Title

Energy Modeling in Urban Districts: Forecast of multi-sector Energy Use and GHG Emissions

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Energy Modeling in Urban Districts

FORECAST OF MULTI-SECTOR ENERGY USE AND GHG EMISSIONS

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Energy Technologies Area
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Disclaimer

The primary objective of the study funded by FivePoint and conducted by Berkeley Lab is to explore a new method of predicting emissions and energy use that takes different sectors and phases of developments into consideration holistically. The study, report, and findings may contain research results that are experimental in nature. Any such findings and reports are strictly hypothetical and exploratory in nature. The report is not meant to represent any specific recommendations to existing/future developments and should not be taken as guidance on development planning or design.

Executive Summary

This document reports the findings of the energy use and greenhouse gases (GHG) emissions model loosely based on three districts in the San Francisco Bay Area, District A, District B, and District C.

Modeling platforms exist for city energy benchmarking, inventorying, and GHG emissions forecasting and planning. However, the wide variety and features of today's tools, their focus on a sub-set or snapshot data from various energy generation and consumption sectors, and the fact that many of them are not open data models, create sub-optimal environments for the energy analysis districts are seeking to conduct. Hence, we have developed a new software tool with customized data and dynamic visualization; DEPICT (*Decision-support and Emissions Prediction Interactive Cities Tool*) to obtain energy and emissions forecasts at different stages of the districts' build-out by varying selected design parameters. This report presents the methodology and framework we have developed to estimate whole district emissions and details the results by district, with the objective of finding insights into the main sources of emissions, and the available levers to reduce them efficiently. This document details the impact of each emissions mitigation measure investigated, along with the assumption and models that were used to reach these values. The key findings for each district are presented in Table 1 and Table 2.

Table 1 : District Emissions Summary, an output from the DEPICT tool

District	*Unmitigated CO_2 Emissions MT /capita*	*Primary Drivers of Emissions* MT /capita*	*Mitigated CO_2 Emissions MT /capita*	*Percent reduction*	*Primary Drivers of Mitigation MT /capita*
District A	4.1	**Gas Vehicle:** 3.6 **Local Retail:** 2.0	3.2	22%	**VMT Reduction:** 0.54 **Geothermal Plant:** 0.13
District B	4.4	**Gas Vehicles:** 3.1 **Large Retail:** 1.5	3.4	25%	**VMT Reduction:** 0.39 **Geothermal Plant:** 0.24
District C	3.1	**Gas Vehicles:** 2.6 **Local Retail**: 1.1	2.2	30%	**VMT Reduction:** 0.37 **Net-Zero Residential** 0.20

**Including building operation and vehicle emissions. Note that gas vehicle emissions are included in the retail emissions. MT=Metric Ton, VMT= Vehicle Miles Traveled*

Table 2 : Mitigation Measures Summary, an output from the DEPICT tool

Measure	*CO_2 Reduction [MT /capita]*		
	District A	District B	District C
VMT Reduction (between 10 and 15%)	0.54	0.39	0.37
Geothermal plant for space heating and hot water	0.13	0.24	0.17
PEV penetration increase to 5%	0.09	0.10	0.07
Smart Traffic Signal	0.09	0.10	0.06
PV on 25% of roof area / Net-Zero Residential	0.06	0.09	0.20
Electrification of gas appliances in residential	0.01	0.02	0.01
Reduction in electrical equipment use by 10%	0.01	0.02	0.02

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Introduction

FivePoint is a real estate developer that designs and develops mixed–use, master–planned communities in coastal California. Their planned developments in Orange County, Los Angeles County, and the San Francisco Bay Area will offer homes, commercial, retail, educational, and recreational elements as well as civic areas, parks, and open spaces (https://www.fivepoint.com/). FivePoint has a strong focus on technology and sustainability as a "blueprint for progress". FivePoint intends to push the envelope to reduce GHG emissions and integrate GHG mitigation strategies in the design of its new district projects. FivePoint has set aggressive sustainability targets, driven by key factors such as: the location of its projects in California, a state that leads the curve in environmental regulations and technology adoption; the build-out of new developments that provide an opportunity for novel approaches to 'leapfrog' over conventional strategies that are possible in existing districts; and an organizational culture of innovation and collaboration.

Lawrence Berkeley National Laboratory (commonly referred to as Berkeley Lab) is a United States national laboratory that conducts scientific research and development on behalf of the United States Department of Energy and has deep expertise in building modeling and building technologies. Berkeley Lab is a third party-neutral R&D organization that regularly works with federal and state government and private sector to help shape policy and technology through studies, models, and early stage technologies.

Berkeley Lab and FivePoint have collaborated to develop a GHG-by-sector analysis study and emissions reduction- decision tool. It uses data from three Districts A, B and C that are all multi-use developments. The characteristics of the three districts are as follows: District A is an urban mixed-use development with residential and commercial (office, retail); District B is urban and primarily residential; District C is a suburban mixed use development, but primarily with single family lower density housing and an educational campus. The explorations include questions about whether the primary emissions creation and mitigation has any relation to the programmatic characteristics of the three districts.

Berkeley Lab activities in this study have provided a focus beyond regulatory compliance, for guidance and access to state-of-the-art and state-of-the-practice strategies that can enable meeting ambitious targets; and to advance the thinking around sustainable land development, community, and infrastructure with the twin goals of clean energy and resilience.

Berkeley Lab has generated scenarios that map to the hypothetical build-out phasing of the districts in order to quantify environmental emissions baselines and emissions reduction opportunities. We have also developed a new software tool with customized data and dynamic visualization, DEPICT (*Decision-support and Emissions Prediction Interactive Cities Tool*) to obtain energy and emissions forecasts at different stages of build out and varying selected design parameters. We used to DEPICT to forecast district-wide greenhouse gas emissions and analyze promising GHG reduction strategies across multiple sectors- buildings, vehicles, renewables, and energy storage.

Purpose

The purpose of the collaboration is for Fivepoint to provide a hypothetical baseline on which to build the new decision software tool, which provides a novel integration of data across sectors.

The objective of this work is to develop and test a new decision software tool that integrates models across various sectors, building operation, construction, renewables, district systems, and vehicles, that can provide a dynamic visualization interface as guidance for reducing emissions.

The tool workflow has two steps. In the first step, baseline is modeled, i.e. the unmitigated emissions per sector in all three districts. This step provides information on the main components of the district that can be targeted to efficiently reduce emissions, such as a specific building end-use or vehicle travel destination-based strategies.

The second step is a recommendation engine, to evaluate and recommend mitigation measures that are adapted and tailored to each hypothetical district's characteristics. Those mitigation measures are then aggregated together to determine the total mitigated emissions for the district.

This study reports CO_2 emissions as the main source of greenhouse gases, but other GHG emissions can be evaluated for vehicle and construction using DEPICT. The scope of the study does not include the cost of emissions reduction measures.

The belief is that new tool could be customized for detailed district-wide modeling to provide any project's emissions. This could enable evaluation various different district scenarios that could potentially yield better results for future developments--not just for FivePoint but for any new district development in California.

Methodology

Overall Architecture

Forecasting district or cities emissions and energy use in California is often done with regulatory tools that use empirical models, such as CalEEMod (The California Emissions Estimator Model; www.caleemod.com) or by discretizing the problem between the different sectors - building operation, construction, renewables, district systems, vehicles - and modeling them separately. Other modeling platforms also exist for city-level energy benchmarking, inventorying, and GHG emissions forecasting and planning. However, the wide variety and features of today's tools, their focus on a sub-set or snapshot data from various energy generation and consumption sectors, and the fact that many of them are not open data models, create sub-optimal environments for the energy analysis districts are seeking to conduct (Piette, Zarin-Pass, Singh, & Hong, 2018). These are inefficient when trying to determine the interaction between multiple sectors or the impact of mitigation measures on the entire district. The empirical models might be using data that do not cover the desired inputs and conditions, and modeling the different sectors separately requires going back and forth between the models to study potential interaction. For instance, analyzing the overlap between solar production and electrical demand from building, district energy systems and electric vehicles would require multiple tools and redundant inputs between the different sectors.

To optimally address the objective of this project, Berkeley Lab has developed the *Decision-support and Emissions Prediction Interactive Cities Tool* (DEPICT), which integrates simulation tools together and handles the interaction between them. At the back-end, DEPICT combines data pre-processed by physical or agent-based models of building, vehicle, or energy production systems with the district construction schedule, and outputs the emissions and energy use associated with each building lot. We also developed an interface for DEPICT to visualize different metrics and edit selected input and parameters quickly.

Figure 1 presents the architecture of DEPICT and the various models used.

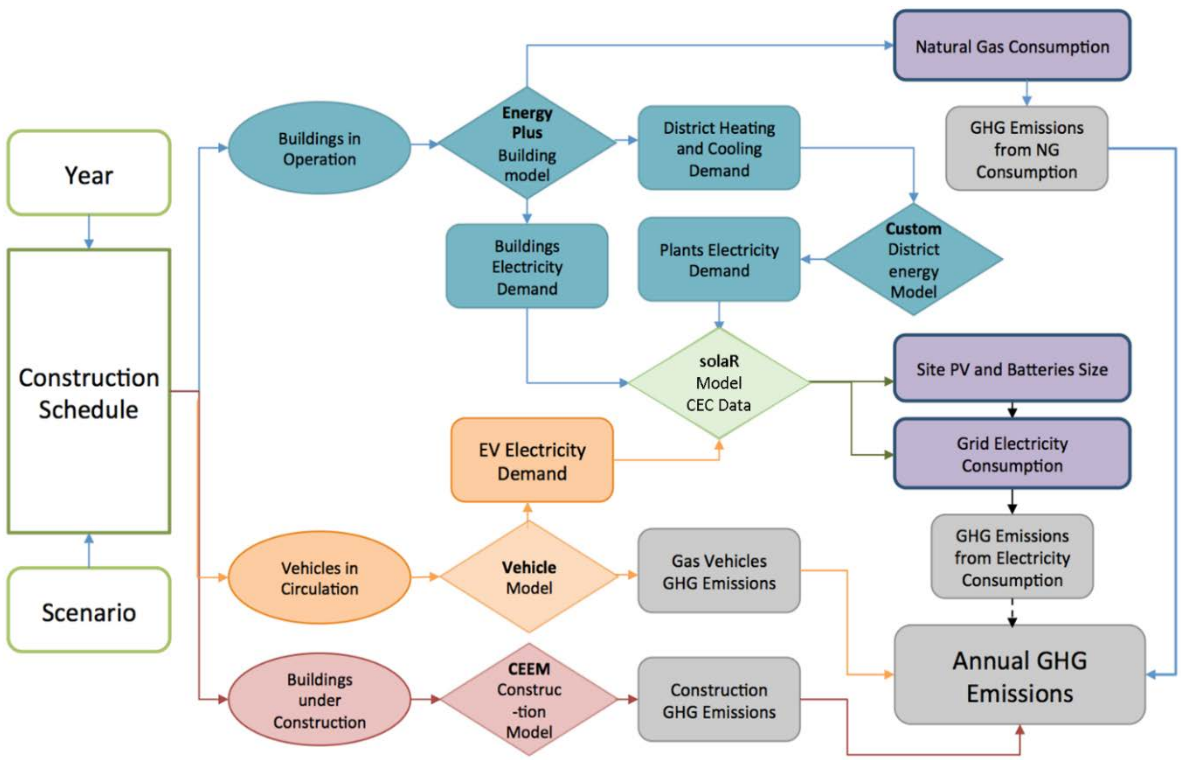

Figure 1: DEPICT back-end architecture. The various models are shown in diamond shaped boxes

The colors represent the different sectors covered by DEPICT: blue for building operation and district energy systems, orange for vehicles (gas and electric), red for building construction, and green for photovoltaics and batteries. Grey boxes represent GHG emissions output, which is the main output of DEPICT, while purple boxes are other metrics that can be extracted from the results. Note that while we recognize that electricity grid emissions will drop over time with SB100, the emissions results from DEPICT use the current snapshot of the electricity emissions factor.

