Evaluation of Greenhouse Gas Emissions in Eilat

by

Rosalyn Bates
Samantha Marcil
David Schwartz

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by
Rosalyn Bates
Samantha Marcil
David Schwartz

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Report Submitted to:

Elad Topel
Eilat Municipality

Assaf Admon
Eilat Municipality

Professors John-Michael Davis and Isa Bar-On
Worcester Polytechnic Institute

ABSTRACT

The City of Eilat is a member of the Global Covenant of Mayors for Climate and Energy, an international coalition of cities working to combat climate change. Members report their greenhouse gas emissions and progress on emission reduction policies. Eilat is required to submit an updated emissions inventory for 2019. This report contains an introduction to the issues of climate change in Eilat, as well as information on electricity usage, transportation, and disposal of municipal solid waste to estimate Eilat's greenhouse gas emissions during 2019.

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CHAPTER 1: INTRODUCTION

The Times of Israel reported on a record-breaking heatwave in May 2020 (TOI Staff, 2020). Temperatures reached as high as 48^{o}C (118.4^{o}F) leading to deaths from heatstroke, emergent wildfires, and record electric power consumption from air-conditioning. The May 2020 heatwave signified to the public the prominent effects of climate change in the Israel-Palestine region. Over the past 70 years, average annual temperatures in Israel increased by 1.4^{o}C, and current models predict a further increase of 1℃ over the next 30 years. Summer-time high temperatures continue to set records and annual precipitation is declining (*Climate Change in Israel*, 2019).

Eilat is a coastal city on the southernmost tip of the Negev desert and is vulnerable to the effects of climate change. Already having an arid climate, the movement to further hot and dry conditions threatens environmental stability and agricultural yields. Consumption of electricity will rise as air-conditioning units increase their load on the electrical grid. Eilat's economy is tourist-driven, hosting approximately 2.5 million overnight visitors in 2018 (Kavaler, 2019). Permanent residents in 2019 numbered 52,299 people (Central Bureau of Statistics, 2020a), and Kissinger et al. (2016) estimated there are 29,000 domestic and foreign visitors at a given time. The offshore coral reefs are a major tourist attraction, yet these habitats are threatened by climate change due to the warming and acidification of ocean water (Fine et al., 2013). The rising temperature and frequency of heatwaves could decrease tourism, and over the long term, compromise the habitability of the region.

Climate change, while typically addressed by national governments, is also being addressed at the city level to circumvent national bureaucracy. In 2015, the City of Eilat became a signatory to the Global Covenant of Mayors for Climate and Energy (GCoM). The GCoM was formed to address greenhouse gas (GHG) emissions in cities and promote adaptation to the effects of climate change. The GCoM works with signatories to compile information about the cities' GHG emissions and climate change mitigation actions. Eilat is in the process of submitting updated information to the GCoM for 2019.

This project evaluated Eilat's progress towards a 20% reduction in GHG emissions relative to 2014. Our evaluation served as a Monitoring Emissions Inventory (MEI) for the GCoM. The

MEI reports Eilat's GHG emissions in 2019 and analyzes the efficacy of implemented emission reduction measures.

In the following section, we describe the role of the GCoM, Eilat's largest emission sources - electricity, transportation, and municipal waste – and discuss measures Eilat has implemented to reduce GHG emissions. The remainder of the report is broken down by type of emissions source: electricity, transportation, and municipal solid waste. Each of these sections presents the methods, results, and discussion pertaining to its emissions source. In the concluding section, we bring together the separate emissions analyses and report the aggregate GHG emissions produced by the city. Comparison to the 2014 GHG emissions shows Eilat has not yet achieved its goal of a 20% reduction. Rather, our calculations estimate a 4.5% reduction from 2014 to 2019. Emissions from electric power consumption decreased due to the incorporation of regional solar energy. Transportation emissions increased due to the greater number of registered vehicles in the city. Emissions from solid waste were unable to be directly compared to those reported previously. While the amount of waste deposited in the landfill has increased, Eilat's methane recapture program has mitigated emissions from waste decomposition.

Lastly, we propose additional reduction measures to further mitigate Eilat's GHG emissions. Within electric power, we show that investment in energy storage solutions will allow Eilat to utilize renewable energy more effectively. Within transportation, we recommend improvements to the public transportation system. Within municipal solid waste, we recommend a recycling program for paper and cardboard.

CHAPTER 2: THE GLOBAL COVENANT OF MAYORS

The Global Covenant of Mayors (GCoM) formed in 2014 to promote climate action plans among its members and reduce environmental impact at the municipal level. Signatories on the GCoM must submit a Baseline Emission Inventory (BEI), a Sustainable Energy Action Plan (SEAP), and Monitoring Emission Inventories (MEI). Signatories must also identify their chosen emission reduction targets. The BEI provides signatories with a starting point to judge any progress they make towards emission reduction. The SEAP outlines which actions signatories plan to take to meet their stated emission goals. By submitting an MEI every two years, the GCoM and signatories can keep track of whether they are meeting their stated goals (Rivas et al., 2018). After joining the GCoM, Eilat submitted their BEI in 2016 and their SEAP in 2018. In the SEAP, Eilat aimed for a 20% reduction in GHG emissions by 2020, relative to their 2014 emission levels. Eilat's next step is to submit their first MEI. The purpose of this report is therefore to serve as a 2019 MEI for the city.

The GCoM provides signatories with resources to reduce greenhouse gas (GHG) emissions, including funding, reporting guidelines, and centralized data. The GCoM also has an initiative to make emissions data accessible to the public, allowing cities to compare policies. Funding for signatories is available through direct funding to public and private entities, as well as through loans and non-traditional funding methods, such as crowd-funding (*Support*, n.d.). The GCoM recommends that signatories report emissions using the Global Protocol for Community-Scale Greenhouse Gas Emissions (GPC).

The GPC requires that cities report emissions using two frameworks: emissions for a specific area and emissions generated by the city. These manifest as the three "scopes" illustrated in *Figure 1*. The first scope involves direct emissions inside the city limits. The second scope evaluates indirect emissions from electric power demand by the city. The third scope involves emissions resulting from activities outside of city limits. The MEI focuses on select sources within Scopes 1 and 2, based on the availability of data. Within Scope 1, we report emissions from transportation within the city and municipal solid waste. However, emissions from transportation fall between Scopes 1 and 3, because the form of our transportation data necessitates including out-of-boundary emissions from vehicles registered in Eilat. From Scope

2, we report electric energy generation, considering the emissions profiles of different sources of generation. Estimates for transmission losses under Scope 3 are included as well.

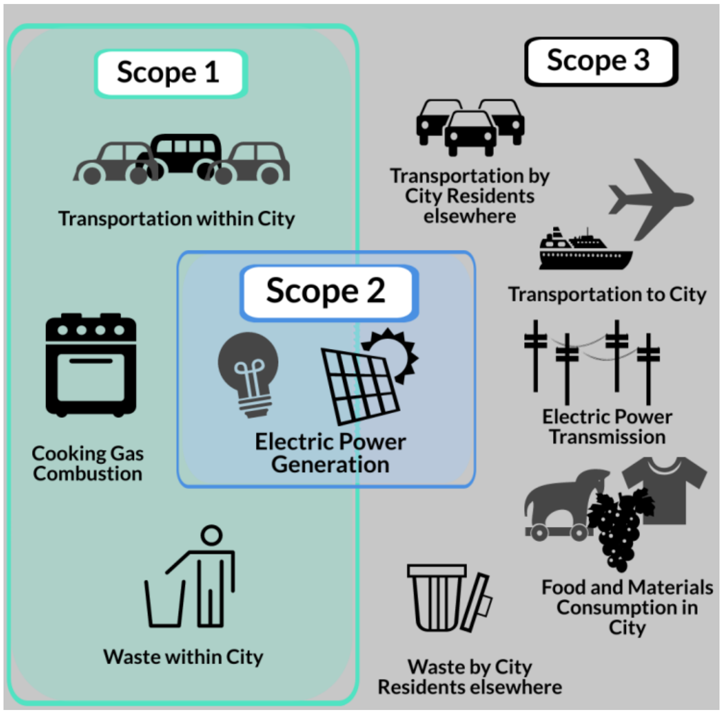

Figure 1. Greenhouse Gas Reporting Scopes

2.1 Baseline Emissions Inventory

As a member of the GCoM, Eilat submitted a Baseline Emissions Inventory (BEI) in 2016 (Kissinger et al., 2016). Emissions are reported in carbon dioxide equivalents (CO_2 eq), which equate all greenhouse gases to a quantity of CO_2 with the same global warming potential[1]. The BEI estimated 2014 GHG emissions in Eilat using 2012 electricity consumption data and 2014 transportation, waste, and liquified petroleum gas data. The BEI did not account for the electricity generation from emissionless sources such as photovoltaics (solar cells). In addition, due to the unavailability of particular data, multiple assumptions were made to determine the emissions factor for the private 4-wheel vehicles (Kissinger et al., 2016).

The BEI showed that the three largest contributors to greenhouse gas emissions in Eilat were commercial electricity, residential electricity, and private transportation. 79% of emissions

[1] Global warming potential is (GWP) is a measure of a gas's ability to absorb infrared radiation, normalized to that of CO_2. GWPs depend on time frame, because different gases remain in the atmosphere for different periods of time. 100 years is the standard time frame under which to report. See: Understanding Global Warming Potentials | Greenhouse Gas (GHG) Emissions | US EPA

resulted from the generation of electricity via fossil fuels and 14% of emissions came from gasoline-fueled vehicles.

The BEI report also analyzed GHG emissions by various sectors - public, household, commercial, and industrial. The commercial sector generated the most GHG emissions as it accounted for 58% of total emissions, followed by the residential sector at 35% of total emissions (Kissinger et al., 2016). These results enabled Eilat to target specific sectors with emissions reduction measures.

2.2 Sustainable Energy Action Plan (2018)

Signatories to the GCoM must also submit a Sustainable Energy Action Plan (SEAP) that includes information about the city's emission reduction initiatives and reduction targets (Rivas et al., 2018). Eilat submitted an SEAP in 2018. Eilat's SEAP reiterates the BEI's findings and expands on what future emissions will look like if no further action is taken. The review of the findings is followed by potential reduction methods and some examples of what had already been implemented prior to writing the SEAP.

The SEAP outlines the three main sectors in Eilat that are implementing GHG reduction measures. These are the municipal government, commercial sector, and city residents (Kissinger & Damari, 2018). Over the past decade, Eilat has planned, promoted, and implemented several measures to reduce GHG emissions. Most of these measures pertain to electricity use or transportation, as these two domains have the greatest emission contributions according to the BEI. Notable measures include adoption of solar energy alternatives, improving energy efficiency in electric appliances and building structure, and promoting hybrid vehicles. We discuss these initiatives below.

2.2.1 Implementation of Solar Power in Eilat

Solar-derived power constitutes the largest source of renewable energy in Israel. The Eilat-Eilot region, including the Southern Arava Valley, receives a large quantity of solar radiation throughout the year. Average annual solar insolation is 2157 kWh/m^2 per year[2]. This degree of

[2]Data on Eilat's solar resource came from PVWatts, an online tool developed by the National Renewable Energy Lab to help to predict the performance of photovoltaics. pvwatts.nrel.gov

irradiance makes solar harvesting technologies the leading prospect for renewable and emissionless power generation in the region. Prominent technologies currently leveraging insolation in Eilat and the Southern Arava include solar water heaters, solar-thermal generators, and photovoltaics (solar panels). Implementation of these technologies is a coordinated effort on the national, municipal, and civilian levels.

Israel has pursued solar water-heaters as an alternative energy solution to conventional gas heating, which in Eilat is liquified petroleum gas (LPG). Newly constructed residential buildings are required by law to install these systems, and as a result the nation is a world leader in per-capita use of solar water heating (Udasin, 2014). In our survey of rooftops using Eilat's geographical information system (***3.1.2 Photovoltaics***), every residential building in Eilat had at least one solar water heater. Most houses had one heater, while apartment buildings had several, one for each unit in the building.

Photovoltaics are the preeminent emissionless source of electrical energy for Israel. Solar panels can be implemented on both small and large scales. Small scale use involves private installation of solar panels on the roofs of buildings and homes. The city of Eilat has promoted solar panel adoption through economic incentives such as tax deductions. Municipal buildings have installed solar panels as well. The Eilat Environmental Unit hopes that municipal solar projects will encourage the private sector to install solar projects of their own. To promote this initiative, the Eilat-Eilot Renewable Energy Company has worked with the company "SolView", a data-analytics company, to develop the SolView software tool that guides homeowners through selecting photovoltaic modules and systems for their home.

The up-front cost of solar technologies can be difficult for an individual customer to afford. An alternative is large-scale solar projects that distribute power through a centralized electrical grid. The Eilat-Eilot Renewable Energy nonprofit has worked with the Arava Power Company (as well as international investors) over the past two decades to construct utility-scale solar plants in the Southern Arava. The projects total a combined rated production of nearly 190 MW and are consistently able to supply 70% of the daytime energy needs to the region (*Eilat-Eilot Renewable Energy*, n.d.). The long-term goal of Eilat-Eilot Renewable Energy is to power the region with 100% renewable sources. This will involve constructing new solar fields and investing in energy storage solutions such as battery stations and pumped-hydro turbines.

2.2.2 Additional Measures

After discovering that streetlights accounted for approximately 40% of municipal electricity consumption in Eilat, city planners replaced existing streetlights with more energy-efficient LEDs (Kissinger & Damari, 2018). By 2019, 14,000 upgrades were complete, reducing annual consumption by 6 GWh, roughly a 75% decrease from streetlights in 2014.

