MWh)	Source
IEC Coal Steam Generator	2180	45.6	3.5	Ministry of Energy
Orot Rabin 1-4	2180	45.6	3.5	As above
IEC NG Steam Generator	2180	45.6	3.5	Ministry of Energy
IEC Diesel Gas Turbine	800	42	5.5	PUA
IEC OCGT NG	800	42	2.5	PUA
IEC Jet Gas Turbine	800	42	5.5	PUA
IEC CCGT E	1200	42	3	PUA
IEC CCGT F	1200	42	3	PUA
IEC Project D	2180	45.6	3.5	Ministry of Energy
IPP CCGT F	1200	42	3	PUA
IPP OCGT NG	800	36	2.5	PUA
IPP OCGT HFO	800	42	5.5	PUA
IPP Cogeneration CCGT F	1200	42	3	PUA
IPP Cogeneration OCGT	800	42	2.5	PUA
IPP Cogeneration NG Steam Generator	2180	45.6	3.5	Ministry of Energy
IPP Cogeneration Diesel Turbine	800	42	2.5	PUA
Solar PV (Ground)	1392.9	27.9	0	Bloomberg
Solar PV (Rooftop)	1513	30.3	0	Bloomberg
CSP Solar Tower*	6739	0***	27	PUA
CSP Parabolic Trough**	4658 / 8253	0***	27	PUA
CSP Hybrid (NG)	5775	54	1.3	Manufacturer's figures with uplift
CSP Hybrid (Biomass)	5941	56	1.3	Manufacturer's figures with uplift
Biogas	4500	0***	70	PUA
New biomass	2,870.6	106.2	70	IRENA
Onshore Wind	1991	27.2	7.5	UK DECC
Offshore Wind	3705	92.8	65	UK DECC
Water Pipe Hydro	5000	125	0	Manufacturer's data
Wave	6799.8	97.8	0	UK DECC

*Cost includes localised storage
**Cost without / with cost of localised storage
***Fixed OPEX included in variable OPEX figure

Appendix 5 - BAU waste facilities

Facility type	Opening year[96]	Annual amount (tonnes)	Site
Organic recycling		219,000	Tuvlan
	2016	91,250	Efeh
	2014	73,000	Avlaim composting
	2017	109,500	Hiun Cooperative composting
	2014	36,500	Bnei Shimon composting
	2017	226,300	Bnei Shimon composting
Anaerobic digestion		1,825	Tambor, Chefer, and partners Ecology - Anaerobic digestion
		73,000	Arrow ecology Anaerobic digestion
	2017	73,000	Evron Anaerobic digestion
	2017	36,500	Univerve Biogas Energy, anaerobic digestion
	2013	12,775	Tambor, Chefer, and partners anaerobic digestion
	2017	365,000	PPP
	2016	146,000	SIE Ashkelon
	2016	124,100	Green net
	2017	74,460	Talia
	2017	54,750	Ashdod municipality
	2016	73,365	Arrow ecology
	2017	73,730	Maale Adumim
	2016	36,500	Eilat
	2018	73,000	Compost Or-Tuvlon Anaerobic digestion
RDF	2017	182,500	Hiriya RDF

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[96] NWhere no date is given, the site is already operational.

Appendix 6 - CBS Emission Factors

Ton emission per ton fuel	CO_2
Other Bituminous Coal	2.320
Gas/Diesel Oil	3.177
Residual Fuel Oil	3.078
Natural gas	2.775
Oil Shale	0.419
Other Kerosene	3.184
LPG	1.641
Naphtha	0.654
Jet Kerosene	3.156
Petroleum Coke	3.511
Gasoline	3.074

N_2O

Kg emission per 1000 ton fuel	Energy production/ refinery	Industry	Aviation	Transportation	Bunker fuel	Household/ commercial	Agricultural
Other Bituminous Coal	35.0	-	-	-	-	-	-
Gas/Diesel Oil	26.0	26.0	-	26.0	26.0	26.0	26.0
Residual Fuel Oil	24.1	24.1	-	-	24.1	-	24.1
Natural gas	5.0	5.0	-	-	-	5.0	-
Oil Shale	2.4	-	-	-	-	-	-
Other Kerosene	26.9	26.9	-	-	26.9	26.9	26.9
LPG	28.4	28.4	-	-	28.4	28.4	28.4
Naphtha	27.0	27.0	-	-	-	-	-
Jet Kerosene	-	-	26.8	-	-	-	-
Petroleum Coke	-	21.1	-	-	-	-	-
Gasoline	-	-	-	26.9	-	-	-

CH_4

Kg emission per 1000 ton fuel	Energy production/ refinery	Industry	Aviation	Transportation	Bunker fuel	Household/ commercial	Agricultural
Other Bituminous Coal	25.0	-	-	-	-	-	-
Gas/Diesel Oil	130.0	86.7	-	216.7	216.7	433.3	433.3
Residual Fuel Oil	120.6	80.4	-	-	201.0	-	401.9
Natural gas	49.7	248.6	-	-	-	248.6	-
Oil Shale	11.9	-	-	-	-	-	-
Other Kerosene	134.3	89.5	-	-	223.8	447.5	447.5
LPG	141.9	94.6	-	-	236.6	473.1	473.1
Naphtha	135.0	90.0	-	-	-	-	-
Jet Kerosene	-	-	22.3	-	-	-	-
Petroleum Coke	-	70.3	-	-	-	-	-
Gasoline	-	-	-	896.0	-	-	-

Appendices 7 - 9 (Hebrew Only)

- Key Policy Measures Compiled by the Sectoral Working Groups
- Carbon and Pollution Pricing: Alternatives for Implementation in Israel
- Assessment of Energy Efficiency and GHG / Pollution Reduction Mechanisms in Israel