The following sections present in depth the assumptions that are used in each model.

District Schedule Assumptions

The main input used by DEPICT is the hypothetical district schedule, containing the building types, area, residential units and construction years expected for each district. Additional inputs are required for the different models and are assumed from the building types, area and/or residential units. All the data being used in DEPICT is input into the default templates created for the tool and may be considered proxy data.

The floor footprint of each building lot, which impacts construction emissions, is computed from the assumed average number of floors for each building type. The average number of floors is taken from the EnergyPlus reference models used for each building type, except for District C where proxy roof area was provided and hence used as building footprint area.

Table 3 : Schedule: Building Floor Assumptions

Building Type	Number of floors
Large Office	12
High-rise apartment	10
Mid-rise apartment	4
Small Hotel	3
R&D Office	3
Large School	2
Large Single Family	2
All Others	1

The number of parking lots, that impacts the electric vehicle charging model, was provided for District A and District B. It was assumed for District C, by using the same ratio of parking spots per area or per residential units or similar building types as Districts A and B.

Table 4 : Schedule: Building Parking Assumptions

Building type	Parking default
All Residential	1 per unit
Retail	3 per 1000ft^2
Office	1.3 per 1000ft^2
School	0.07 per 1000ft^2
Hotel	0.4 per 1000ft^2
Community Use	0.5 per 1000ft^2

The service population, used for normalizing emissions, was estimated using the population density by building type used in an environmental impact report for the city of Los Angeles (Corbin and Nordhoff, 2003), with similar buildings usage.

Table 5 : Schedule: Building Population Density Assumptions

Building Type	Service Population Density
Office Space	4.17 employees per 1000ft^2
Retail	2.5 employees per 1000ft^2
Senior Housing	0.33 employees per 1000ft^2 1.5 residents per unit
School	1.0 employee per 13 students*
Hotel	1.0 employee per hotel room**
Residential	2.5 residents per unit

*15.6 students per 1000ft^2 in small school, 5.44 students per 1000ft^2 in large school, per CalEEMod
**1452ft^2 per room, per CalEEMod

Building Construction Model

DEPICT construction models were built using the equations detailed in the Appendix A of the CalEEMod user's manual (Trinity Consultants, 2016) for on-road and off-road vehicles emissions. The model described here omits the calculations relative to dust emissions, since they do not contribute to the total count of GHG emissions. The model uses the same assumption used by CalEEMod and was validated by comparing the results to CalEEMod report for the same input.

The model assumes the duration, type of construction vehicles, and number of workers and vendors required to complete a building project based on the size, ground footprint area and type of building (single family, multi-family, commercial/retail or office/industrial). The phases of construction considered are the following in order of occurrence: *Demolition, Preparation, Grading, Construction*, and *Architectural Coating and Paving*. The intensity of use of off-road vehicles is a function of the duration and number of workers on a construction site.

The distance travelled by vendors and workers, which are accounted for in the on-road vehicles emissions, are determined by the location of the project. The emission rates of on-road and off-road vehicles are taken from the emission factors database (EMFAC 2014), which is a model of the emissions of all Californian land vehicles, separated by county, and predicted until 2050.

The DEPICT model uses the start year of each phase of construction or assumes the schedule with the start year of the construction project. This was changed to use the start and end years as input, by assuming that Demolition, Preparation and Grading happen during the start year. Architectural Coating and Paving happen during the end year. Building Construction is evenly distributed from the start year to the end year (CalEEMod does not calculate embedded emissions). This means that if the model estimates that, given its size, the Building Construction of a block would take 200 days and the input values taken from the schedule specify that the construction is planned over 4 years, this construction would be scheduled for 50 days each year. The year of end of construction is either the earliest or latest scheduled year, depending on user input.

The output of the model is the total annual gas emissions from construction. Gases accounted for are ROG, CO, NOx, SO_2, CO_2 and CH_4. The output can be normalized by building area (each year uses the total of size of all buildings under construction) or by final service population for the district.

Building Operation Model

Building energy consumption during operation was modeled using EnergyPlus (Crawley, et al., 2001). For each building type, a building model was developed as a proxy representation. The modeling results are normalized by area (or units for residential) and scaled to the size intensity of each building type. For commercial buildings, we used the models from CBECC-Com (Lee, Hong, Piette, & Taylor-Lange, 2015), a tool to validate that building design is code-compliant to Title 24 2019 (California Energy Commission, 2018). For residential buildings, we used the models from CBECC-Res and translated to EnergyPlus; these are also compliant to Title 24 2019. In addition, guidelines on PV production were used that are described in the Distributed Energy Resources Model section and are handled separately in DEPICT.

The residential models are normalized by residential units, which assumes that the energy usage is not highly correlated to the size of the unit. This assumption is supported by the end-use breakdown of energy in the apartment models, where the highest end-uses are equipment, lights and domestic hot water, which typically have a higher correlation to the number of residents than to the size of a unit, and the lowest end-uses are heating and cooling, which would have a higher correlation to the size of a unit. For districts where the size of units was not given, the size of the reference model unit was used. This assumption only impacts the validity of the results when normalized by area, but the total results would be the same with a different assumption on unit area.

For baseline results, the metrics extracted from the model are annual values, whereas the district energy systems and distributed energy resources model take hourly energy demand values from those models as input. CO_2 emissions resulting from electricity and gas consumption is post-processed depending on the emissions rate selected. The default CO_2 emission factor for electricity was derived from PG&E emissions factors (The Climate Registry, 2016) and renewable portfolio (CPUC, 2014-2018) for the period 2011-2016 and extrapolated to a renewable portfolio of 50%, which is a required target for California Public Utilities Commission (CPUC) for 2030 (California State Senate, 2015). This corresponds to an emissions factor of 0.12 $MTCO_2$/MWh. The emissions factor for gas consumption is comparable between CPUC, regions and years, as the composition of natural gas does not change significantly, and we use a factor of 12.12 MT CO_2 / therms (Deru & Torcellini, 2007).

Each building type used in the three districts schedules (with building types, area, residential units and construction years expected for each district) was associated to a reference model. The models selected for each building type are presented in the district presentation sections.

Vehicle Model

DEPICT model for vehicle emissions is composed of two different models: one for plug-in electric vehicles (PEV) and another one for gas vehicles.

For gas vehicles, the model utilizes CalEEMod equations to determine the vehicles miles travelled (VMT). This model is based on survey data and uses the building type and area as input. The original model uses that information and user input to determine the amount of VMT to and from the buildings site, and the distance covered is depending on the 'tour' that a given building type is associated with. For instance, retail might be associated with a 'home to retail' tour or with a 'home to work to retail' tour. In DEPICT, the default values for the Bay Area are used to determine the ratio of tours and the typical distance travelled. When a more accurate VMT is available, DEPICT can reduce the total VMT to match this value, while conserving the same ratio between work-, residential- and retail-related travels.

In addition, the model is using the vehicle emission factors from EMFAC 2017 (California Air Resources Board, 2018), which can be derived to arrive at GHG emissions of a typical gas vehicle by location. The location impacts the mix of vehicle fleet in this region, based on survey results. This database also contains predictions on the profile of the gas vehicle fleet in the future, which was used to create a more accurate model.

For electric vehicles, DEPICT uses hourly charging pattern data computed using BEAM (Sheppard, Waraich, Campbell, Pozdnukhov, & Gopal, 2017), an agent-based model for transportation analysis, for weekdays and weekends, and separated by charge location (home, work or public/retail) and type of PEV – either plug-in hybrid electric vehicle (PHEV) or battery electric vehicle (BEV). For this reason, the model works differently than for gas vehicles since the VMT is already integrated in that charge profile. In other words, the charge used by a typical electric vehicle reflects its typical travel distance. The main assumption is therefore that the behavior of PEV owner will remain the same on average between now and the forecasted year.

Another data source considered for electric vehicle is EVI-Pro (Wood, Rames, Muratori, Raghavan, & Melaina, 2017), which uses empirical data to determine the typical charging behavior of an average fleet of PEV in California. The two models have very similar output for residential charging, but EVI-Pro has a higher estimate of public and workplace charging. A comparison of the two tools output is shown in Figure 2. Since residential charging is the predominant source of electricity use for PEV, the models report similar pattern at the district level.