Eilat has introduced other energy efficiency initiatives in public buildings, including schools, community and recreational centers, libraries, and government buildings. These initiatives involve efficient indoor lighting, improved air-conditioning units, and better building insulation. The municipal government has incentivized businesses to adopt conservation practices and install more efficient appliances in buildings. The municipality has also introduced new design guidelines to make buildings more energy efficient (Kissinger & Damari, 2018). Eilat will continue encouraging energy efficiency by using an ad campaign, smart meters, and remote control of electrical appliances.

The municipality also looked at reducing emissions from transportation within the city. Private vehicles made up the largest source of transportation emissions in 2014 so the municipality made plans to promote the use of public transportation in the city. To encourage city residents to transition to hybrid and electric vehicles, the municipality planned to switch the municipal fleet of vehicles to hybrid and electric vehicles.

Table 1 outlines all the emissions reduction measures mentioned in the SEAP. The measures are categorized by sector responsible for implementation as well as the status of the measures as of 2018. The emission reduction measures in the SEAP were organized by the City of Eilat and targeted the largest areas of emissions based on the 2016 BEI.

Table 1: *GHG Emission Reduction Measures in Eilat as of 2018*

Policy	Sector	Status
Solar Panels	Residential/Municipal	In Progress[1]
Solar Water Heaters	Residential/Municipal	Completed[2]
Efficient Streetlights	Municipal	Completed
Efficient Indoor Lights	Municipal	Planned[3]
Improved Air-Conditioning Units	Municipal	In Progress
Building Insulation	Municipal/Commercial	Planned
Energy Conservation Practices	Commercial	Planned
Efficient Appliances	Residential/Municipal/Commercial	In Progress
Water Management System	Municipal/Residential	Completed
Electric/Hybrid Vehicles	Municipal	Planned
Increased Public Transportation	Residential	Planned

[1]In progress - Started to be implemented in 2018 but not finished
[2]Completed - Finished as of 2018
[3]Planned - Proposed measure in 2018 SEAP

2.3 Introduction to the Monitoring Emissions Inventory

The GCoM expects an updated MEI from its signatories every two years. This report is the first Monitoring Emissions Inventory (MEI) for Eilat, providing updated information on GHG emissions from the city. Changes in emissions compared to the 2014 data will be analyzed with respect to electricity, transportation, and waste emissions. However, unlike the 2016 BEI, we did not have data pertaining to different economic sectors in the city, these being the residential, commercial, municipal, and industrial sectors. GHG emissions were therefore categorized only by source (electricity, transportation, and waste).

EILAT CITY

MONITORING EMISSIONS INVENTORY 2021

Survey of 2019 Greenhouse Gas Emissions in Eilat

This MEI is submitted as part of the Eilat Municipality's obligations under the Global Covenant of Mayors for Climate and Energy.

Authors of the Report:

Rosalyn Bates, Samantha Marcil, David Schwartz

CHAPTER 3: ELECTRIC POWER

Greenhouse gas emissions due to electric power consumption result from the combustion of fossil fuels to drive electric generators. The semi-private Israel Electric Corporation (IEC) owns and operates Israel's natural gas and coal power plants, as well as the nation's electrical grid for the transmission and distribution of electrical power. Power delivered to loads connected to the grid, including the substation connected to Eilat, are measured and recorded by the IEC. An IEC plant containing three gas turbines[3] exists in Eilat. Photovoltaics (PVs) are on rooftops in Eilat, and utility-scale PV fields are present in the Eilat-Eilot region and Southern Arava Valley. Unlike fuel-driven turbines, photovoltaics do not emit greenhouse gases when generating electric power. Gas turbines cooperate well with renewables because they can change their output quickly in response to changing loads.

3.1 Methods

In general, deriving carbon emissions from electric power usage involves collecting the raw consumption data, subtracting supply from photovoltaics, and applying the appropriate IEC emissions factor. The emissions factor relates electric energy generated to greenhouse gas emitted from the combustion of a fossil fuel (in weight CO_2 eq/Watt-hour). Performing this computation requires data on the city's power demand, composition of generation from renewables and fossil fuels, and emission factors for fossil-fuel-based generators. This is most accurately computed on an hourly basis (**3.1.4 Calculating Carbon Emissions**).

3.1.1 Power Demand in Eilat

Information on power demand and emission factors were obtained from the Israel Electric Corporation (IEC). The IEC annually publishes environmental reports that include energy and emissions data for its facilities (*Annual Environmental Reports*, n.d.). These include emissions factors for both coal-fired and natural gas-fired turbines, as well as an averaged emission factor pertaining to the national electric grid that includes typical transmission losses. The IEC measures the power demand of consumers throughout the year to bill its customers. Since semi-

[3] "Gas turbine" refers to the air-fuel mixture sent through the system's compressor. The fuel is usually a natural gas (methane), but the technology is flexible and can use petroleum derivatives instead.

privatization in 2012, the IEC no longer provides public access to consumption data within cities and their various sectors. However, our sponsors from the Eilat Environmental Unit were able to extract Eilat's power draw by hour for the entire year of 2014. The total for 2014 is 715.121 GWh. *Figure 2* shows the energy utilized during each month, and *Figure 3* shows the power demand throughout a typical day in each month. Emission factors were obtained from the Israel Electric Corporation (IEC). Consumption is greatest during summer months due to the influx of tourists and increased load from air conditioning systems.

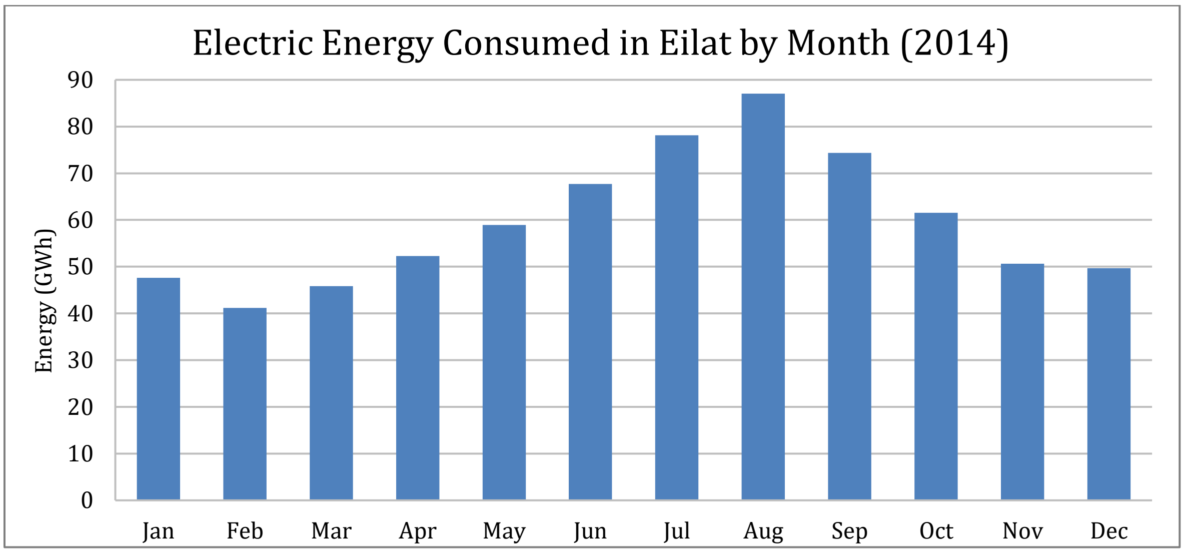

Figure 2. Energy Consumption by Month

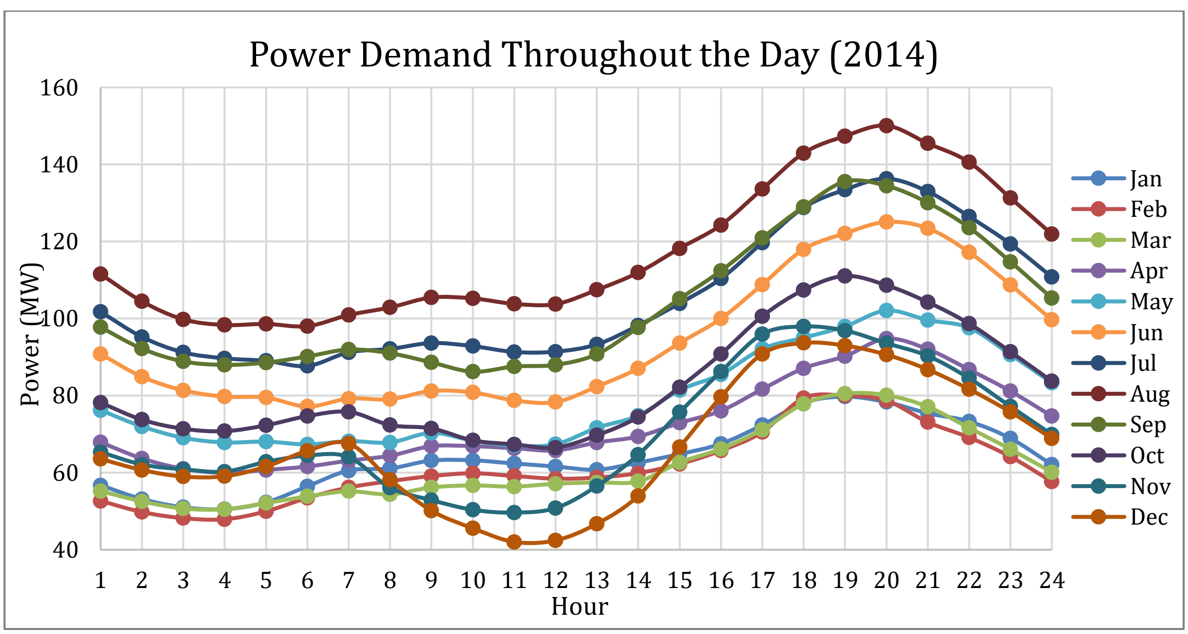

Figure 3. Power Demand by Hour for the Average Day of the Month

Because the data pertained to 2014, we developed two approaches to obtain results for 2019. The first approach considered demand linearly proportional to population. In 2014, Eilat had a permanent resident population of 48,910, with an additional 10,000 temporary national residents and 19,000 international visitors at a given time (Kissinger et al., 2016). Between 2014 and 2019, Eilat's permanent population increased by 3,353 individuals (Central Bureau of Statistics, 2019), and temporary residents by 2,000 *(*Eilat- A Smart City*, n.d.)*. Assuming steady international visitation, the aggregate population of the city increased by 8.15%. The predicted power demand for 2019 was scaled by this factor.

The second approach used the 2014 data directly. It proposes that previous data are representative of 2019 because per-capita energy consumption has decreased over time: Israel's energy consumption has remained relatively constant even as its population increased (*Annual Environmental Reports*, n.d.). This could in part be due to operational improvements to the electric grid and improved efficiency of electric appliances.

3.1.2 Photovoltaics

We conducted energy analysis of PVs on the roofs of homes, schools, and businesses in Eilat, as well as PVs operating at utility-scale solar plants in the Southern Arava valley. Rooftop PVs in Eilat were analyzed separately from the Arava PV fields outside of city limits to distinguish between internal and external activities.

We identified rooftop installations in Eilat using the Geographic Information System (GIS) (*GISNET V5*, n.d.). The team scanned the entire city, dividing it into three main sections — north, central, and south. Rooftop installations were identified, and their coordinates recorded. Individual panels were counted by zooming to the smallest scale. *Figure 4* shows the process of identifying installations, including an example of solar panels on a high school.

Figure 4. GIS Solar Panel Counting.
Top Left: Eilat. Top Right: Central Eilat. Bottom Left: Solar Panels Marked on GIS. Bottom Right: Solar panels on School

As this method only resulted in a numerical count of photovoltaics modules, it was necessary to make assumptions regarding their specifications. The major assumption was the size of the panel. Using the GIS, we sampled roof-mount modules on near-flat roofs. Their areas were measured to obtain a mean and standard deviation for residential, commercial, and municipal buildings, respectively. These were used as an estimate for the entire city. Only relatively flat roofs were considered to avoid inaccuracy when measuring area from an overhead photograph[4]. The rated power (i.e., the power output under standard test conditions) for rooftop PVs was calculated using the following formula (Masters, 2013):

Equation 1

$$P_{STC}[W] = A\ [m^2] * \eta * S\ \left[\frac{W}{m^2}\right]$$

P_{STC} = rated power under standard test conditions [W]
η =efficiency, was assumed 15% for rooftop PVs.
S = 1-sun, or 1000 W/m^2.

[4] Comparable accuracy would have been obtained if the PV area was measured on every roof. Roofs in regions without snow have comparable slopes to open-rack modules on flat roofs. The relative standard deviations were also high: 14.8% among residential buildings, and 9.63% among commercial buildings.

We also performed an analysis on the utility-scale photovoltaic fields in the Southern Arava and Eilot region. The Eilat Environmental Unit provided an inventory on rated power supply from connected fields. Since the Arava solar fields are outside of the city limits, determining the proportion of this power delivered to the city proper is non-trivial. The proportion of Arava PV output delivered to Eilat through the national grid is a function of the transmission distance and the design and operation of the transmission network. These calculations are beyond the scope of this report and were replaced with three distinct models (***3.1.4 Calculating Carbon Emissions***). Various sources, such as the Eilat-Eilot Renewable Energy nonprofit, and local newspapers, claim between 70-100% of the region's daytime energy are supplied from solar power (*Eilat-Eilot Renewable Energy*, n.d.). A report on the Eilat-Eilot website corroborates the assumption that energy distribution is prioritized regionally (*About Eilat-Eilot*, n.d.).

Relevant data from the inventory provided by the Eilat Environmental Unit (**Table 2**) originally showed that a total rated power of 190.28 MW in the region is currently connected to the national electric grid (as of February 2021). However, this included an estimated 10 MW from rooftops in Eilat, whereas our GIS solar panel count gave a result of 6.7 MW. Therefore, our computations used 180.28 MW from solar fields, and 6.7 MW from rooftops in Eilat.

Table 2: Inventory of Photovoltaics in the Southern Arava

Settlement	Currently Connected (MW)	Settlement	Currently Connected (MW)
High Willow	25	Lotan	0.2
Rooftops Eilat	6.7	Yael	1
Eilot	2	Neve Harif	0.08
Elipaz	5	Neot Smadar	8.55
Samar	11.3	Timna	60
Yotvata	5.8	Timna Mines	5
Grophit	5.22	Evrona	5
Ketura	45.13	Regional Center	1
Total	**186.98 MW**		

3.1.3 Modeling Photovoltaic Performance

As noted above, the values assigned to photovoltaics in **Table 2** refer to the "rated" power of the PV modules. Rated power is determined by ideal standard test conditions, and in practice will usually not be the actual system output. Major environmental factors affecting solar-energy performance include position of the sun, intensity of sunlight, and PV cell temperature. We

modeled PV systems using National Renewable Energy Lab's PVWatts calculator (*PVWatts Calculator*, n.d.). A list of our decisions for user-defined inputs is in the Appendix B.
Given the system information, the PVWatts tool will display the results of its calculations. These include the DC array output (W) and the AC power transferred to the grid (W) for each hour of the year. The tool was applied separately to the inventory of residential, commercial, and municipal installations in Eilat, and utility-scale fields in the Southern Arava. For Eilat's rooftop PVs we assumed "standard" 15% efficiency, whereas for utility-scale installations we assumed "premium" anti-reflective glass afforded 19% efficiency. These assumptions have a significant effect on simulations of photovoltaic performance.

3.1.4 Calculating Carbon Emissions

The datasets for Eilat's power demand and PV supply consisted of data points for each hour of the year (1 to 8760). Hourly datasets allowed us to use three distinct models to compute greenhouse gas emissions. The first model considers only the national electric grid and rooftop PVs. The second model includes external PV systems in the Southern Arava. The third model includes both Eilat's gas turbines and the regional PV systems.

Model I: National Electric Grid

In terms of greenhouse gas (GHG) emissions, the worst-case assumption is that electric power is distributed widely rather than regionally or locally. In this model, Arava solar fields and the Eilat power plant do not prioritize the city's power demand; only PV production on rooftops within Eilat are deducted from emissions, and only the emissions factor for the national grid is used. Since rooftop PV power supply never exceeds the city's power demand, computing the result involves taking the total energy consumption for the year, subtracting the total energy supply from rooftop PVs[5], and applying the national grid emission factor. This calculation produced an upper-bound for annual GHG emissions.

Equation 2

$$Emissions = \left(Annual\ Energy\ Usage - Annual\ Energy\ PV_{roofs}\right) * EF_{grid}$$

EF_{grid}= 645 [$\frac{Kg\ CO_2eq}{MWh}$], general emissions factor for the Israeli electric grid (2019).

[5] Model I did not set rooftop PV production to 0 during the few power outages that occurred in 2014.

Model II: Inclusion of Southern Arava PV Fields

The intermediary assumption is that generation from Southern Arava PVs is primarily distributed to regional consumers in Eilat and the Arava. Given that Eilat is the region's major city, with a population of 52,299, plus nearly 29,000 visitors at a given time, and the population of the Arava is around 5,100, we estimated that 95% of the energy generated from PVs is allocated to Eilat (Central Bureau of Statistics, 2019) (Kissinger et al., 2016). Losses due to transmission and transformation were estimated to be an additional 5% (Masters, 2013). When PV supply is greater than demand, the excess power is either stored or transmitted to other regions through the grid. When demand is greater than PV supply, the remainder is supplied by fossil fuels through the national grid, and the generalized grid emission factor is applied. The following algorithm was iterated over the hourly data sets to compute the equivalent CO_2 emissions:

Equation 3

$$for\ each\ hour\ in\ the\ data\ set:$$

$$fueled = demand - (PV_{fields} * Trans) - PV_{roofs}$$

$$if \quad fueled > 0,$$

$$emissions \mathrel{+}= fueled * EF_{grid}$$

Demand and PV_{roofs} are the hourly data sets, converted to MW
Trans = (0.95)*(0.95) = (0.9025), estimate net transmission from Southern Arava fields to Eilat
$CF_{grid} = 645 \left[\frac{Kg\ CO_2 eq}{MWh}\right]$, for national grid (IEC, 2019)

For now, storage of excess PV generation is non-existent. If PV supply exceeds city demand, then emissions are 0 instead of negative.

Model III: Inclusion of Eilat's Gas Turbines

The best-case assumption is that all regional power generation is distributed from source to regional or local consumers, as opposed to far-away consumers, which presumably receive power from their own regional source. This means that Eilat's 34 MW industrial gas turbine, 58 MW jet or "aeroderivative" gas turbines, and PV systems in the Southern Arava all prioritize the city's power demand.

When PV supply is greater than demand, the excess is either stored or transmitted to other regions through the grid. However, when demand is greater than PV supply, then Eilat' s gas turbines supply the difference up to their combined net nominal output[6]. This is reasonable because gas turbines can change their output quickly in response to changing loads, particularly jet gas turbines (Masters, 2013). The CO_2 eq emission factor for natural-gas plants is applied to the energy produced by Eilat' s gas turbines. If demand is still higher than the combined generation of both photovoltaics and Eilat's local plant, then the remainder is supplied by fossil fuels from the national grid, and the general grid emissions factor is applied. The following algorithm was iterated over the data set to compute the equivalent CO_2 emissions:

Equation 4

$$\begin{aligned}
&for\ each\ hour\ in\ the\ data\ set:\\
&\qquad fueled = demand - (PV_{fields} * Trans) - PV_{roofs}\\
&if \quad 0 < fueled \leq GT_{Eilat},\\
&\qquad emission \mathrel{+}= fueled * EF_{gas}\\
&if \quad fueled > GT_{Eilat},\\
&\qquad emission \mathrel{+}= (GT_{Eilat} * EF_{gas}) + (fueled - GT_{Eilat}) * EF_{grid}
\end{aligned}$$

Demand, PV_{fields}, and PV_{roofs} are the hourly data sets, converted to MW
Trans = (0.95)*(0.95) = (0.9025), estimate net transmission from Southern Arava fields to Eilat
GT_{Eilat} = (34+58)*(0.95) = 87.4 [MW], the net nominal output of Eilat's gas turbines transmitted within the city (IEC, 2019)
$CF_{gas} = 400 \left[\frac{Kg\ CO_2 eq}{MWh}\right]$, for natural-gas power plants (IEC, 2019)
$CF_{grid} = 645 \left[\frac{Kg\ CO_2 eq}{MWh}\right]$, average for national grid (IEC, 2019)

Again, for now, storage of excess PV generation is non-existent. If PV supply exceeds city demand, then emissions are 0 instead of negative.

Comparison Between Different Years

To accurately compare emissions across different years, the methods described in this section were extended to 2014, the year from which the power demand data were sourced. In 2014, the connected PV power in the Southern Arava was 106 MW, and the Eilat gas turbines were present with the same nominal capacity (*About Eilat-Eilot*, n.d.) (*Israel Electric Corporation*, 2020). Since Israel's electric grid was majority coal powered, the emissions factor for the grid was larger, at 688 $KgCO_2eq/GWh$. Lastly, the previous BEI included an inventory of PVs, on

[6] Eilat's power plant was modeled to only supply up to its nominal 92 MW output. Draw from exterior communities in the region was again estimated at 5% of total supply. Therefore, the net supply to Eilat is 0.95*92 MW = 87.4 MW.

municipal rooftops, and arrived at a reduction in 700 tons CO_2. These parameters were used to determine the emissions for 2014 via the same methodology used for 2019.

3.2 Results

3.2.1 Photovoltaics

The total count of solar panels on rooftops in Eilat was 24,126, consisting of 7,735 on residential homes and apartments, 12,008 on commercial buildings, and 4,383 on school and municipal buildings as shown in **Table 3.** The total rating for Eilat's rooftop PVs summed to 6.713 MW.

Table 3: *GIS Solar Panel Count*

	Residential	Commercial	School/Municipal
Panel Count	7735	12008	4383
Mean Area (m2)	1.615	1.963	2
Relative Stdev	0.1479	0.0963	0
Rated Power (W)	242.3	294.5	300.0
Total (W)	1.868E+06	3.530E+06	1.315E+06

Figure 5 shows the breakdown of energy production from Eilat's rooftop PVs. Annual DC output is 10.79 GWh, consisting of 3.00 GWh (28%) residential, 5.67 GWh (53%) commercial, and 2.11 GWh (19%) school and municipal. The capacity factor for rooftop PVs was 17.6.

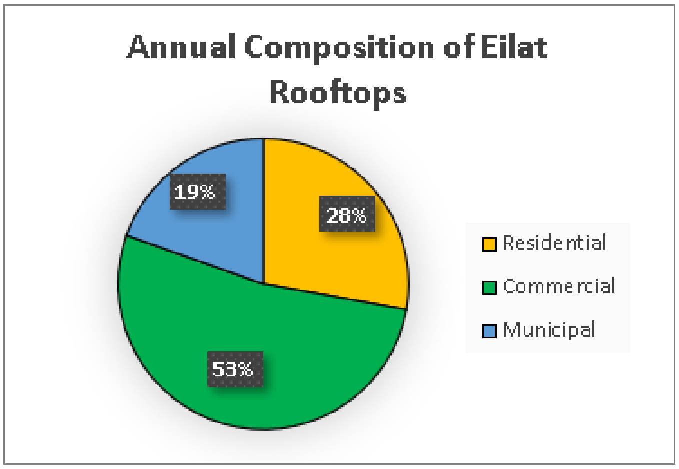

Figure 5. Composition of Eilat's Rooftop PV Energy

Arava PV systems are of utility-scale and as such produce energy an order above Eilat's rooftop inventory. Eilat's rooftop PVs constitute 3% of annual PV production, the other 97% coming from PVs in the Southern Arava (*Figure 6*).

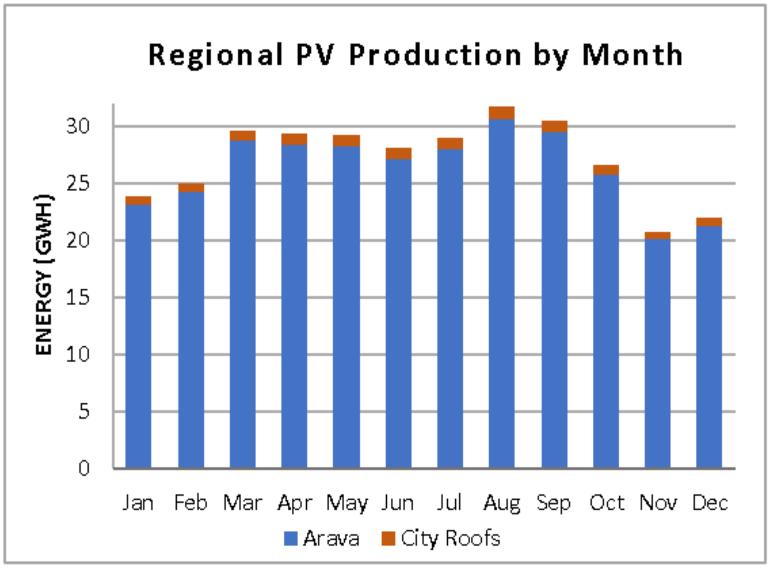

Figure 6. Composition of Regional PV Energy Generation by Month during 2019
(DC Output)

Annual PV production from the Southern Arava is 315.55 GWh (**Table 4**) with a capacity factor of 19.6. The combined total of Southern Arava and Eilat rooftop PVs is 326.34 GWh.

Table 4: *Annual PV Energy (DC array output)*. Values in GWh

Residential	Commercial	Municipal	S. Arava	Total
3.00	5.67	2.11	315.55	326.34

Figure 7 shows daily PV performance during different months of the year. PV production occurs during daylight intervals, the length of which depend on the time of year. The maximum daylight interval, near the summer solstice, is approximately 14 hours, from 6 a.m. to 8 p.m. The minimum, near the winter solstice, is 10 hours, from 8 a.m. to 6 p.m. Peak production occurs near noon when the sun is directly overhead the PV array. The greatest producing months are August, while the greatest peak generation occurs during March.