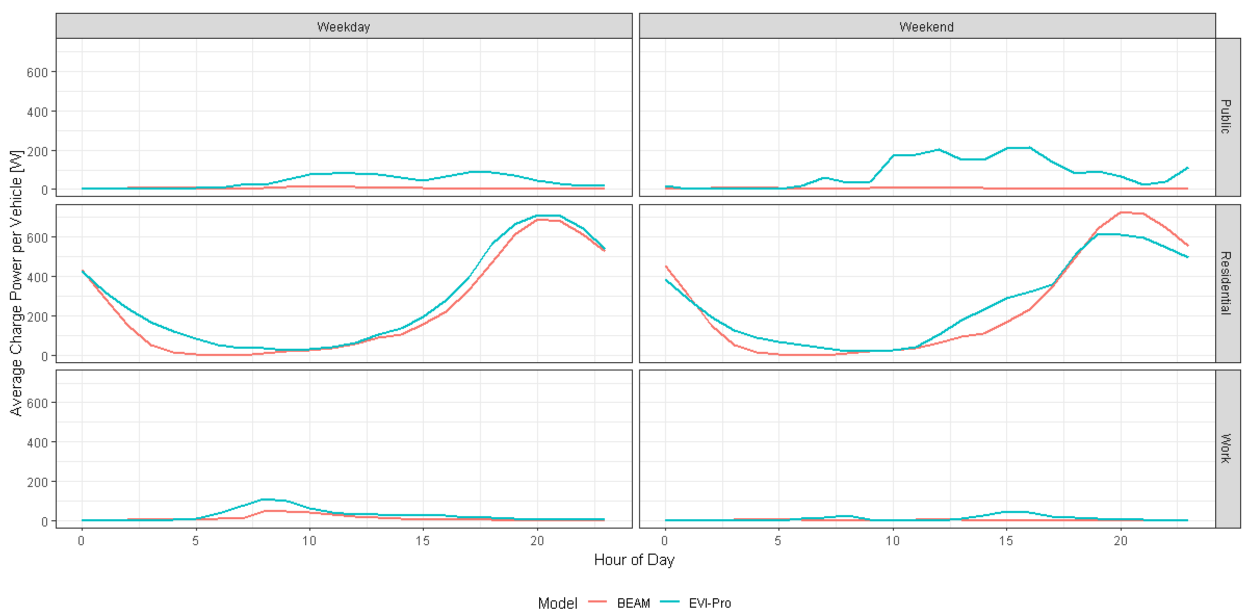

Figure 2 : Electric Vehicle Charging Pattern Model Comparison between BEAM(red) and EVIPro (blue) Models

The modeled electrical consumption of PEV vehicles is the product of the hourly charge profile by the number of PEV vehicles for a given location. That number is assumed to be a user input ratio of the number of parking spot for each building lot. The electricity consumption is translated into CO_2 with the same emission factor used in the building operation model.

District Energy Systems Model

District energy systems are thermal networks and plants that supply or extract heat to a collection of building or industries. In the context of DEPICT, a district energy system can be connected to part or the entirety of the building stock to provide for the space heating, space cooling or domestic/service hot water demand in that network. One advantage provided by district energy systems is to centralize the demand and provide a better production efficiency than with decentralized system. Another advantage is to be able to remove excess heat from a building and distribute it to other buildings, exploiting the diversity of building schedules. This second advantage is not yet modeled in DEPICT, and the benefit of district systems studied are the increase of efficiency and wider range of heating and cooling energy sources.

The model for District Energy Systems uses the hourly heating or cooling demand from building and calculates the required energy consumption to supply it. The model takes an energy source and production efficiency as parameters. Currently, the model assumes an average efficiency over the year and the output energy consumption is calculated from the total annual demand multiplied by that efficiency. Future development of DEPICT aims at incorporating distribution of demand between building and a more accurate modeling of plant performances, especially for geothermal plant.

Distributed Energy Resources Model

The model for photovoltaic (PV) production, a distributed energy resource (DER) is based on two aspects: the performance of PV modules is taken from the CEC module database, which lists the performance of all commercially available modules in California, and the engine that produces the energy output based on PV performance, modules count, tilt and azimuth, and weather information. The weather data is taken from the TMY3 data for each simulated location, which is the same weather data used to compute the building operation consumption and is modeled through the solaR library (Perpinan, 2016) functions to create the normalized energy output by area. It is assumed that the modules are working optimally and that their output is proportional to the size of the solar plant.

The battery model takes the total installed capacity and a loss coefficient as parameters. The loss coefficient is defined as a percentage of stored energy dissipated per hour. This model is used with the hourly building and electric vehicle demand and the potential PV production to determine the amount of energy stored or released by the battery. The rest of the energy is assumed to be provided by the grid.

On Energy Modeling Accuracy

Modeling of energy use and emissions relies on assumptions that can be difficult to assess accurately. The error associated with each assumption can add up and increase model uncertainties. Moreover, differences between design and operation behavior will further impact model accuracies (Piette, Nordman, deBuen, & Diamond, 1993). Nevertheless, energy modeling results can drive the analysis of performance of a building or district and inform on potential areas of improvement.

Results – District A Development

District presentation

District A has a mix of residential and commercial buildings. An overview of the full district buildout is shown in Table 6 and the construction schedule (2023-2031) is illustrated in Figure 3. The service population estimated from the district schedule is 8,635 residents and 19,663 workers for a total of **28,298 people**.

Table 6 : District A Buildout Description used as the schedule for District A

Building Type	*Total Area [ft²]* ***(units)***	*Residents/Employees*
Artist Studio	255,000	255
Community Use	50,000	50
High Rise Apartment	3,688,000 **(3454 units)**	8,635
Hotel	120,000	83
Mixed Offices	4,265,000	17,785
Regional Retail	100,000	250
Retail and Maker Space	300,000	750
School	410,000	490

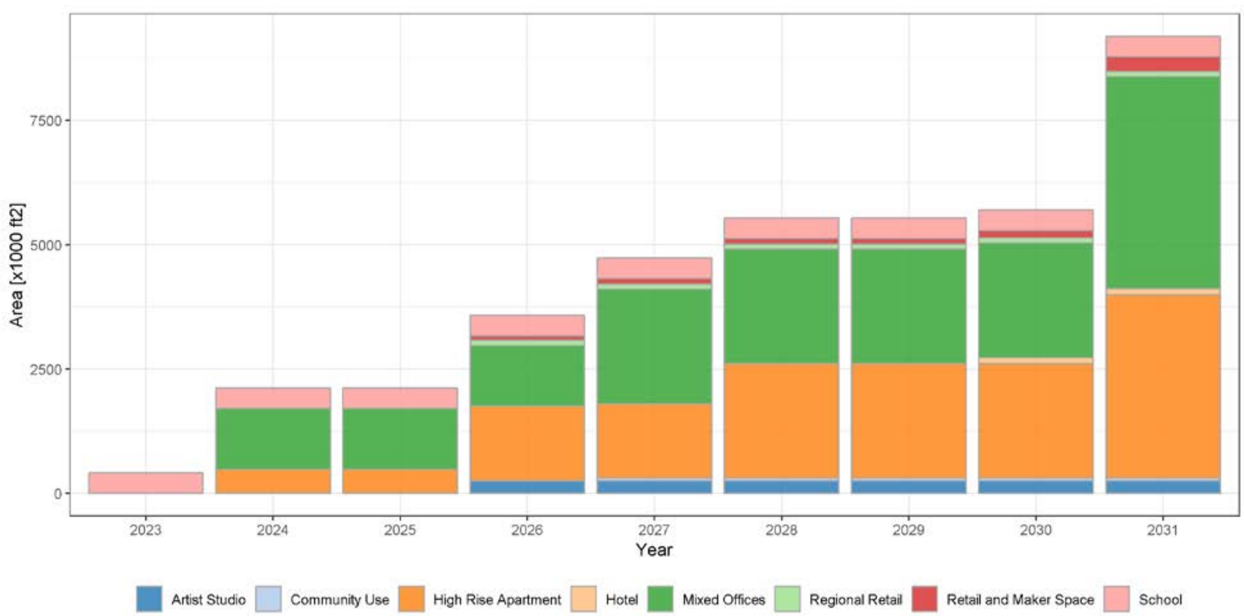

Figure 3 : District A Construction Schedule

Building Construction

The building construction modeled was developed using the later year of end of construction. Most of the building construction emissions are due to the on-road vehicles that are used for commute by construction workers or to carry materials in and out of the construction site. Figure 4 shows the total CO_2 emitted throughout the district construction separated by phase of construction.

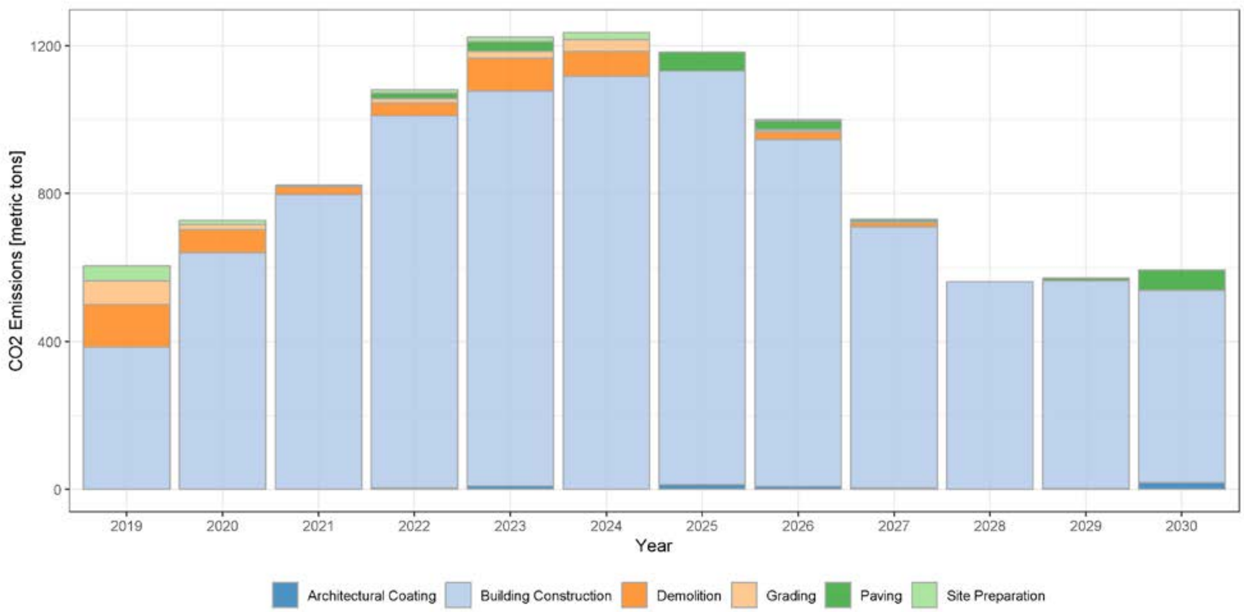

Figure 4 : DEPICT results: District A Construction Emissions

Overall, building construction accounts for **0.37 MT CO_2/capita** over the 2019-2030 period.