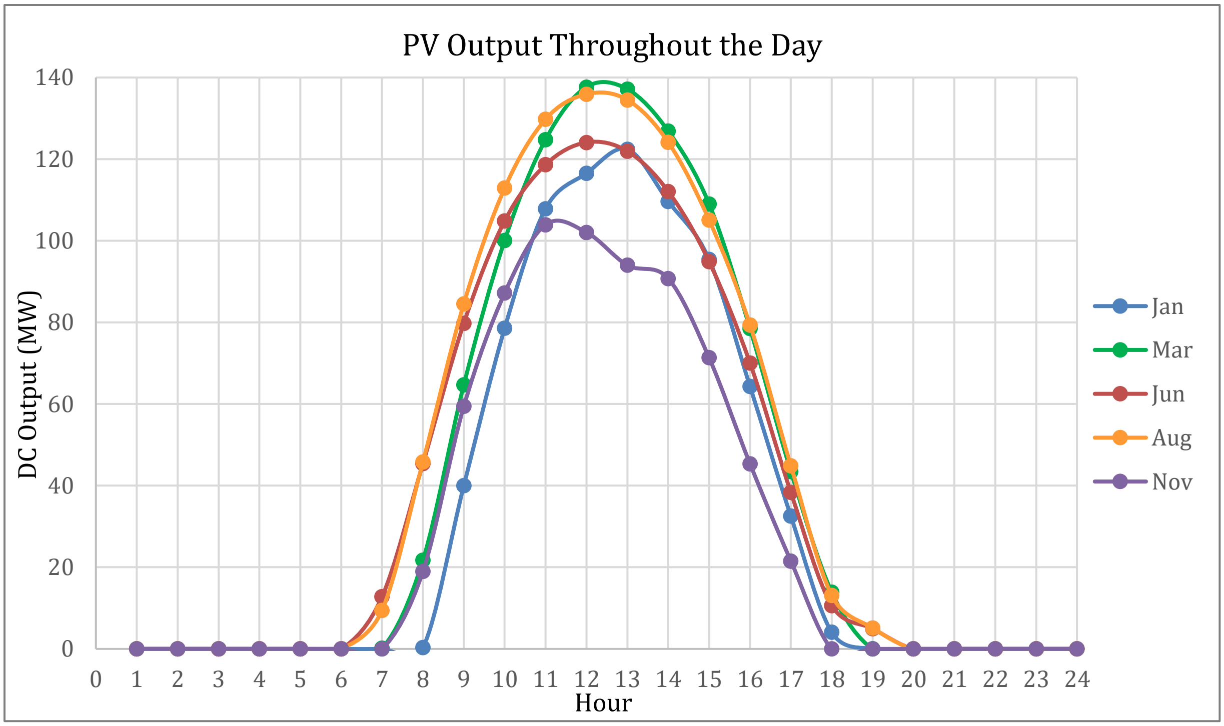

Figure 7. PV Output Throughout a Typical Day of the Month
(DC Output)

3.2.2 Emissions

Table 5 summarizes the results of Models I, II, and III, applied to data from 2014 and 2019. *Figure 8* is graphical representation of the data in table 5, showing how emissions change between different years and models.

Table 5*:* Predicted Emissions for 2014 and 2019

Emissions	Model I (tons CO2eq)	Model II (tons CO_2eq)	Model III (tons CO_2eq)
2014	491,074	383,229	236,938
2019 Not Scaled	454,584	319,788	209,524
2019 Population Scaled	492,179	350,903	234,041

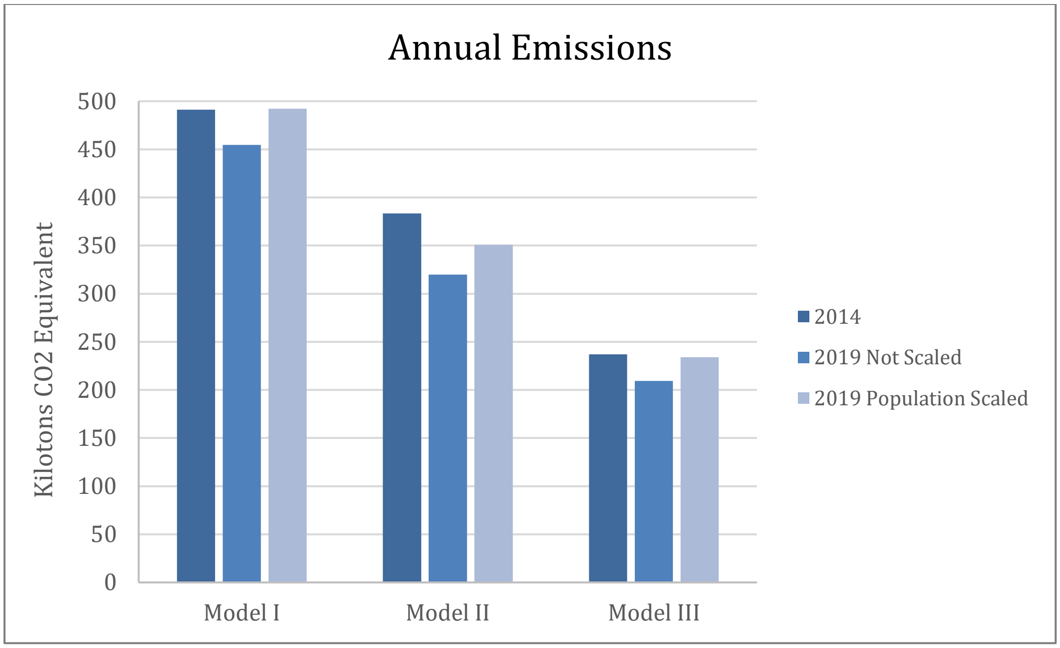

Figure 8. Emissions by Model and Year.
Values from table 5.

Model I

Considering only the general grid emissions factor and generation from Eilat's rooftop PVs provides an upper-bound for carbon emissions. From 2014 to 2019, the grid emissions factor decreased from 688 KgCO2 eq/MWh to 645 KgCO2 eq/MWh, largely due to the incorporation of natural gas-fired plants over coal-fired plants. When not scaling by population growth, this results in 454,584 tons CO2 eq, a 7.4% reduction from 2014. When scaling by population, the result is 492,179 tons CO2 eq, a 0.2% increase from 2014 (Table 5). Rooftop PVs reduced emissions by 6,673 tons CO2 eq.

Model II

Including Arava PVs results in a significant drop in emissions compared to those in Model I. The relative emissions reduction over time improved as well (Figure 8). In 2014, 106 MW of connected PVs resulted in 383,229 tons CO_2 eq. Without scaling by population, 2019 emissions are 319,788 tons CO_2 eq, a 16.6% decrease from 2014. Scaling by population, emissions are 350,903 tons CO_2 eq, an 8.44% decrease from 2014.

Shown in *Figure 9*, Model II, scaled by population, has 229.37 GWh (30%) supplied by PVs and 544.04 GWh (70%) supplied by the national grid. Note that supply from PVs is less than the 326.34 GWh total DC output shown in **Table 4**.

After inverter efficiency and transmission to Eilat, most losses with respect to the city's consumption came from the absence of storage for excess PV production during peak-sun hours (*Figure 13*).

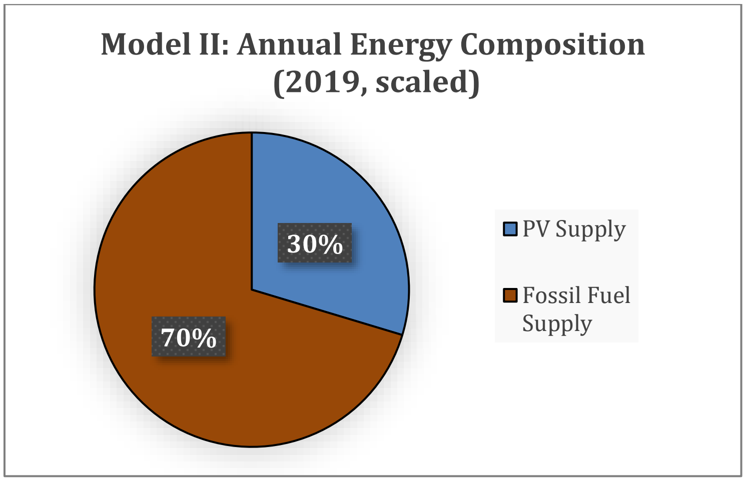

Figure 9. Annual Energy Composition.
Model II, scaling by population growth for 2019.

Figure 10 shows the total and composition of energy supply for each month. As expected, load is greater in the warmer months of the year, in part a result of active air conditioning systems. Minimum consumption occurs from February to March, where photovoltaics supply over one third of the energy demand. Utilization reaches its maximum in August, the hottest month of the year, in which cooling systems and air-conditioning units are in full use. December has the smallest PV contribution at 23.1% of total supply, 6.9% less than the annual composition.

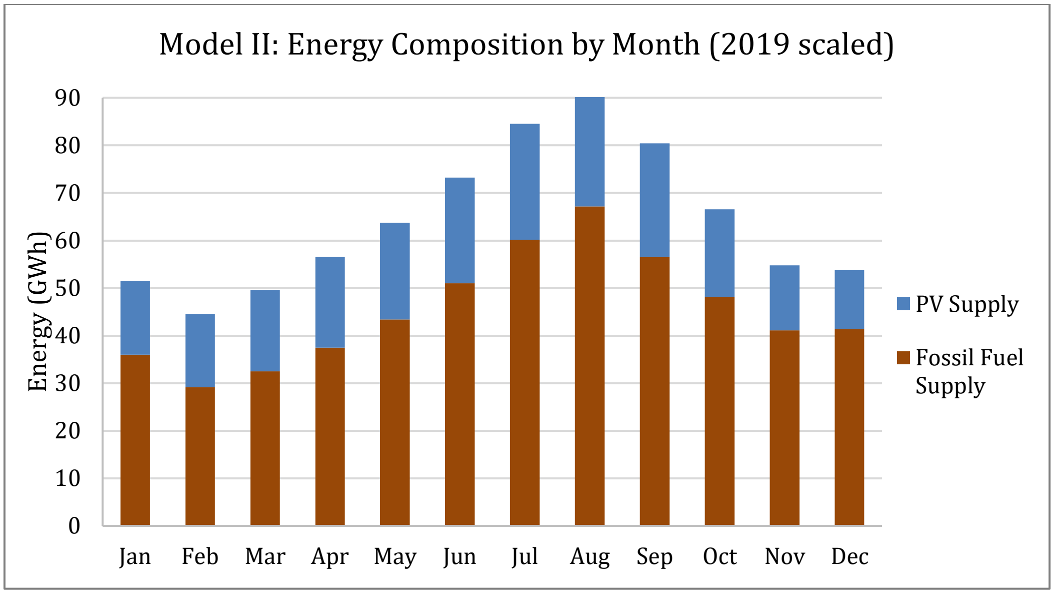

Figure 10. Composition of Eilat's Energy Supply by Month During 2019.
Model II, scaling by population growth for 2019.

Model III

Including generation from Eilat gas turbines in addition to utility-scale PVs provided a drop in emissions compared to Model II. This is due to the emissions factor for gas-fired plants being 400 KgCO_2 eq/MWh, compared to the 645 KgCO_2 eq/MWh of the general electric grid. The generalized grid emissions factor is derived from the composition of Israel's natural gas and coal power plants, and coal-fired plants have an emissions factor of 890 KgCO_2/MWh, over double that of natural gas plants (*Annual Environmental Reports,* n.d.). While total emissions are lowest in Model III, the relative reduction over time is inferior. In Model II, the emissions reduction observed between years 2014 and 2019 was a result of both new PV installations and the incorporation of gas turbines to Israel's centralized power grid. However, as Model III assumes Eilat's power demand is supplied by the local gas turbine, the activities of the rest of the grid therefore play a less significant role.

In 2014, 106 MW of connected PVs resulted in 236,938 tons CO_2 eq. Without scaling by population for 2019, 186.98 MW of connected PVs resulted in 209,524 tons CO_2 eq, an 11.57% decrease. Scaling by population, the result was 234,041 tons CO_2 eq, a 1% decrease.
Model III, scaled by population, has 229.37 GWh (29.7%) supplied by PVs, 476.99 GWh (61.7%) supplied by Eilat's gas turbines, and 67.05 GWh (8.7%) supplied by the grid (*Figure* 11).

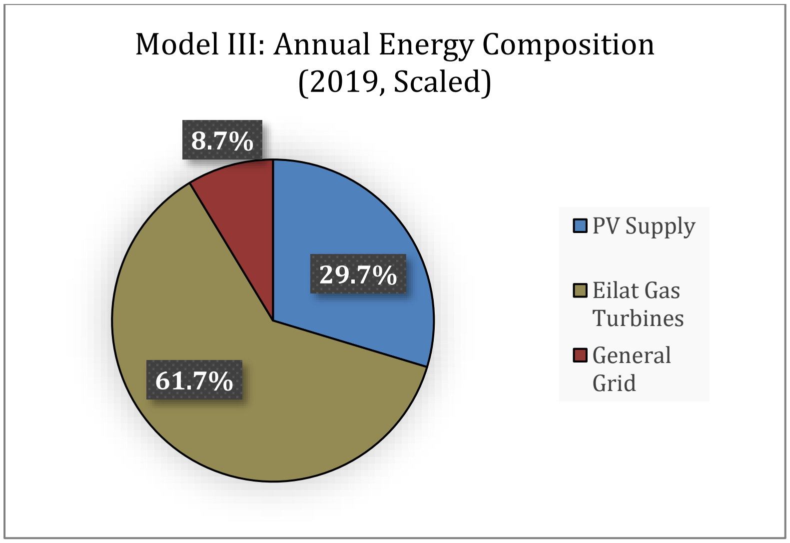

Figure 11. Composition of Eilat's Energy Supply in 2019 (Model III).

Figure 12 shows the composition of energy supply for each month. August, the hottest month of the year, has the greatest energy demand. While August also contains the greatest PV output, this is not enough to compensate for the increased demand. As a result, the 19.8% of August's energy demand must be drawn from the central grid.