Building Operations

Baseline Analysis

For building operations, mixed offices were assumed to be composed of 75% of large office building and 25% of R&D office. Retail and "Maker Space" was assumed to be composed of 50% of mixed-use building and 50% of local retail spaces. The detail of the reference model used for each building type in the schedule, along with the normalized electricity and gas energy use intensity (EUI) and the annual normalized CO_2 emission rate is presented in Table 7.

Table 7 : District A Building Model Description

Building Type	*EnergyPlus Model*	*Elec. EUI [kBTU/ft²/yr]*	*Gas EUI [kBTU/ft²/yr]*	*CO_2 Em. [lb./ft²/yr]*
High Rise Apartment	Multi Family Small	8.81	16.80	2.73
Mixed Offices	75% Large Office 25% Labs	23.46	15.43	3.72
Artist Studio	Mixed Use Space	33.27	6.15	3.37
Retail and Maker Space	50% Mixed Use Space 50% Local Retail	26.78	9.79	3.30
Regional Retail	Large Retail	19.17	8.76	2.57
School	Small School	13.18	14.97	2.85
Hotel	Small Hotel	13.04	5.56	1.70
Community Use	Mixed Use Space	33.27	6.15	3.37

Figure 5 shows the annual CO_2 emissions from building operation, assuming that buildings are fully operational on the year directly following end of construction.

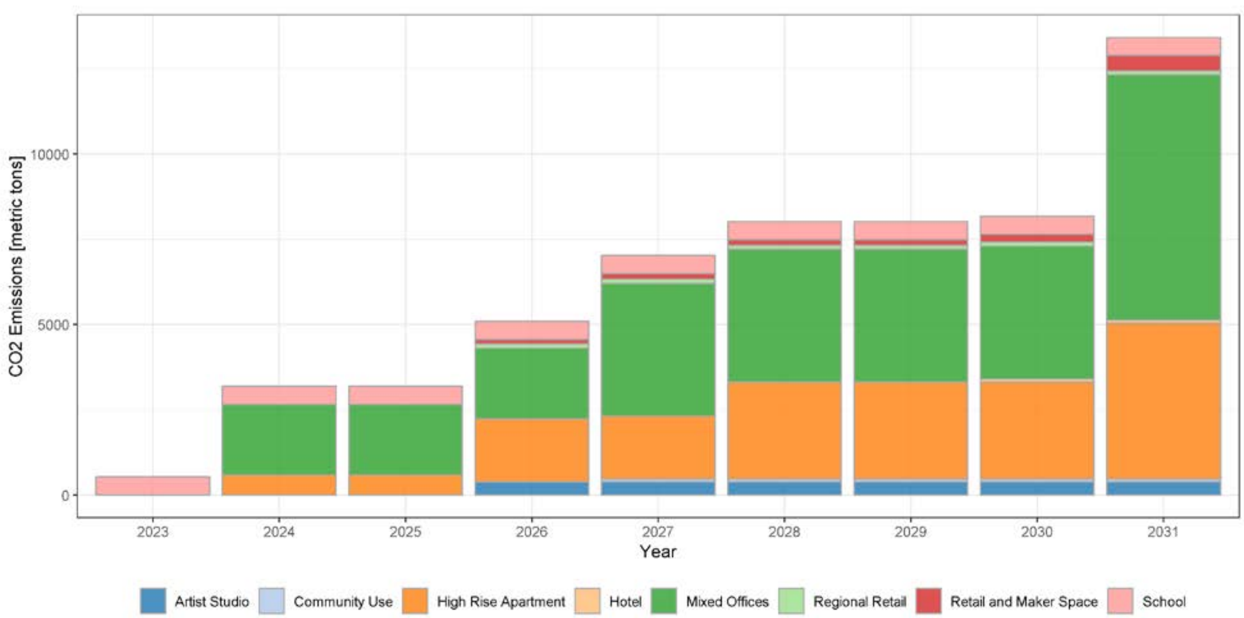

Figure 5 : DEPICT results: District A Building Operation CO_2 Emissions

High-Rise Apartments and Mixed Offices are the main sources of CO_2 emissions for building operation. While they correspond to **40%** and **46%** of the total area buildout respectively, they are responsible for **34%** and **54%** of the total building operation emissions when fully operational in 2031.

In terms of end-uses, Table 8 shows the breakdown of CO_2 emissions by end uses and energy source. The main end-use is gas heating (**29.6%**), followed by electrical equipment (**26.7%**), gas water heating (**19.6%**) and gas equipment from residential appliances (**8.3%**). This is a snapshot since gas emissions factors will reamin constant, but electricity emissions factors would probably be reducing over time.

Table 8 : District A Building CO_2 End Uses Ratio.

End Use	*Energy Source*	*Ratio of CO_2 Emissions*
Heating	Gas	29.6%
Interior Equipment	Electricity	26.7%
Water Systems	Gas	19.6%
Interior Equipment	Gas	8.3%
Interior Lighting	Electricity	7.7%
Fans	Electricity	6.1%
Cooling	Electricity	1.4%
Pumps	Electricity	0.5%
Water Systems	Electricity	0.2%
Heating	Electricity	0.0%

The baseline total CO_2 emissions from building after complete buildout is **13,416 MT CO_2 annually**. When normalized by the service population (28,298 people), the value is **0.474 MT CO_2 / capita**.

GHG Reduction Measures

The following measures are suggestions to reduce CO_2 emissions coming from building operations. These measures have been selected as providing the most significant emissions reduction benefit, from a variety of potential measures analyzed through in the DEPICT model.

- Reduce gas heating from mixed offices and residential units by either connecting the load to a district heating system and/or replacing production source from gas to electricity. Electricity has a lower emission factor (0.12 MT CO_2/MWh compared to 0.19 MT CO_2/MWh), and heat can be produced with a higher efficiency. A heat pump would greatly increase the impact of this measure. The impact of this measure is analyzed in the district energy systems section.

- Propose solutions to reduce interior equipment electricity use in office building, by using fewer appliances or less electricity demand with same number of appliances but more efficient equipment, smart plugs and energy management systems (EMS). Some EMS solutions (Choi, Park, & Lee, 2015) have shown to help reduce computer consumption by 31.9% and lights consumption by 15.3% by reducing energy use when not in use. Reducing the office electrical equipment consumption by 10%, could reduce the district annual CO_2 emission by **272 MT CO_2** or **0.010 MT CO_2 /capita.**

- Replace gas equipment in residential house, such as cookstoves, by electrical equipment in order to make use of lower electricity emissions factor. Assuming an equivalent end-use efficiency, this could reduce up to **398.6 MT CO_2** or **0.014 MT CO_2 /capita** of CO_2 emissions annually.

On the other hand, mitigation measures aimed at reducing cooling or interior lights would not have a strong impact, considering that those loads represent a lower fraction of the CO_2 emissions and the lighting requirements in Title 24 2019 buildings do not leave a lot of margin for improvement. Improving the envelope of building would also be inefficient since the envelopes are already efficient for Title 24 2019 buildings and most of the heating load comes from ventilating buildings with outside air.

District Energy Systems

The district energy model was built using the heating, cooling and hot water hourly demand from EnergyPlus models in that district. Figure 6 provides a breakdown of the CO_2 emissions from space heating, cooling and hot water demand by building types. It is evident from that chart that higher reductions of CO_2 emissions can be achieved by improving the production of energy for domestic hot water in high-rise apartment and for space heating in mixed offices.

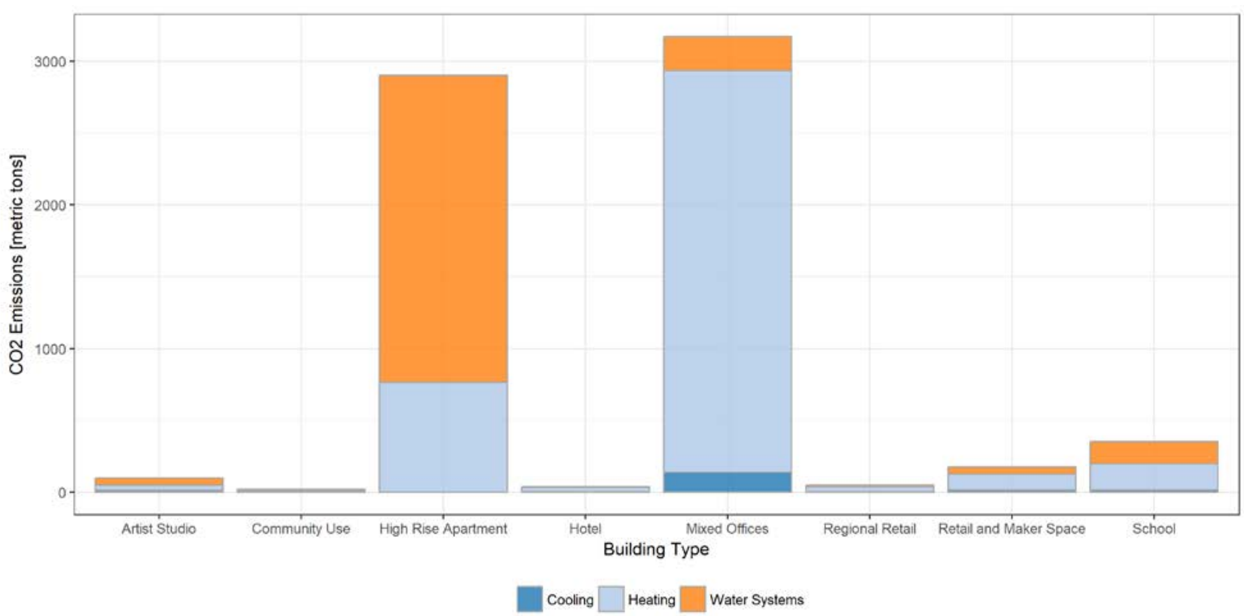

Figure 6 : DEPICT results: District A Heating, Cooling, and Hot Water CO_2 Emissions

The main benefit of district energy systems studied in this document is improving the efficiency of space heating and hot water production. The suggested mitigation measured is to connect some or all the demand to a centralized geothermal heat plant. Typical geothermal systems have an average coefficient of performance (COP), which is the ratio of heating energy delivered to electrical energy consumed, between 2.5 and 3.5, but some new geothermal technologies, especially when integrated with solar heat collectors, have proven to have a seasonal COP of 5 and higher (Hepbasli & Kalinci, 2008). For this analysis, we will assume an average COP of 4.

Table 9 shows the impact on CO_2 mitigation of connecting some of the space heating and hot water demand to a centralized geothermal plant with an average COP of 4. It should be noted that the same

CO_2 reduction could be achieved with a decentralized system that has the same annual average COP, however, decentralized systems generally achieve lower annual average efficiency from being run at partial load.

The table is sorted from the highest CO_2 emission reduction potential measure to the lowest.

Table 9 : District A Geothermal Plant CO_2 Reduction Potential

Building Type	*Demand Type*	*Annual Energy [MBTU/yr]*	*Unmitigated CO_2 Emissions [MT CO_2 /yr]*	*CO_2 Reduction [MT CO_2 /yr]*
Mixed Offices	Space Heating	35090	2798	**2171**
High Rise Apartment	Water Systems	31037	2138	**1583**
High Rise Apartment	Space Heating	11045	765	**568**
Mixed Offices	Water Systems	3392	235	**174**
School	Space Heating	2235	182	**142**
School	Water Systems	2307	155	**114**
Retail/Maker Space	Space Heating	1256	110	**88**
Retail/Maker Space	Water Systems	652	51	**39**
Artist Studio	Water Systems	590	49	**38**
Artist Studio	Space Heating	328	38	**32**
Regional Retail	Space Heating	348	34	**28**
Hotel	Space Heating	369	31	**24**
Regional Retail	Water Systems	205	14	**10**
Community Use	Water Systems	116	10	**8**
Community Use	Space Heating	65	7	**6**
Hotel	Water Systems	61	5	**4**

If the space heating for the office buildings were connected to a geothermal plant, this could reduce CO_2 emissions by **2,171 MT CO_2** annually, or **0.077 MT CO_2 / capita**. In addition, the CO_2 emissions from hot water production in high rise apartments could be reduced by **1,583 MT CO_2**, or **0.056 MT CO_2 / capita**. Those results are assuming that the entirety of each building type is connected to a centralized plant, but the CO_2 emission reduction is proportional to the building area, therefore if only 30% of a building type is connected, the impact would be 30% of what is shown in the table, provided that the same plant efficiency can be achieved. Other production system and efficiency can be investigated using DEPICT.

Vehicles

Baseline Analysis

Gas vehicle emissions were computed using the default parameters value for the CalEEMod VMT calculation algorithm. When fully operational, the average daily VMT for vehicles is estimated at **895,685 miles**, or **31.65 miles/capita/day**. Table 10 shows the CalEEMod land use subtype used to represent each building type in the district along with the annual VMT by area created by each building type.

Table 10 : District A VMT Model

Building Type	*CalEEMod Model*	*VMT per area [miles/ft2/yr]*
Retail and Maker Space	Convenience Market (24 hour)	6237
Regional Retail	Supermarket	1500
School	Elementary School	262
Artist Studio	General Office Building	216
Community Use	General Office Building	216
Mixed Offices	General Office Building	216
Hotel	Hotel	111
High Rise Apartment	Apartments High Rise	106

The emissions factor and fleet mix were taken for each year from the San Francisco forecast in EMFAC 2017. For electric vehicles, the baseline is assuming a 2% penetration for PEV with 33.1% PHEV and 66.9% BEV, which is consistent with recent new registration ratio of PEV in the Bay Area (Clean Vehicle Rebate Program, 2019). Figure 7 shows the CO_2 emissions from the first year of operation until full buildout, separated by travel type.

For the year 2031, the expected annual emissions from vehicles are **102,794 MT CO_2**. This is equivalent to **3.6 MT CO_2 /capita**, assuming default VMT calculation for the district and 2% of PEV in the vehicle fleet. These unmitigated results are driven by a higher ratio of retail travel (**60%**), combined with a lower service population associated with retail spaces. PEV in the district requires an estimated annual charge of **149.40MWh**, which accounts for **17.9 MT CO_2** of the emissions, or about 0.02% of the vehicle emissions.

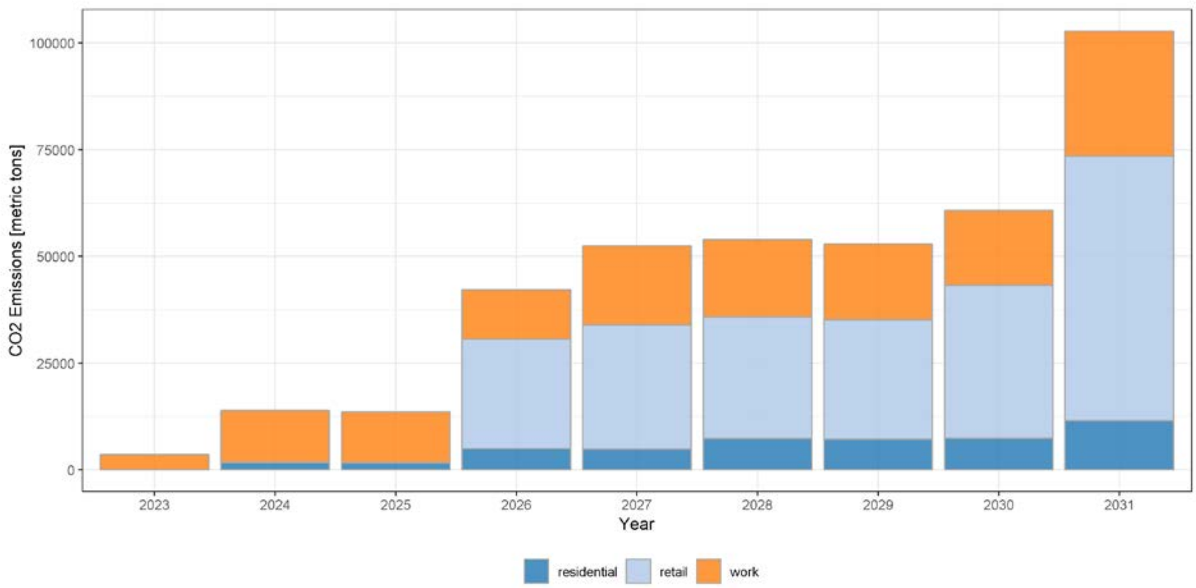

Figure 7 : DEPICT results: District A Vehicle Emissions

GHG Reduction Measures

Reducing vehicle emissions can be achieved through three different types of measures:

- Reducing VMT by proposing alternative mode of travel or reducing the distance between residential, work and retail areas.
- Increasing the penetration of electric or alternative vehicles.
- Improve traffic flow with an efficient roadways design and using smart traffic signals.

Another source of mitigation comes from improving the efficiency of gas vehicle, but this effect is already modeled in the vehicle emission factor schedule.

District A is a mixed-use district, which theoretically reduces the distance travelled by residents and workers. It is also planned to have fast connection to BART and CalTrain, which would further reduce the need for using personal vehicles. While these factors are not modeled in DEPICT, we can assume that it would reduce baseline VMT calculation by a factor of 15%, consistent with available models performed by a transportation consultant, that have a similar mix of residential, business and retail buildings.

The reduction of VMT by 15% would bring daily VMT to **761,332 miles** and reduce mobile CO_2 emissions by **15,418 MT CO_2**, or **0.38 MT CO_2 / capita.**

Additionally, promoting the use of electric vehicles by installing fast-charging stations and dedicated parking spots may drive the penetration of PEV for that district from 2% to 5%. Each increment of 1% of PEV penetration would further reduce emissions by 884 MT, and a total penetration of 5% would reduce vehicles emissions by **2,652 MT CO_2**, or **0.094 MT CO_2 / capita**.

Improving traffic flow with smart traffic signals is assumed to further reduce CO_2 emissions by 3%, which corresponds to another **2,542 MT CO_2**, or **0.090 MT CO_2 / capita** annually.

Solar and Battery

Photovoltaic panels and batteries can help reduce electricity import and cost, but have a minor impact on greenhouse gases emissions, since electricity has a lower emission factor.

The solar model was run with the baseline building and vehicle electricity hourly consumption. The measures that impact electricity use or PEV penetration would have an impact on the total amount and shape of the electricity demand but would not have an impact on the amount of electricity shed by the photovoltaic panels. After complete buildout, the building operations have an annual electricity demand of 46.78 GWh and electric vehicle have an annual charge of 0.13 GWh.

If the district uses monocrystalline 370W modules with no solar tracking, which corresponds to mid-range performance panels, covering the district electricity demand would require **97,451 solar units**, covering **1,710,546 ft^2**. This would reduce annual CO_2 emissions by **5,629 MT CO_2**, or **0.20 MT CO_2 / capita**. Using the number of stories of the reference model, we estimate the total roof area for the district to be 2,171,787 ft^2. If installed on building's roof, the PV modules would cover 79% of the area. If we look at the impact of installing PV on 25% of roof area, the annual production would reach **14.85 GWh**, and reduces CO_2 emissions by **1,782 MT CO_2** annually, or **0.062 MT CO_2 / capita**.

DEPICT allows the user to determine the minimum amount of batteries required to minimize the amount of electricity purchased from the grid. This assumes a simple charging and discharging algorithm (charge when overproducing; discharge when site consumption exceeds solar production). In the scenario where 25% of the roof area is covered with monocrystalline panels, 24,973 kWh of batteries would need to be installed. Figure 8 shows what the average hourly electrical consumption would look like for the entire district.

Table 11 shows the area of PV modules and roof coverage that would be required to cover each building type electricity demand, and the associated CO_2 emissions from that electricity demand.

Table 11 : District A Electricity Consumption, PV Coverage

Building Type	*Electricity Demand [GWh]*	*CO_2 Emissions [MT CO_2]*	*Roof Area [ft^2]*	*PV Area [ft^2]*	*Roof Coverage [%]*
Mixed Offices	29.33	3,520	852,997	1,073,971	126%
High-Rise Apartment	9.66	1,159	368,795	353,597	96%
Artist Studio	2.49	298	254,999	91,040	36%
Retail/Maker Space	2.36	283	299,999	86,231	29%
School	1.58	190	204,999	57,988	28%
Regional Retail	0.56	67	100,000	20,580	21%
Community Use	0.49	59	50,000	17,851	36%
Hotel	0.46	55	40,000	16,850	42%

DEPICT allows the user to determine the minimum amount of batteries required to minimize the amount of electricity purchased from the grid. In the scenario where 25% of the roof area is covered with monocrystalline panels, **24,973 kWh** of batteries would need to be installed. Figure 8 shows what the average hourly electrical consumption would look like for the entire district. Depending on the utility rate and discharge rate of the battery, the battery may want to discharge more relative energy at 17hrs-19hrs.