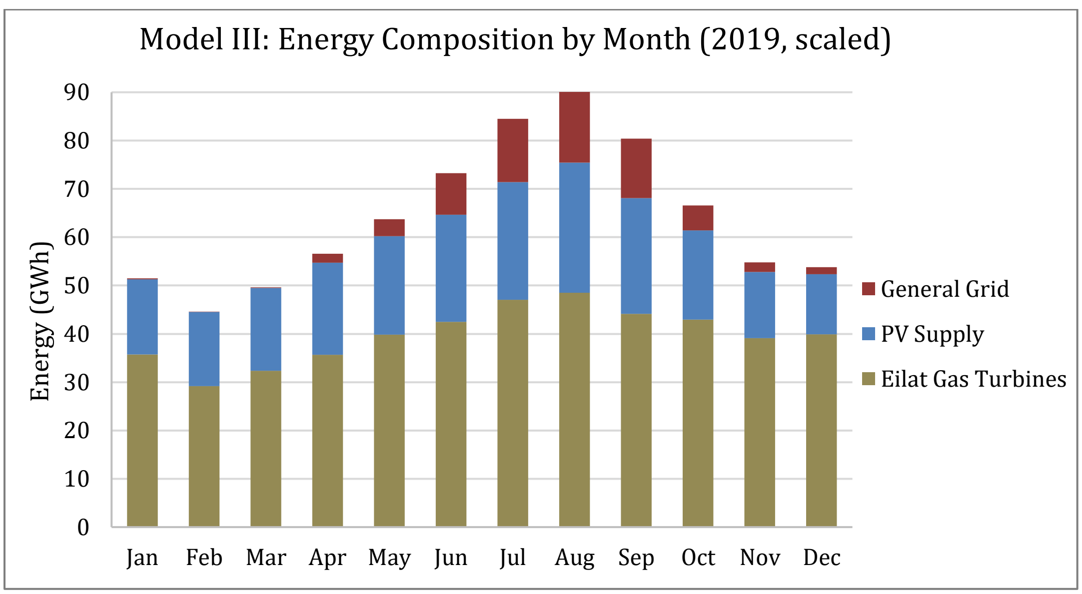

Figure 12. Energy Supplied by Month to Eilat during 2019 (Model III, 2019)
PVs in AC output delivered to Eilat.

3.3 Discussion

3.3.1 Reduction Measures

At the generation level, Eilat has significant potential for further rooftop PV systems. Our GIS count of rooftop PVs found PVs on 350 roofs in the city. While solar-water heaters were present on every rooftop, many homes and hotels were observed to have available area for PV installations.

Model I indicates that as Israel incorporates cleaner energy sources such as natural gas and renewables to the electric grid, the general emissions factor will decrease, thereby reducing Eilat's GHG contribution. Models II and III indicate that storage of excess PV production during the day will provide a significant emissions reduction. With the current capacity of 186.98 MW, during the peak-sun hours, supply from PVs is consistently more than demand (*Figure 13*). As the region installs more PVs, the quantity of this excess power will increase, providing diminishing returns with respect to reducing GHG emissions. Implementation energy storage will allow excess energy production during the day to be used at night, when power demand is greater.

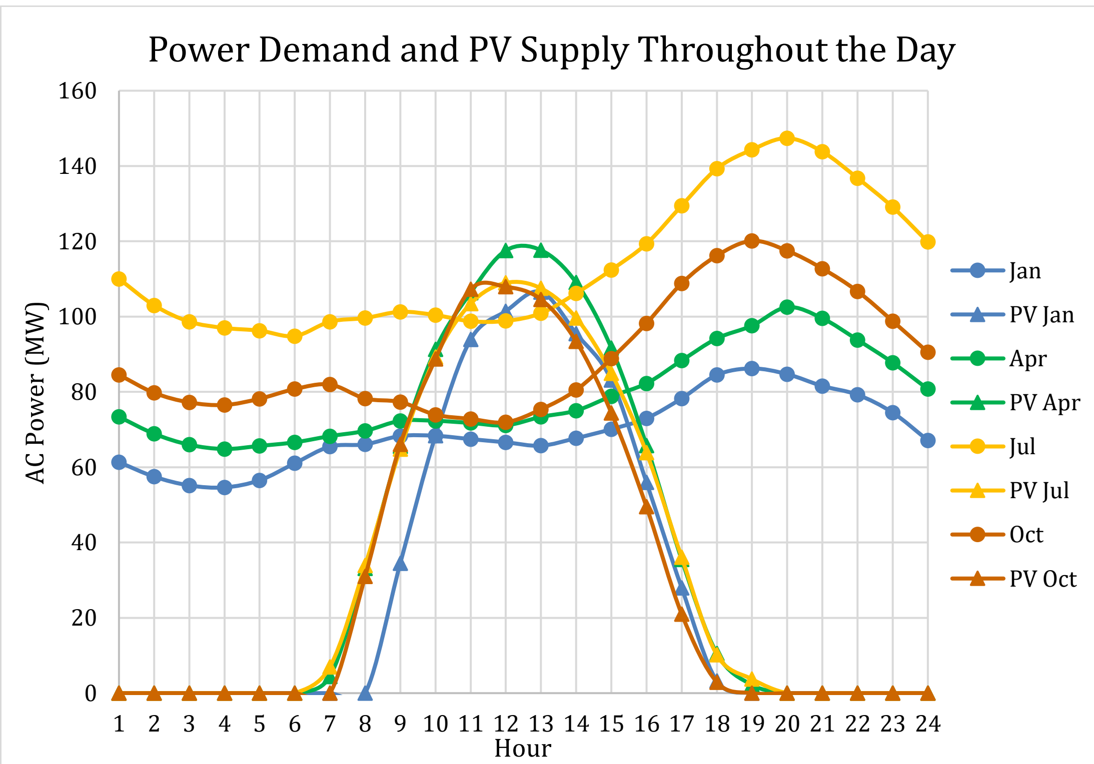

Figure 13. Eilat's Power Demand and Supply from PVs During a Typical Day of the Month.
(PVs in AC output delivered to Eilat)

Scaling by population, an estimated 65.76 GWh (AC) from Arava PVs is not transmitted to Eilat due to being excess supply. Storing the entirety of this energy would reduce emissions by 42,413 tons CO_2 eq (12.1%) following Model II, and at least 26,302 tons CO_2 eq (11.2%) following Model III. This does not include an evaluation of net efficiencies of battery or pumped-hydro storage facilities.

At the consumer end, reducing per capita energy usage is effective at all levels of emissions modelling because it helps to decrease the city-wide power demand. Reducing energy usage can be approached at the appliance level, incentivizing residents and business owners to install energy-efficient cooling units, insulation, lighting systems, and other electronic devices.

3.3.2 Limitations

Analysis of electric power consumption was limited by the availability of data. As the power demand dataset came from 2014, it was necessary to make predictions for power demand in 2019. The population-scaling approach does not model changes in per-capita consumption, growth of industry, nor developments in the technology of electrical devices and systems. International visitation was also assumed to be the same for 2014 and 2019. The non-scaling approach is limited in that it assumes the same power demand for 2014 and 2019, although it provides a useful comparison to the population-scaling approach.

Measuring photovoltaic area using the GIS system is inaccurate, which propagates through to the modeling of rooftop PV performance throughout the year. Modeling PV performance required many assumptions regarding PV module specifications, system losses, and inverter efficiency. Local meteorological data used by the PVWatts tool came from the year 2017 rather than 2019. In addition, it is an imprecise estimation that 95% of PV and gas turbine output is sent to Eilat. However, this is a reasonable approximation given the population distribution of the region.

The three models used to compute emissions are each based on simplistic assumptions regarding the operation of the electric grid. Actual operation of the Israel electric grid may involve a combination of different characteristics expressed in the three Models. For example, Eilat’s gas turbines may serve as “peakers”, turning on only at night or when demand is at its peak. The fuel-content used by Eilat’s gas turbines is also unknown. Varying fuel-content changes the emissions factor applicable to gas turbines. Models I and III therefore serve as upper and lower bounds for emissions, respectively.

3.3.3 Improvements to Computations

During this evaluation, it was unknown whether power measurements in the hourly datasets referred to the average power over the interval, or the sampled power at the given point in time. If the latter is the case, an improvement to our calculations would be to use trapezoidal rather than rectangular summations.

If future evaluations obtain more specific information on PV installations, the National Renewable Energy Lab's System Advisor Model (SAM) is recommended for in-depth modeling of PV systems.

As the Israeli national electric grid incorporates a greater proportion of emissionless sources, emission factors pertaining to the grid become less accurate. Future assessments should scale the emissions factors found in IEC environmental reports by the national fraction of energy provided by fossil fuels.

CHAPTER 4: TRANSPORTATION

In 2014, emissions from transportation were the second largest source of emissions within Eilat. Transportation emissions are the result of combustion of fuel in vehicles. The type of fuel as well as the age of the vehicle influences how much carbon dioxide (CO_2) is emitted during combustion. This section explains how we estimated transportation emissions in Eilat for 2019 and reports the estimated values that we found.

4.1 Transportation Methods

Emissions from transportation were calculated using data for vehicles registered in the City of Eilat. The Central Bureau of Statistics (CBS) provides the number of vehicles registered in Eilat in 2019, categorized by the type of vehicle (**Table 6**) (Central Bureau of Statistics, 2020). The CBS also provided the average annual distance traveled by private vehicles registered in Eilat. Most of the other vehicle categories used national averages provided by the CBS. Total annual distance traveled was found by multiplying the number of vehicles by the average annual distance traveled per vehicle. The total annual distance listed in **Table 6** for trucks was calculated using a method from the BEI in which trucks were assumed to enter and exit Eilat from the port using a 20 km access road. We estimated that this distance was traveled twice each day[7] by each truck. The national average distance was unrealistically high for trucks registered in Eilat due to the size of the city. Municipal vehicle numbers were received from the municipality for each individual vehicle and are not an estimate.

[7] To account for weekends and holidays, the daily numbers for truck calculations were multiplied by 300 to get the annual total.

Table 6: Vehicle Information in Eilat 2019
(CBS Table 7, 2020) (CBS Table 8, 2020) (CBS Table 9, 2020)

Vehicle Category	Number of Vehicles	Total Annual Distance (km)
Private Vehicle	17,430	242,277,000
Light Truck	1,122	23,898,600
Truck	597	8,716,200
Minibus	44	2,204,400
Bus	55	3,162,500
Taxi	503	36,618,400
Motorcycle	1,617	11,642,400
Municipal Vehicles	12	121,915
Special Vehicles	33	597,300
Total:	**21,413**	**329,238,715**

Table 6 shows the different categories of vehicles that we considered in our calculations. Light Trucks include trucks under 3.5 tons and vans. Buses and minibuses include the numbers for both public and private buses. Municipal vehicles in this report refer to city garbage trucks, with numbers from 2020 instead of 2019. Special vehicles include ambulances, fire trucks, and sanitary vans. We were unable to separate for the distance driven by Eilat residents outside of the city from the total annual mileage. This would normally fall under Scope 3 measurements but is included in our Scope 2 evaluation of the city.

We used two different methods to estimate GHG emissions from transportation in Eilat. The first method replicated the method used in the 2016 BEI. The BEI used CO_2 emission factors from the 15th Forum of the Intergovernmental Panel on Climate Change (IPCC) applied to the different categories of vehicles (Kissinger et al., 2016). The BEI did not report the emission factors that were used for every category of vehicle that we analyzed. We used a second estimation method since we did not have full access to updated versions of the 2014 data.

The second method estimated CO_2 emissions based on annual fuel consumption. The European Environment Agency (EEA) sets emission standards for vehicles based on their age.[8] According to the Israel Ministry of Environmental Protection, "Israel has adopted European standards for emission exhaust tests." This means that the data found in the CBS tables matches European

[8] The age of a vehicle determines its Euro rating. Euro ratings are used to estimate average fuel consumption per kilometer traveled.

standards. The EEA has developed several methods for estimating GHG emissions from vehicles (Ntziachristos & Samaras, 2020). The method that we chose requires information about the number of vehicles in different categories as well as information about the annual fuel consumption of these vehicles.

4.1.1 Explanation of BEI Estimation

The CBS publishes an annual report about the vehicles registered in Israel. They also have a report that contains information about the average annual distance traveled by vehicles registered in the country. These reports include tables that categorize the number of vehicles by type, city of registration, and age of the vehicle. Similar information can be found in the annual distance report. When vehicle owners renew vehicle registration each year, Ministry of Transportation officials take a reading of the odometer. Average annual distance traveled for 2019 is found by taking the new odometer reading and subtracting it from the 2018 reading. The CBS tables provided the numbers that we used in our calculations for every category except trucks and municipal vehicles. Truck data was estimated as previously mentioned and data on municipal vehicles was provided by the Eilat Municipality.

The BEI provided the CO_2 emission factors for private vehicles, motorcycles, taxis, buses, and municipal vehicles (**Table 7**). Emission factors for trucks, light trucks, and special vehicles were found in the IPCC Emission Factor Database (*Emission Factor Database*, n.d.). The emission factors are then multiplied by the total annual distance traveled for each vehicle category.

Table 7: *2016 BEI Emission Factors and IPCC Emission Factors (Kissinger et al., 2016) (Emission Factor Database, n.d.)*

Vehicle Category	Emission Factor (g CO_2 eq/km)
Private Vehicle	300
Light Truck	396
Truck	1011
Bus	820
Taxi	300
Motorcycle	100
Municipal Vehicle	847
Special Vehicle	847

4.1.2 Explanation of EEA Estimation Method

In addition to the number of vehicles and total annual distance traveled, the EEA estimation method also requires total annual fuel consumption by type of vehicle. The EEA guidelines outlined the average fuel consumption per kilometer for most of the vehicle types (Ntziachristos & Samaras, 2020). Fuel consumption for minibuses, special vehicles, and municipal vehicles was estimated using consumption averages found in the U.S. Department of Energy's Alternative Fuels Data Center (*AFDC*, 2020). The average age of motorcycles also played a role in average fuel consumption. According to the EEA guidelines, fuel consumption for Euro 3 rated[9] motorcycles is different from earlier Euro rated motorcycles (Ntziachristos & Samaras, 2020). Table 8 shows the fuel consumption values that we used when completing the calculation for annual fuel consumption by vehicle type.

Table 8: Average Fuel Consumption by Vehicle Type
(Ntziachristos & Samaras, 2020) (AFDC, 2020)

Vehicle Category	Fuel Consumed (g/km)	Emission Factor (g CO_2 eq/km)
Private Vehicle	66	209
Light Trucks	85	269
Trucks	240	761
Minibus	331	1049
Buses	301	954
Taxis	66	209
Motorcycles	17	54
Municipal Vehicles	930	2948
Special Vehicles	392	1242

The fuel consumption numbers were multiplied with the total annual distance traveled for each vehicle category to estimate annual fuel consumption for each vehicle type. The annual fuel consumption was used in the CO_2 combustion formula in the EEA guidelines document. The combustion formula is shown in *Figure 14*.

[9] Euro 3 rated motorcycles were made in 2008 or later. According to the CBS, the average age of motorcycles in Israel is 5.5 years so the Euro 3 rating was used to estimate fuel consumption.

$$E_{CO_2,k,m}^{CALC} = 44.011 \times \frac{FC_{k,m}^{CALC}}{12.011 + 1.008 r_{H:C,m} + 16.000 r_{O:C,m}}$$

$E_{CO_2,k,m}^{CALC}$ = Annual Mass of CO2 Emitted

$FC_{k,m}^{CALC}$ = Total Annual Fuel Consumption

$r_{H:C}$ = Ratio of hydrogen to carbon atoms in fuel

$r_{O:C}$ = Ratio of oxygen to carbon atoms in fuel

44.011 = Molar Mass of CO_2

12.011 = Atomic Mass of carbon

1.008 = Atomic Mass of hydrogen

16.000 = Atomic Mass of oxygen

Figure 14. CO_2 Combustion Formula

The ratios of hydrogen and oxygen atoms to carbon atoms varies depending on the type of fuel used. For both gasoline and diesel, $r_{H:C}$ = 1.86 and $r_{O:C}$ = 0 (Ntziachristos & Samaras, 2020). Our analysis assumed that all the vehicles either ran on gasoline or diesel. This way all the calculations could be done using the same ratio as we did not have vehicle counts for different fuel types.

4.2 Transportation Results

Using different assumptions for distance traveled, our analysis found several estimates for emissions between the two estimation methods. The three scenarios that we focused on included a high estimate, a middle estimate, and a low estimate. The high, middle, and low estimates will be referred to as Scenario 1, Scenario 2, and Scenario 3, respectively. Scenario 1 used the BEI method and the distance numbers presented in Table 6. Scenarios 2 used the EEA estimation method and the distance numbers also shown in Table 6. Scenario 3 used the EEA estimation method with new assumptions for trucks and buses.

4.2.1 BEI Estimation Method Results: Scenario 1

The results from the first estimation method are displayed in **Table 9** and *Figure 15*. Table 9 shows the total annual emissions for each vehicle category. *Figure 15* compares the data from Table 9 to the 2014 numbers found in Table 5 of the 2016 BEI.

Table 9: *2019 Transportation Emissions in Scenario 1*

Vehicle Category	2019 CO_2 Emissions (tons)
Private Vehicles	72,683
Light Trucks	9,464
Trucks	8,812
Buses	2,593
Taxis	10,986
Motorcycles	1,164
Municipal Vehicles	103
Special Vehicles	506
Total:	**106,311**

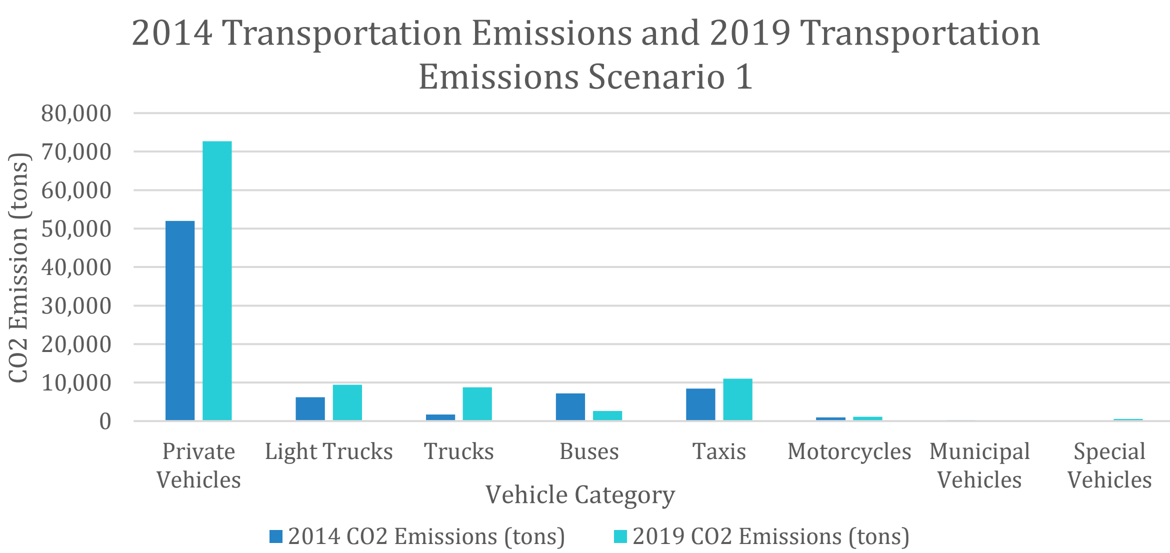

Figure 15. 2014 Transportation Emissions and 2019 Transportation Emissions Scenario 1

4.2.2 EEA Estimation Results: Scenario 2

Using the EEA estimation method and annual distance numbers from **Table 6**, the total transportation emissions in 2019 were 78,469 tons of CO_2 eq (**Table 10**). *Figure 16* compares the data from Table 10 to the 2014 numbers found in Table 5 of the 2016 BEI.

Table 10: *2019 Transportation Emissions in Scenario 2*

Vehicle Category	2019 CO2 Emissions (tons)
Private Vehicles	50,681
Light Trucks	6,438
Trucks	6,630
Minibuses	2,313
Buses	3,017
Taxis	7,660
Motorcycles	627
Municipal Vehicles	359
Special Vehicles	742
Total:	**78,469**

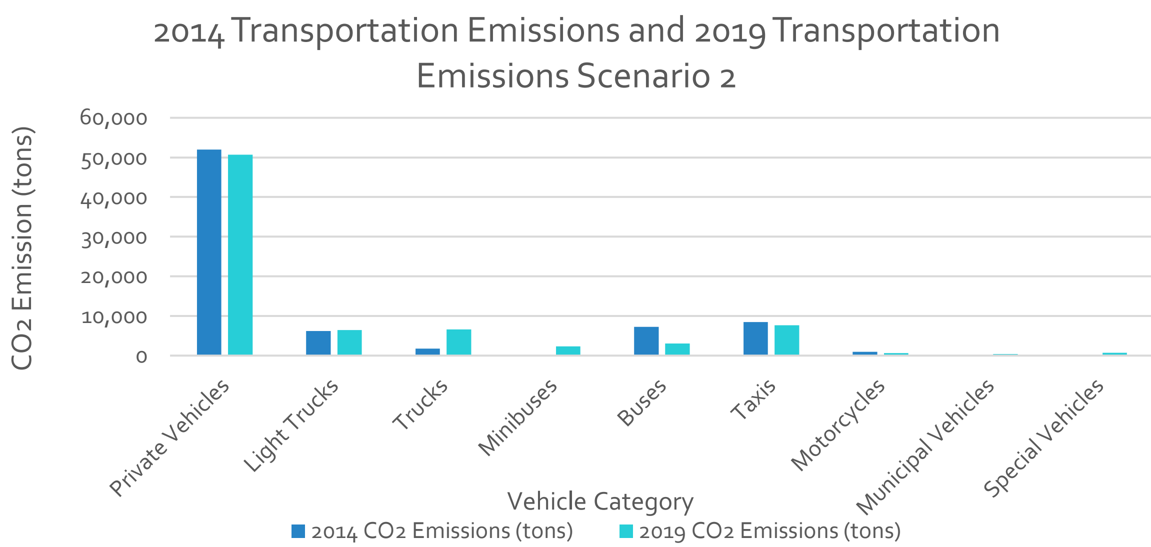

Figure 16. 2014 Transportation Emissions and 2019 Transportation Emissions Scenario 2

This estimation shows only a 2.25% increase from 2014 totals compared to Scenario 1 which was a 38.53% increase in emissions. Given that the number of vehicles registered in Eilat has also increased, it makes sense to see some increase in estimated emissions. There has been a 42% increase in the annual distance traveled from 2014 and neither of these scenarios presented an increase in emissions of that same amount. Both Scenario 1 and 2 suggest that there has been an increase in the number of lower pollution vehicles on the roads in Eilat.

4.2.3 EEA Estimation Results: Scenario 3

Scenario 3 presents the lowest estimation of transportation emissions in Eilat in 2019. To get a more detailed estimation of the emissions from transportation, we made calculations using various assumptions about annual distance traveled for trucks and buses. National averages for these categories do not consider that Eilat is smaller than other cities in Israel.

Our new assumption method for trucks split them into two categories. It is unreasonable to expect that all trucks registered in the city only travel to and from the port. In the BEI only 200 trucks were counted as making the journey to the port each day, so we categorized 250 trucks as traveling from the port each day (Kissinger et al., 2016). The remaining 347 trucks registered in Eilat were assumed to be carrying goods out of Eilat and were calculated as only making the 20 km trip once a day[10]. This decreased the annual distance traveled by trucks to 5,082,000 km. Buses were split into three categories: public buses, private buses, and intercity buses. These are the three types of buses that can be found in Eilat, but we did not have data split by type of bus. Bus assumptions were made without detailed information of bus routes. We estimated 30 public buses and 25 private buses. For public buses, we assumed that each bus took roughly 10 trips each day and that each trip was about 30 km[11]. For private buses, we assumed they entered the city once each day and traveled 10 km once within city limits. There are approximately 25 intercity buses that arrive in Eilat each day (*Passenger Information*, n.d.). Each intercity bus travels approximately 6.7 km from the entrance of the city to the central bus station. The new annual distance traveled for buses was estimated to be 395,250 km.

Below, Table 11 shows the estimated 2019 transportation emissions in Scenario 3. There is a 4.96% decrease in emissions as compared to 2014. This estimation is the lowest that we calculated and considers the most detailed assumptions for annual distance traveled. *Figure 17* compares the data from Table 11 to the 2014 numbers found in Table 5 of the 2016 BEI.

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[10] Daily numbers were multiplied by 300 for an annual total to account for weekends and holidays.
[11] A loop around the city is approximately 15 km. This accounts for circuitous routes down side streets.

Table 11: *2019 Transportation Emissions in Scenario 3*

Vehicle Category	2019 CO2 Emissions (tons)
Private Vehicle	50,681
Light Truck	6,438
Port Truck	2,282
Shipping Truck	1,584
Minibus	2,185
Public Bus	258
Private Bus	72
Intercity Bus	48
Taxi	7,660
Motorcycle	627
Municipal Vehicle	359
Special Vehicles	742
Total:	**72,936**

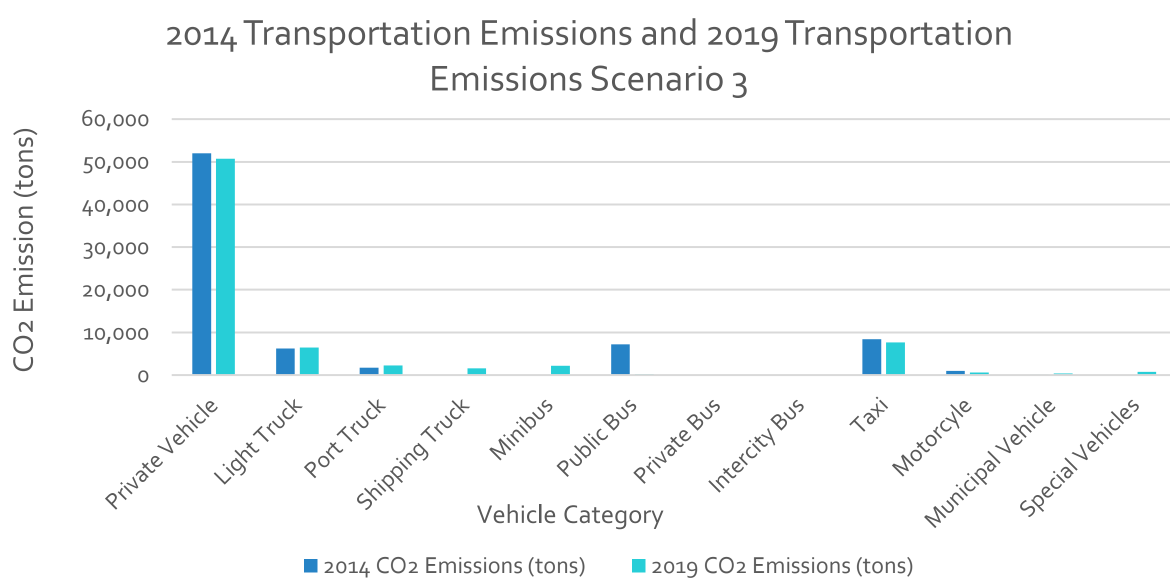

Figure 17. 2014 Transportation Emissions and 2019 Transportation Emissions Scenario 3

4.2.4 Discussion of Results

The estimates using the EEA method provided numbers that were reasonable when compared to the 2014 numbers. However, the estimates using the BEI method resulted in much larger numbers than those seen in 2014. In the BEI method, the emission factors for each vehicle category were not based on the age of the vehicle[12]. This means that the change in ages of vehicles between 2014 and 2019 is not accounted for. Because the EEA method factors in vehicle ages through fuel consumption, it is a measure of how newer vehicles are more fuel efficient. Higher fuel efficiency means less CO_2 emitted into the air.

Private vehicles comprised the largest percentage of transportation emissions in all three scenarios. In Scenarios 2 and 3, private vehicles made up 65% and 69% respectively, compared to 68% in the BEI. However, Scenario 3 did find a decrease in total private vehicle emissions as compared to 2014 levels. Reducing private vehicles emissions is a necessary step to reducing transportation emissions in Eilat.