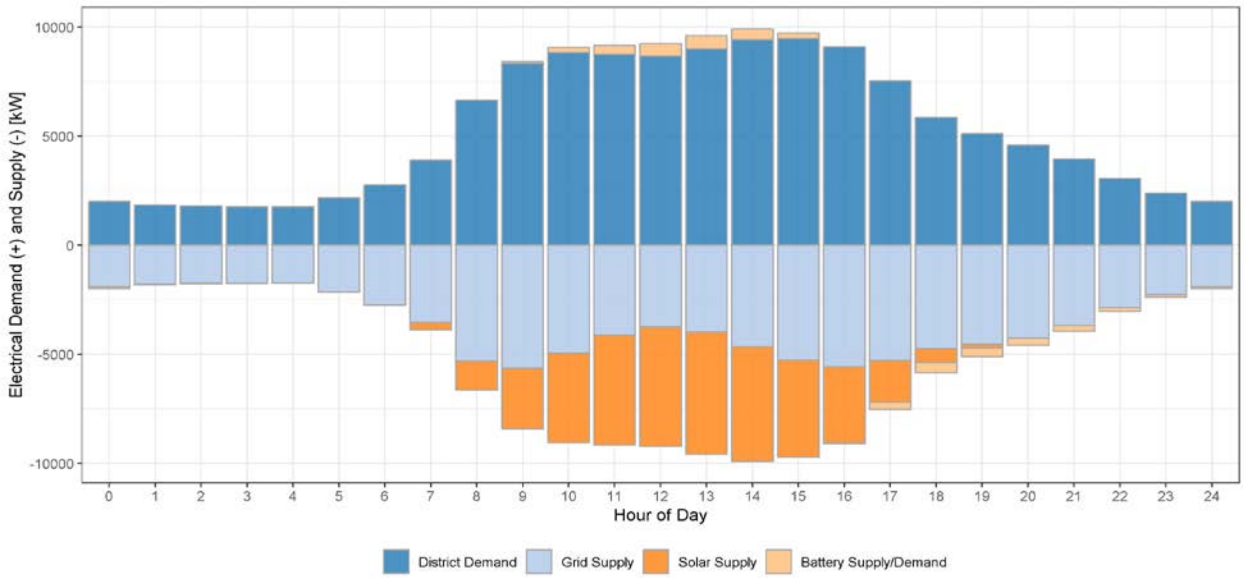

Figure 8 : DEPICT results: District A Hourly Average Electrical Consumption - PV covering 25% of rooftop areas

More options for PV panels, areas and batteries capacity can be explored using DEPICT.

Total Emissions

Unmitigated emissions

District A has unmitigated CO_2 emissions of **116,210 MT CO_2 / year** after full buildout, which corresponds to **4.1 MT CO_2 / capita**. Figure 9 is showing the breakdown of emissions by sector. Construction emissions only play a small role in the district emissions and are absent after 2031. In 2031, it is estimated that 88% of emissions will be due to vehicles.

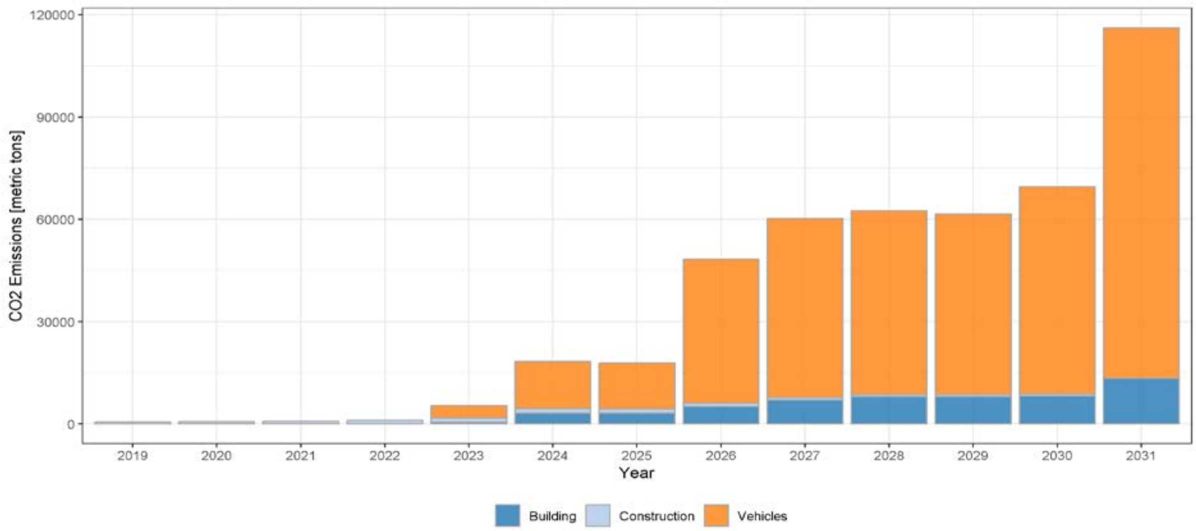

Figure 9 : DEPICT results: District A Unmitigated Emissions

Mitigation packages

The various measures packages contemplated for District A are summarized in Table 12. This table uses a conservative 5% EV penetration. For reference the California 2030 ZEV mandate is 5 million vehicles and there are currently ~25 million automobiles registered. In an optimum scenario, at this rate, since 2030 is about 10 years away, roughly 2/3 of the passenger fleet will turnover.

Table 12 : District A Mitigation Measures

Measure	*CO_2 Reduction* [MT **CO_2**]	[MT/capita]
VMT Reduction by 15%	15,418	0.54
Geothermal plant for Office Space Heating and High-Rise Apartments Service Hot Water	3,754	0.13
PEV penetration increase to 5%	2,652	0.09
Smart Traffic Signal (3% reduction of gas vehicle emissions)	2,542	0.09
PV on 25% of roof area	1,782	0.06
Electrification of gas appliances in residential	399	0.01
Reducing office electrical equipment use by 10%	272	0.01

Overall, the implementation of all the proposed measures would reduce the district CO_2 emissions by 26,819 MT. This would bring the annual emissions in year 2031 to **89,391 MT CO_2** or **3.2 MT CO_2 / capita**.

Results – District B Development

District presentation

District B is a primarily residential district in development in the San Francisco Bay Area. An overview of the full district buildout is shown in Table 13 and the construction schedule is illustrated in Figure 10. The service population estimated from the district schedule is 17,504 residents and 2,321 workers for a total of **19,825 people**.

Table 13 : District B Buildout Description

Building Type	*Total Area [ft^2] **(units)***	*Residents/Employees*
Community Use	50,000	50
Entertainment Venue (FAC)	46,000	115
High Rise Apartment	6,352,000 **(5931 units)**	14,828
Hotel	150,000	103
Inclusionary Housing	605,000 **(567 units)**	1,038
Local Retail	131,000	328
Regional Retail	690,000	1,725
Single Family Housing	513,000 **(480 units)**	1,200
Workforce Housing	256,000 **(240 units)**	439

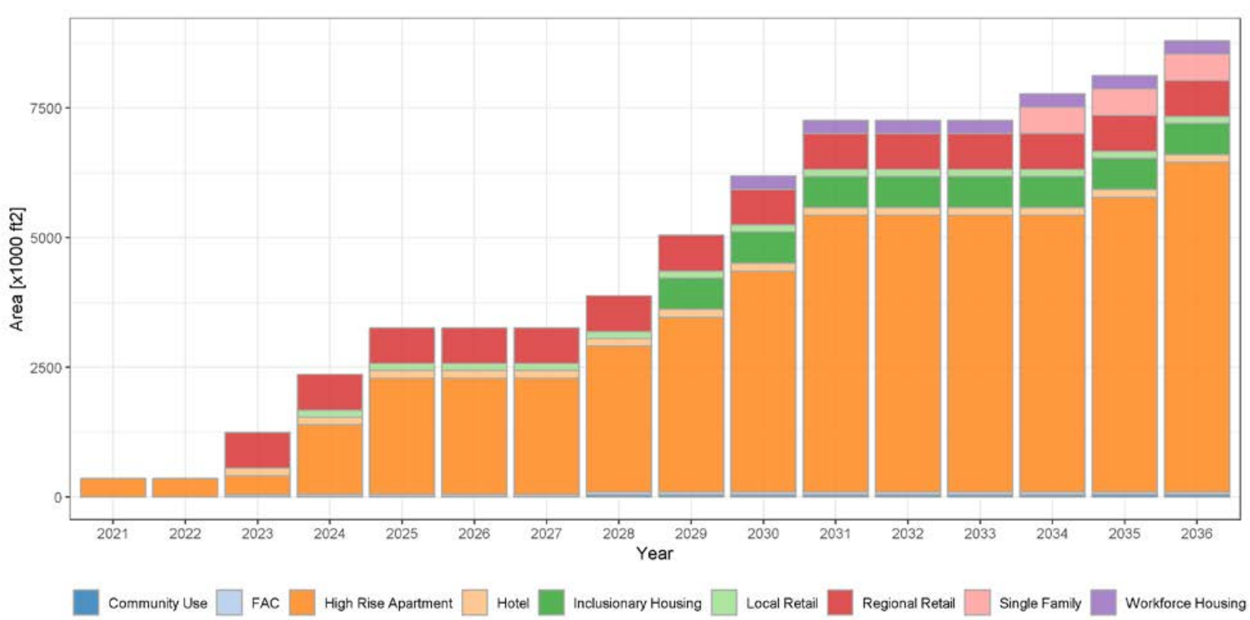

Figure 10 : District B Construction Schedule

Building Construction

The building construction model was developed using the later year of end of construction. Most of the building construction emissions are due to on-road vehicles that are used for commute by construction workers or to carry materials in and out of the construction site. Figure 11 shows the total CO_2 emitted throughout the district construction, separated by phase of construction.

Mitigation measures to reduce the emissions from construction such as alternative transportation solutions or new construction methods may reduce the vehicle miles traveled (VMT) to site, although the impact of these mitigation measures is beyond the scope of this Phase 1 study.

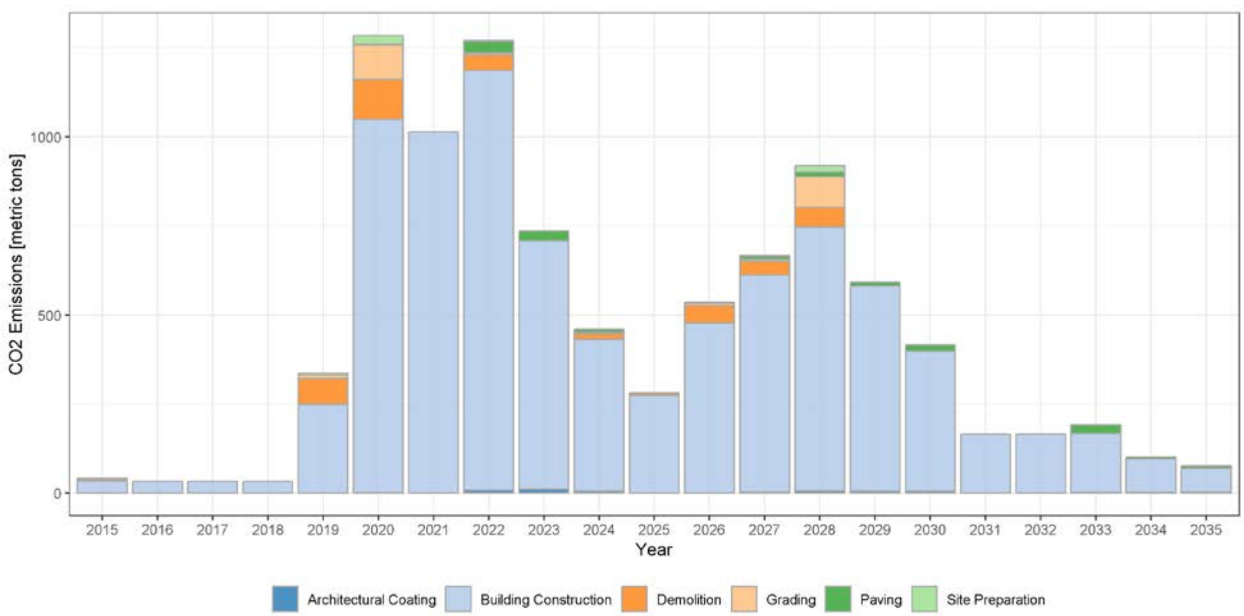

Figure 11 : DEPICT results: District B Construction Emissions

Overall, building construction accounts for **0.47 MT CO_2/capita** over the 2015-2035 period.

Building Operations

Baseline Analysis

The detail of the reference model used for each building type in the schedule, along with the normalized electricity and gas energy use intensity (EUI) and the annual normalized CO_2 emission rate is presented in Table 14.

Table 14 : District B Building Model Description

Building Type	*EnergyPlus Reference Model*	*Elec. EUI kBTU/ft^2/yr*	*Gas EUI kBTU/ft^2/yr*	*CO_2 Em. lb./ft^2/yr*
High Rise Apartment	Multi Family Small	8.78	16.75	2.72
Hotel	Small Hotel	13.04	5.56	1.70
Regional Retail	Large Retail	19.17	8.76	2.57
Community Use	Mixed Use Space	33.27	6.15	3.37
Entertainment Venue (FAC)	Strip Mall	36.02	8.34	3.85
Local Retail	Local Retail	20.28	13.44	3.23
Inclusionary Housing	Multi Family Small	8.81	16.8	2.73
Workforce Housing	Multi Family Small	8.81	16.80	2.73
Single Family	Single Family Large	13.98	35.28	5.38

Figure 12 shows the annual CO_2 emissions from building operations, assuming that buildings are fully operational on the year directly following end of construction.

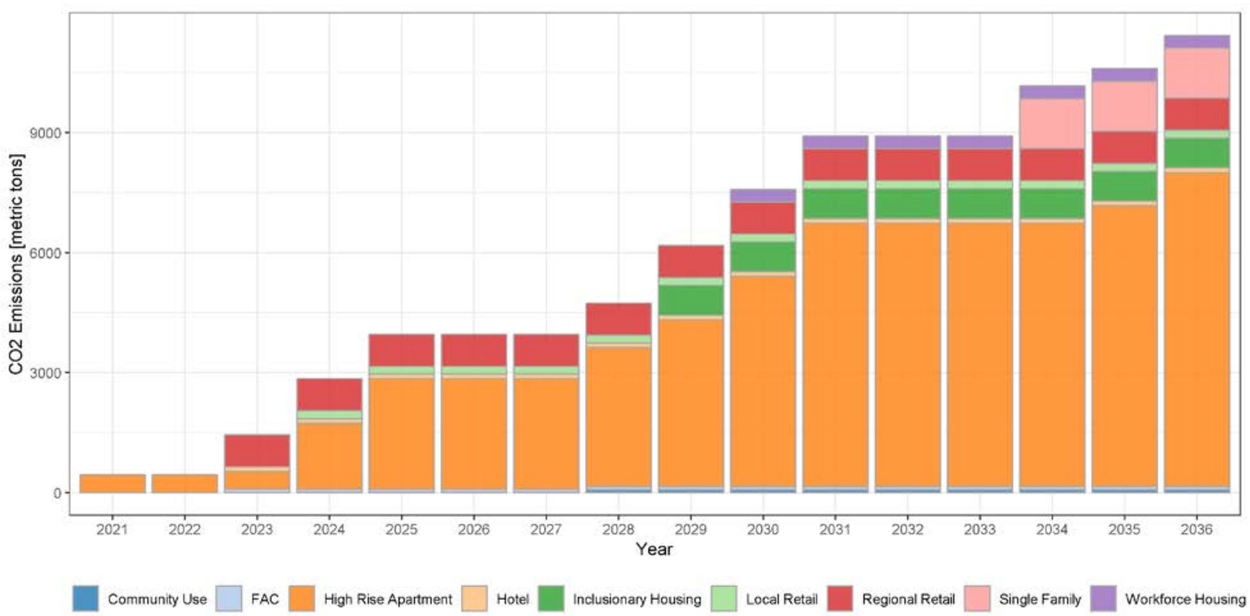

Figure 12 : DEPICT results: District B Building Operation CO_2 Emissions

High-Rise Apartments, which accounts for 72.2% of the total district area represents 68.6% of the total CO_2 emissions for building operation.

In terms of end-uses, Table 15 shows the breakdown of CO_2 emissions by end uses and energy source. The main end-use is gas water heating (**41.4%**), followed by electrical equipment (**22.3%**), gas heating (**19.9%**) and gas equipment, from residential appliances (**10.0%**).

Table 15 : District B Building CO_2 End Uses Ratio

End Use	*Energy Source*	*Ratio of CO_2 Emissions*
Water Systems	Gas	41.4%
Interior Equipment	Electricity	22.3%
Heating	Gas	19.9%
Interior Equipment	Gas	10.0%
Interior Lighting	Electricity	4.3%
Fans	Electricity	1.3%
Water Systems	Electricity	0.5%
Cooling	Electricity	0.2%
Exterior Lighting	Electricity	0.1%
Pumps	Electricity	0.0%
Heating	Electricity	0.0%

The baseline total CO_2 emissions from building after complete buildout is **11,428 MT CO_2 annually**. When normalized by the service population (19,825 people), the value is **0.576 MT CO_2 / capita**.

GHG Reduction Measures

The following measures are suggestions to reduce CO_2 emissions coming from building operations. These measures have been selected as providing the most significant emissions reduction benefit, from a variety of potential measures analyzed through in the DEPICT model.

- Connect residential building space heating and domestic hot water demand to a district energy system, using either geothermal or low emission sources. This measure is investigated in the following section.

- Equip residential units with efficient appliances to reduce electrical consumption. A reduction of the interior equipment consumption in residential units by 10% would reduce CO_2 emissions by **333.8 MT CO_2** or **0.017 MT CO_2 /capita** annually**.**

- Gas equipment in residential, such as cookstoves (subject to consumer acceptance), should be replaced by electrical equipment, to make use of electricity lower emission factor. Assuming an equivalent end-use efficiency, this could reduce up to **400.8 MT CO_2** or **0.020 MT CO_2 /capita** of CO_2 emissions annually.

On the other hand, mitigation measures aimed at reducing cooling or interior lights would not have a strong impact, considering that those loads represent a lower fraction of the CO_2 emissions and the lighting requirements in Title 24 2019 buildings do not leave a lot of margin for improvement. Improving the envelope of building further would not be useful since the envelopes are already efficient for Title 24 2019 buildings and most of the heating load comes from ventilating outside air in buildings.

District Energy Systems

The district energy model was built using the heating, cooling and hot water hourly demand from EnergyPlus models in that district. Figure 13 provides a breakdown of the CO_2 emissions from space heating, cooling and hot water demand by building types. Unsurprisingly, the main source of CO_2 emissions come from the high-rise apartment space heating and hot water end uses, since this building type has the highest built area in the district.

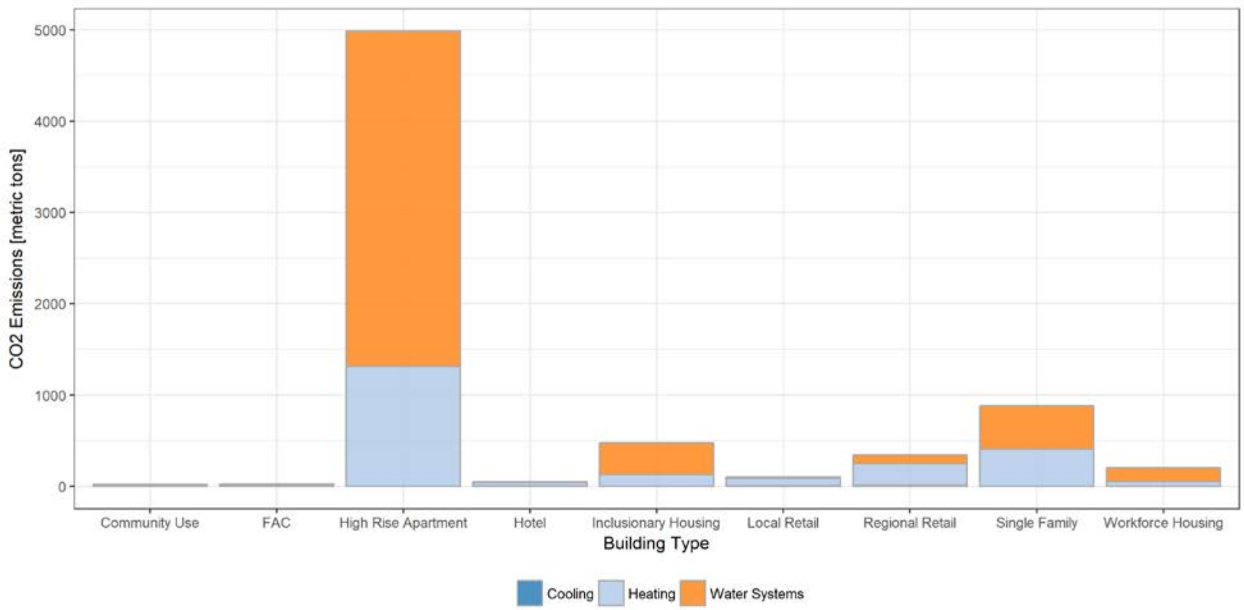

Figure 13 : DEPICT results: District B Heating, Cooling, and Hot Water CO_2 Emissions

The main benefit of district energy systems studied in this document is improving the efficiency of space heating and hot water production. One potential mitigation measure is to connect some or all the demand to a centralized geothermal heat plant with an average coefficient of performance (COP) of 4. Note that a cogeneration system could have system efficiency improvement producing both power and heating but not necessarily CO2 emissions reductions unless the cogeneration system was using a renewable fuel such as biomass.