Despite the decrease in private vehicle emissions that has been estimated so far, the municipality of Eilat can still take steps to further reduce emissions. The public transportation system in Eilat is not an efficient method of getting around the city, leading to the heavy reliance on private vehicles (Goldstein et al., 2019). Based on the fuel consumption data in the EEA guidelines, if at least 5 people are riding a bus, less CO_2 is being emitted per kilometer compared to if each person were to drive a private vehicle. If Eilat could find a way to improve the appeal of public transportation within the city, they could further decrease the emissions from private vehicles.

The municipal vehicles do not account for a large amount of emissions in our report as the numbers we used only include garbage trucks. However, the municipality has been switching their fleet of other vehicles to hybrid and electric vehicles. This is designed to encourage private vehicle owners to invest in hybrid and electric vehicles. If more private vehicles were hybrid or electric, there would be a decline in total transportation emissions.

In the BEI, tourism data was not included in the estimation of transportation emissions. Our report indirectly includes this information. Tourists often arrive via the intercity buses, a number that is included in Scenario 3. Once in the city, tourists typically walk, take a taxi, or ride public buses. There is likely a small amount of emissions not accounted for by tourists who might use private vehicles within the city limits but there is insufficient data to estimate this amount.

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[12] The emission factors do change if vehicles are more than 15 years old. The emission factors are from 2006 and 1996 IPCC guidelines.

The three scenarios provided a wide range of estimates for 2019 transportation emissions in Eilat. Only one method suggested a decline in emissions from 2014. This was likely a result of the municipality's lack of reduction policies targeted towards transportation emissions.

CHAPTER 5: WASTE

5.1 Methods

This section models carbon dioxide (CO_2) and methane (CH_4) emissions from the decomposition of municipal solid waste (MSW) in Eilat during 2019. Waste is deposited in the Nimra landfill, where the decomposition process occurs (*Eilat-Eilot Renewable Energy Newsletter*, 2012). The first stage in waste decomposition is an aerobic (with oxygen) process that produces only small amounts of methane. Primary methane emissions occur under anaerobic (without oxygen) conditions, where methane-excreting bacteria decompose organic waste. This usually takes at least half a year after deposition (*2006 IPCC Guidelines*, 2007). Steady-state conditions typically involve emission compositions of approximately half CO_2 and half CH_4.

Decomposition rates depend on moisture levels of the environment. When modeling Eilat's MSW sites, we considered the dry environment of Eilat, which decreases decomposition rates. Decomposition rates also differ between the types of materials present in a landfill. This analysis includes 5 types of organic waste: food, garden, paper and cardboard, textiles, and diapers.

5.1.1 Overview of Waste Methods

We calculated the methane (CH_4) and carbon dioxide (CO_2) emissions in 2019 produced by waste using a first order decay method modified from Bhide et al. (2018). The first order decay method creates a time dependent emission model that accurately depicts the degradation process. It requires waste deposition data from previous years. Decomposition is modeled by exponential decay.

The first step in the calculation is to determine the amount of decomposed waste during the year of investigation, described by the following equation:

Equation 5

$$DW(t) = \sum_i MSW_i(t) * DOC_i * (1 - e^{-k_i})\, e^{-k_i t} \quad ,$$

$$MSW_i(t) = MSW_{total}(t) * f_i$$

DW = Decomposed waste [tons]
MSW_{total} = Total municipal solid waste [tons]
MSW_i = Municipal solid waste from *i*th *type* [tons]
f_i = Fraction of composition of *i*th type
DOC_i = Degradable organic carbon * degradable fraction [Gg C/Gg MSW]

k_i = decomposition rate constant for the *i*th type of waste [$year^{-1}$]
t = time [years]

Data on total municipal solid waste deposition within Eilat was provided by the Eilat Environmental Unit for the years 2015-2019. The quantity of waste for the i_{th} type (MSW_i) was found by multiplying its fractional composition f_i by the total amount of waste. Composition by type of waste was found from the 2012-2013 Ministry of Environmental Protection survey on waste composition in Israel.

MSW_i was multiplied by its corresponding degradable organic carbon, DOC_i. DOC_i is the proportion of organic matter (by weight) contained within a given type of waste[13] that is emitted as CH_4 or CO_2.

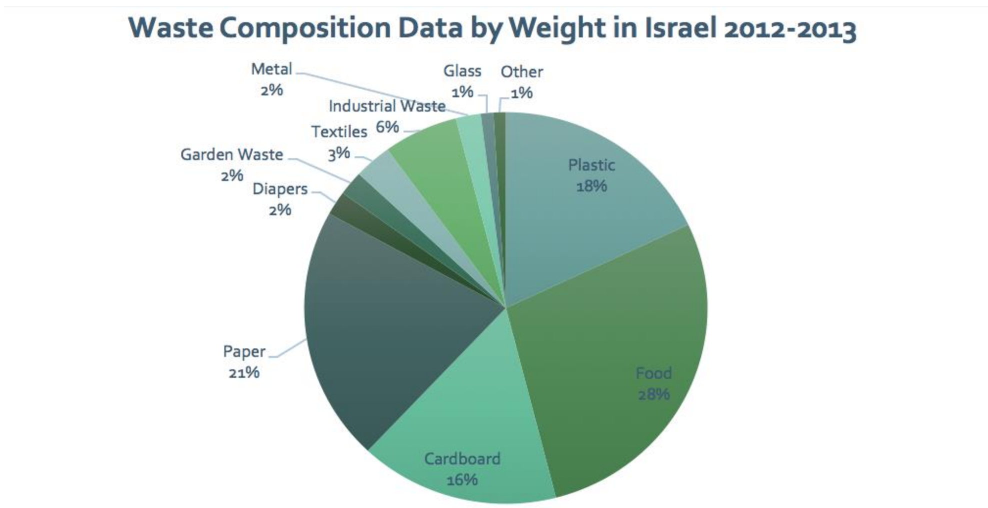

Figure 18. Waste Composition Data by Weight

Waste decays exponentially according to $MSW_i*DOC_i*e^{-kt}$, *i*, and t is the time. Therefore, emissions over a one-year interval are described by $MSW_i*DOC_i*(e^{-kt}-e^{-k(t+1)})$.

Table *12* shows the composition (f_i), degradable content fraction (DOC_i), and decay rate (k) for each type of waste. The k values for each type of waste came from the EPA and pertain to dry environments in the Middle East (RTI International, 2010).

Table 12: *Waste Composition, Degradable Organic Carbon, and Decay Rate*

[13] DOC_i was found by multiplying DOC by DOC_f. The default DOC_f available was 0.77 for all sources of waste (Bhide et al, 2018).

Type	Composition (f_i)	Degradable Organic Carbon (DOC_i)[5]	Decay Rate k_i (1/yr)
Food waste	0.28	0.1155	0.06
Garden	0.02	0.1309	0.05
Paper and Cardboard	0.37	0.308	0.04
Textiles	0.03	0.308	0.04
Diapers	0.02	0.1848	0.05

The next step in the calculation is determine the mass of methane (CH_4) and carbon dioxide (CO_2) released by decomposition, described by the following equation:

Equation 6

$$MTH(t) = \left(\frac{16}{12} * F * DW(t)\right) - R(t)$$

$$CD(t) = \frac{44}{12} * (1 - F) * DW(t)$$

MTH = Methane [tons]
F = Fraction by molecule of CH_4 in landfill gas
R = Methane Recovery [tons]
CD = Carbon dioxide [tons]

The amount of decomposed waste was multiplied by the methane fraction, F. The default value of F is 0.5 (Bhide et al., 2018).To convert to mass of CH_4, the amount of methane was multiplied by 16/12, the ratio of molecular weight of CH_4 to C. To calculate the amount of CO_2 produced, the amount of decomposed waste was multiplied by the carbon dioxide fraction, 1-F. To convert to mass of CO_2, the amount of CO_2 was multiplied by 44/12, the ratio of molecular weight of CO_2 to C. Eilat's landfill has active methane recapture, in which 70% of CH_4 emissions are recovered.

Lastly, methane was converted to CO_2 equivalents, and the contribution from each previous year was summed:

Equation 7

$$GHG(t) = \sum_{\tau} 25 * MTH(t-\tau) + CD(t-\tau)$$

τ = time of deposition [years]
25 = the global warming potential for CH_4

5.2 Results

The total amount of waste that was sent to the landfill within 2015, 2016, 2017, 2018, and 2019 was 55,908, 59,909, 61,352, 63,474, and 59,449 tons respectively (**Table 13**). Within each year, most of the waste came from households, with a small portion coming from containers that had been placed throughout Eilat.

Table 13: *Annual Total Waste Sent to Landfill (tons)*

Year	**2015**	**2016**	**2017**	**2018**	**2019**
Waste (tons)	55,908	59,909	61,352	63,474	59,449

The emissions in 2019, with contributions from waste deposited in previous years, are displayed in **Table 14**. The net amount of emissions during 2019 was 12,186 CO_2 (eq). For waste deposited in 2019, the emission contribution is lowest at 1,443 tons CO_2 (eq) because the decomposition process was not active for the full interval of one year. The waste deposited in 2018 has the greatest contribution at 3,144 CO_2 (eq) tons because it most recently began decomposing. The contribution from each year decreases as one looks further back in time.

Table 14: *Annual and Net Methane and Carbon Dioxide Emissions*

Year	**Net CH_4** (tons)	**CO_2** (tons)	**CO_2** eq (tons)
2015	67	613	2,286
2016	75	688	2,564
2017	80	737	2,749
2018	92	843	3,144
2019	42	387	1,443
Total	**357**	**3,269**	**12,186**

The CO_2 (eq) produced by each type of waste is shown in **Table 15** and *Figure 19*. The largest contributor was paper and cardboard, which released a total of 7,887 CO_2 (eq) (64%). This was followed by food waste with a total of 3,149 CO_2 (eq) (25.8%).

Table 15*: Emissions Produced by Waste Type*

Type	Total CO_2 eq Emissions
Food waste	3,149
Garden	217
Paper and Cardboard	7,887
Textiles	626
Diapers	306

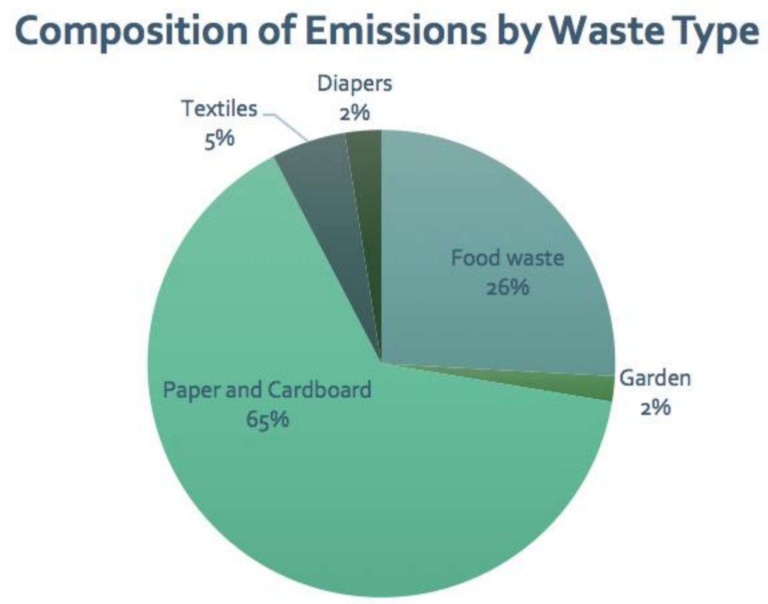

Figure 19. Composition of Emissions by Waste Type

5.3 Discussion

When considering the 70% recovery value, the waste emissions were determined to be 12,186 CO_2 eq tons. The total amount of CH_4 recovered was valued to 832 tons which equates to 20,805 CO_2 eq tons. Therefore, if there was no CH_4 recovery, the total waste emissions would have been 32,991 CO_2 eq tons.

The further back we go with data, one can see that the emissions released do not quickly drop to 0 - the contributions from 2015 are still significant in 2019. Decay rates in arid regions are slow: the half-lives for different types of waste range from 11.6 years to 17.3 years. Therefore, to arrive at more accurate results, we recommend that waste data is obtained for at least 17 years prior to the year of investigation.

The city of Eilat should focus efforts to reduce the types of waste that serve as the largest contributors of emissions. The largest contributor to waste emissions was paper and cardboard which contributed 7,887 CO_2 eq and 64.7% of the total emissions produced by waste. This was followed by food waste which accounted for 3,149 CO_2 eq and 25.8% of total emissions. Efforts to encourage recycling of paper and cardboard should be considered so that these materials can be reused instead of ending up in the landfill. Similarly, the city of Eilat should think of ways to utilize food waste rather than having it sent to the landfill. They could encourage or facilitate a composting operation where food waste may be repurposed.

When comparing the waste emissions calculated within the 2016 report to our calculations, an accurate comparison cannot be made because the methods used within the 2016 report are not completely understood. Within the BEI there is no discussion on methane recovery from waste which significantly reduced the value of emissions.

CHAPTER 6: COMBINING RESULTS

6.1 Emissions Models

Three different models were used to evaluate emissions due to electric power consumption. Model I provided an upper bound, Model II a middle value, and Model III a lower bound (***3.1.4 Calculating Carbon Emissions***). Independently, three different scenarios were used to evaluate transportation emissions, providing a separate upper bound, middle value, and lower bound for transportation (***4.1 Transportation Methods***). A single model was used to evaluate emissions from municipal solid waste (***5.1 Methods)***. The results are shown in **Table 16**. A graphical comparison between the different models is illustrated below in *Figure 20*.

Table 16: *Estimated Total Greenhouse Gas Emissions in Eilat in 2019 (CO_2 eq tons)*

	Upper	Middle	Lower
Electric Power (Population-Scaled)	492,179	350,903	234,041
Transportation	106,311	78,469	72,936
Waste	12,186	12,186	12,186

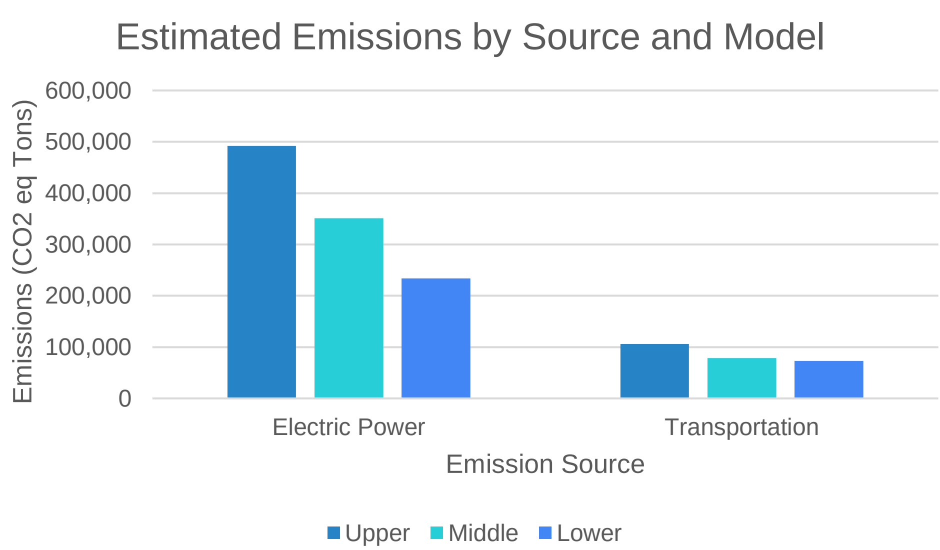

Figure 20. 2019 Estimated Emissions by Source and Model

Within population-scaled electric power consumption (***3.1.1 Power Demand in Eilat***), emissions vary significantly between the different models due to their different assumptions (***3.1.4***

Calculating Carbon Emissions). The upper-bound model does not include solar fields in the Southern Arava, whereas the intermediary model does, and the lower-bound model includes Eilat's gas turbines in addition to solar fields in the Southern Arava.

Within transportation, there is a notable difference between the upper-bound and intermediary scenarios due to the Scenario 1 using IPCC standards, and Scenario 2 using European standards (***4.1 Transportation Methods)***. The difference between Scenario 2 and Scenario 3 is less significant because they only differ in their assumptions of truck and bus routes within the city.

Between the three models pertaining to electric power, the three scenarios pertaining to transportation, and the single model pertaining to municipal solid waste, there are nine possibilities for the aggregation of emissions. The results are compiled in the following Emissions Matrix (**Table 17**). Grouping components of the same color in **Figure 20** gives the diagonal elements of the matrix, while grouping components of different color give the non-diagonal elements.

Table 17: *Emissions Matrix. (CO_2 eq tons)*

		Electric Models		
		Upper	**Middle**	**Lower**
Transport Models	**Upper**	610,675	469,400	352,538
	Middle	582,833	441,558	324,696
	Lower	577,300	436,025	319,163

Seen in **Table 17**: cell (1,1) is the uppermost bound for emissions in 2019, while cell (3,3) is the lowermost bound for emissions. Emissions change significantly across columns, which correspond to the different models of electric power consumption. Emissions change moderately across rows, which correspond to different transportation models. Depending on selection of models, emissions from electric power consumption range from 66.4% to 85.3% of the total, emissions from transportation range 12.5% to 30.1% of the total, and emissions from municipal solid waste range from 2.00% to 3.82% of the total.

Compared to 2014, the relative change in emissions differ considerably depending on choice of model (**Table 18**). 2014 emissions from electric power consumption were determined in **3.1.4 Calculating Carbon Emissions**. 2014 emissions from transportation and waste were taken from the 2016 BEI (Kissinger et al.).

Table 18: *Change in Emissions. (CO_2 eq tons).*

		Electric Models		
		Upper	**Middle**	**Lower**
Transport Models	**Upper**	+41,331 (+7.26%)	+7,901 (+1.71%)	37,330 (+11.8%)
	Middle	13,489 (+2.37%)	-19,941 (-4.32%)	9,488 (+3.01%)
	Lower	+7,956 (+1.40%)	-25,474 (-5.52%)	3,955 (+1.25%)

While no model predicts Eilat to have reached its 20% reduction goal, nearly all models predict a decrease in per capita emissions since 2014 (**Table 19**). This includes temporary residents and visitors in the population count (**3.1.1 Power Demand in Eilat**).

Table 19: *Relative Change in Emissions Per Capita*

		Electric Models		
		Upper	**Middle**	**Lower**
Transport Models	**Upper**	-0.82%	-5.95%	3.41%
	Middle	-5.35%	-11.53%	-4.75%
	Lower	-6.24%	-12.64%	-6.38%

To continue its involvement with Covenant of Mayors, Eilat must establish well-defined processes for preparing emissions inventories. Towards this end, we recommend that comprehensive data are obtained by the Eilat Environmental Unit, minimizing the need for assumptions and extrapolation. A rigorous method for monitoring emissions should be built off those used in this project, and emissions reports should be reproducible and transparent in their methods. Future inventories should also include emissions due to the combustion of liquified petroleum gas for heating and cooking.

6.2 Final Conclusion of Results

For the purposes of submission to the Covenant of Mayors, the results are taken from the intermediate models of electric power consumption and transportation (**Table 17**). The total GHG emissions for 2019 was 441,558 CO_2 eq tons. This is an 4.32% decrease from 2014. *Figure* 21 shows the sources of emissions. *Figure 22* shows the comparison of 2014 and 2019 emissions for electric power, transportation, and waste. Electric power emissions decreased by 8.44% and transportation emissions increased by 2.28%.

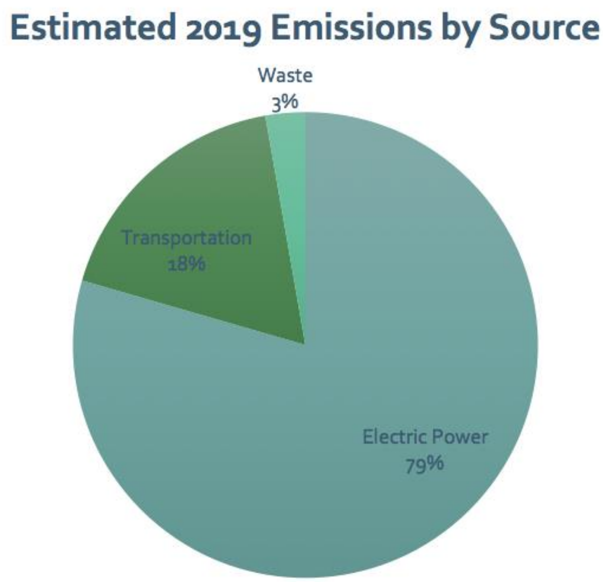

Figure 21. Estimated 2019 Emissions by Source

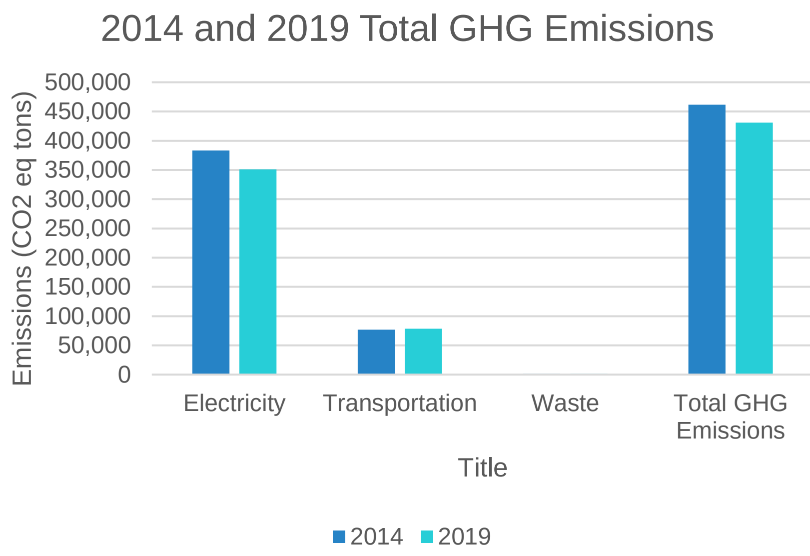

Figure 22. Comparison of GHG Emissions by Year and Sector

6.3 Updated Emission Reduction Measures

We reassessed the GHG emission reduction measures as proposed in the 2018 SEAP for the year 2021. The status of the policies as of 2018 are presented in **Table 1**.**Table 20** shows updated information for each policy as of 2021.

Table 20: *GHG Emission Reduction Measures in Eilat as of 2021*

Policy	Sector	Status
Building Insulation	Municipal/Commercial	Not Completed[1]
Energy Conservation Practices	Commercial	Completed[2]
Efficient Appliances	Residential/Municipal/Commercial	Completed
Electric/Hybrid Vehicles	Municipal	Completed
Promotion of Public Transportation	Residential	Not Completed

[1]Not Completed = Proposed measure in 2018 SEAP that has not been implemented
[2]Completed = Finished as of 2021

If these policies are all implemented and more are added, Eilat might be able to achieve the reduction goal of 20%. The focus of any future emission reduction policies should be on the largest sources of emissions, electricity and transportation.

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APPENDIX A

Spreadsheets and MATLAB code can be found at the Github repository: https://github.com/dsschwartz/IQP-Smart-Eilat-2021

APPENDIX B

PVWatts Inputs. Meteorological data collected in Eilat (29.55, 34.95) during 2017.

Residential Modules		
Parameter	**Value**	**Explanation**
rated power	0.2415	1 kW/m^2 * area * efficency
Module Type: Standard		
cell type	crystalline silicon	
nominal efficiency	0.15	
module cover	glass	
temperature coefficient	0.0047	loss per °C
array type	fixed, roof mount	
System Losses		
soiling	0.03	light rainfall
shading	0.02	little shading
snow	0	none
mismatch	0.02	default
wiring	0.02	default
connections	0.005	default
light-induced degradatio	0.015	default
nameplate rating	0.01	default
age	0.025	estimating .005/yr
availability	0.03	default
estimated cumulative	0.1622	apparently not quite a summation
tilt angle (°)	20	default
azimuth angle (°)	180	facing south
Advanced Parameters		
DC to AC ratio	1.2	inverter power rating, default
inverter efficiency	0.96	default
ground coverage ratio	n/a	applies only to tracking arrays
Result	**372**	**kWh/module/year**

Commercial Modules		
Parameter	**Value**	**Explanation**
rated power	0.294	1 kW/m^2 * area * efficency (area estimation in calculations)
Module Type: Standard		
cell type	crystalline silicon	
nominal efficiency	0.15	
module cover	glass	
temperature coefficien	0.0047	loss per °C
array type	fixed, roof mount	
System Losses		
soiling	0.03	litght rainfall
shading	0.02	little shading
snow	0	none
mismatch	0.02	default
wiring	0.02	default
connections	0.005	default
light-induced degradati	0.015	default
nameplate rating	0.01	default
age	0.025	estimating .005/yr
availability	0.03	default
estimated cumulative	0.1622	apparently not quite a summation
tilt angle (°)	20	default
azimuth angle (°)	180	facing south
Advanced Parameters		
DC to AC ratio	1.2	inverter power rating, default
inverter efficiency	0.96	default
ground coverage ratio	n/a	applies only to tracking arrays
Result	**453**	**kWh/module/year**

Municipal Modules		
Parameter	**Value**	**Explanation**
rated power	0.3	1 kW/m^2 * area * efficency
Module Type: Standard		
cell type	crystalline silicon	
nominal efficiency	0.15	
module cover	glass	
temperature coefficient	0.0047	loss per °C
array type	fixed, roof mount	
System Losses		
soiling	0.03	light rainfall
shading	0.02	little shading
snow	0	none
mismatch	0.02	default
wiring	0.02	default
connections	0.005	default
light-induced degradation	0.015	default
nameplate rating	0.01	default
age	0.025	estimating .005/yr (source: Gilbert M
availability	0.03	default
estimated cumulative	0.1622	apparently not quite a summation
tilt angle (°)	20	default
azimuth angle (°)	180	facing south
Advanced Parameters		
DC to AC ratio	1.2	inverter power rating, default
inverter efficiency	0.96	default
ground coverage ratio	n/a	applies only to tracking arrays
Result	**462**	**kWh/module/year**

Eilot and Arava Valley PV Fields		
Parameter	**Value**	**Explanation**
rated power	180280	1 kW/m^2 * area * efficency
Module Type: Premium		
cell type	crystalline silicon	
nominal efficiency	0.19	
module cover	glass, anti reflective coating	
temperature coefficient	0.0035	loss per °C
array type	fixed, open rack	
System Losses		
soiling	0.03	dust, assuming cleaning
shading	0.01	open field
snow	0	none
mismatch	0.02	defaullt
wiring	0.02	default
connections	0.001	default
light-induced degradation	0.015	default
nameplate rating	0.01	default
age	0.025	estimating .005/yr
availability	0	accounted in power demand data
estimated cumulative	0.1275	multiplied sequentially
tilt angle (°)	30	observational guess
azimuth angle (°)	180	facing south
Advanced Parameters		
DC to AC ratio	1.2	inverter power rating, default
inverter efficiency	0.96	default
ground coverage ratio	0.4	default
Result	**302696512**	**kWh/year**