Table 16 shows the impact on CO_2 mitigation of connecting some of the space heating and hot water demand to a centralized geothermal plant with an average COP of 4. It should be noted that the same CO_2 reduction could be achieve with a decentralized system that has the same annual average COP, but decentralized systems generally have lower annual average efficiency due to being run at partial load.

The table is sorted from the highest CO_2 emission reduction potential to the lowest.

Table 16 : District B Geothermal Plant CO_2 Reduction Potential

Building Type	*Demand Type*	*Annual Energy [MBTU/yr]*	*Unmitigated CO_2 Emissions [MT CO_2 /yr]*	*CO_2 Reduction [MT CO_2]*
High Rise Apartment	Water Systems	53298	3671	2718
High Rise Apartment	Space Heating	18968	1313	974
Single Family	Water Systems	7114	477	350
Single Family	Space Heating	5883	406	301
Inclusionary Housing	Water Systems	5094	351	260
Regional Retail	Space Heating	2399	235	192
Workforce Housing	Water Systems	2156	149	110
Inclusionary Housing	Space Heating	1812	126	94
Regional Retail	Water Systems	1413	97	72
Local Retail	Space Heating	928	77	60
Workforce Housing	Space Heating	768	53	39
Hotel	Space Heating	464	39	31
Local Retail	Water Systems	263	20	15
Entertainment Venue	Space Heating	130	13	11
Community Use	Water Systems	116	10	8
Community Use	Space Heating	65	7	6
FAC	Water Systems	102	8	6
Hotel	Water Systems	75	6	5

Connecting the high-rise apartment domestic hot water or space heating load to a geothermal plant would reduce annual CO_2 emissions by **2,718** and **974 MT CO_2** respectively, or **0.14** and **0.049 MT CO_2 / capita** when normalizing by the entire district service population. More notably, if all the residential building types (high rise apartment, single family, inclusionary and workforce housing) were connected to a district energy system for their hot water and space heating demand, the building operation CO_2 emissions would be reduced by **4,846 MT CO_2**, which is 42% of the total building operation emission.

Those results are assuming that the entirety of each building type is connected to a centralized plant, but the CO_2 emission reduction is proportional to the building area, therefore if only 30% of a building type is connected, the impact would be 30% of what is shown in the table, provided that the same plant efficiency can be achieved. Other production system and efficiency can be investigated using DEPICT.

Vehicles

Baseline Analysis

Gas vehicle emissions were computed using the default parameters value for the CalEEMod VMT calculation algorithm. When fully operational, the estimated average daily VMT is **700,662 miles**, or **35.34 miles/capita/day**. Table 17 shows the CalEEMod land use subtype used to represent each building type in the district along with the annual VMT by area created by each building type.

Table 17 : District B VMT Model

Building Type	*CalEEMod Model*	*VMT per area [miles/ft2/yr]*
Local Retail	Convenience Market (24 hour)	6237
Entertainment Venue	Movie Theater (No Matinee)	1890
Regional Retail	Supermarket	1500
Community Use	General Office Building	216
Single Family	Single Family Housing	131
Hotel	Hotel	111
High Rise Apartment	Apartments High Rise	106
Inclusionary Housing	Retirement Community	57
Workforce Housing	Retirement Community	57

The emissions factor and fleet mix were taken for each year from the San Francisco forecast in EMFAC 2017. For electric vehicle, the baseline is assuming a 2% penetration for PEV and an even mix between PHEV and BEV. Figure 14 shows the CO_2 emissions from the first year of operation until full buildout, separated by travel type.

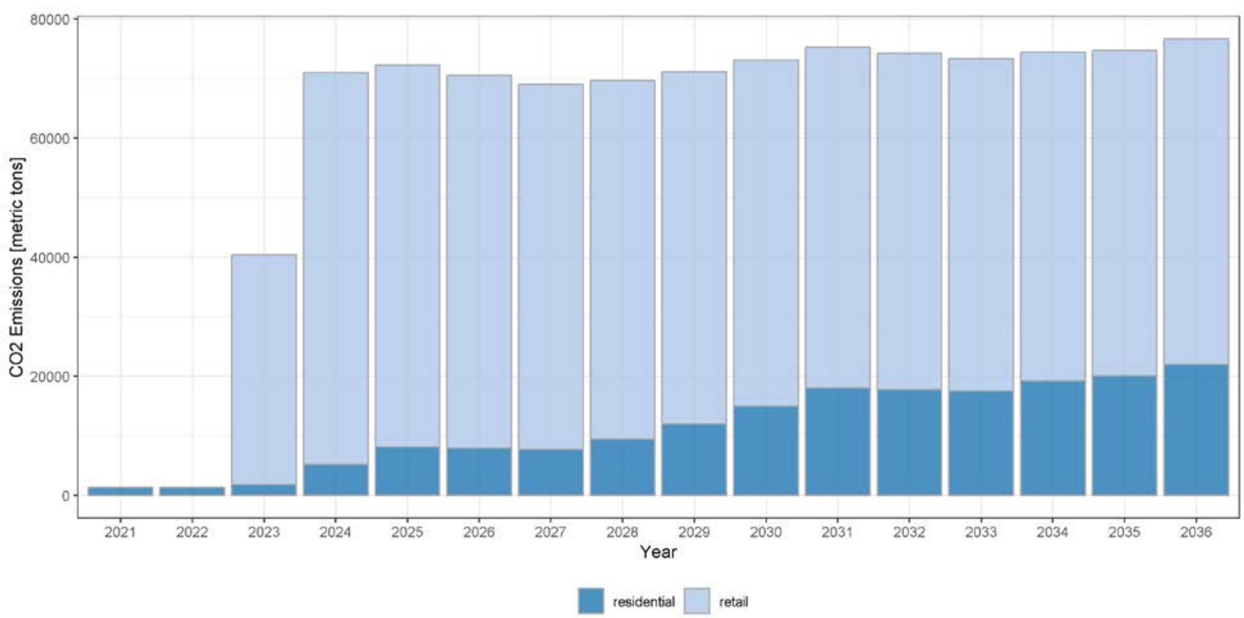

Figure 14 : DEPICT results: District B Vehicle Emissions

For the year 2036, the expected annual emissions from vehicles are **76,682 MT CO_2**. This is equivalent to **3.9 MT CO_2 /capita**, assuming default VMT calculation for the district and 2% of PEV in the vehicle fleet. These unmitigated results are driven by a higher ratio of retail travel (**71%**), combined with a lower service population associated with retail spaces. PEV in the district requires an estimated annual charge of **292.50 MWh**, which accounts for **35.7 MT CO_2** of the CO_2 emissions, or about 0.05% of the vehicle emissions.

GHG Reduction Measures

Reducing vehicle emissions can be achieved through three different types of measures:

- Reducing VMT by proposing alternative mode of travel or reducing the distance between residential, work and retail areas.
- Increasing the penetration of electric vehicle.
- Improve traffic flow with an efficient roadways design and using smart traffic signal.

Another source of mitigation comes from improving the efficiency of gas vehicle, but this effect is already modeled in the vehicle emission factor schedule.

Since District B is a highly residential district, reducing VMT might be more difficult than in mixed-use district. We will assume that the baseline VMT can be reduced by 10% from the proximity of local and regional retail and fast connection to BART and CalTrain.

The reduction of VMT by 10% would bring daily VMT to **630,596 miles** and reduce mobile CO_2 emissions by **7,667 MT CO_2**, or **0.38 MT CO_2 / capita.**

Additionally, promoting the use of electric vehicle by installing fast-charging station and dedicated parking spots might drive the penetration of PEV for that district from 2% to 5%. Each increment of 1% of PEV penetration would further reduce emissions by 688 MT, and a total penetration of 5% would create an emission reduction from vehicle by **2,064 MT CO_2**, or **0.10 MT CO_2 / capita**.

Improving traffic flow with smart traffic signal is assumed to further reduce CO_2 emissions by 3%, which corresponds to another **2,009 MT CO_2**, or **0.10 MT CO_2 / capita** annually.

Solar and Battery

Photovoltaic panels and batteries can help reduce electricity import and cost, but have a minor impact on greenhouse gases emissions, since electricity have a low emission factor.

The solar model was run with the baseline building and vehicle electricity hourly consumption. The measures that impacts electricity use or PEV penetration would have an impact on the total amount and shape of the electricity demand but would not have an impact on the amount of electricity shed by the photovoltaic panels. After complete buildout, the building operation has an annual electricity demand of 26.87 GWh and electric vehicle have an annual charge of 0.29 GWh.

If the district uses monocrystalline 370W modules with no solar tracking, which corresponds to mid-range performance panels, covering the district electricity demand would require **56,588 solar units**, covering **993,283 ft^2**. This would reduce annual CO_2 emissions by **3,259 MT CO_2**, or **0.16 MT CO_2 / capita**. Using the number of stories of the reference model, we estimate the total roof area for the district to be 2,177,867 ft^2. If installed on building's roof, the PV modules would cover 45% of the area. If we look at the impact of installing PV on 25% of roof area, the annual production would reach **14.89 GWh**, and reduces CO_2 emissions by **1,787 MT CO_2** annually, or **0.090 MT CO_2 / capita**.

Table 18 shows the area of PV modules and roof coverage for each building type's electricity demand.

Table 18 : District B Electricity Consumption, PV Coverage

Building Type	*Electricity Demand [GWh]*	*CO_2 Emissions [MT CO_2]*	*Roof Area [ft^2]*	*PV Area [ft^2]*	*Roof Coverage [%]*
High Rise Apartment	16.58	1,990	635,194	607,175	96%
Regional Retail	3.88	465	689,997	142,004	21%
Single Family	2.12	254	512,511	77,574	15%
Inclusionary Housing	1.59	190	60,540	58,046	96%
Local Retail	0.78	93	130,999	28,518	22%
Workforce Housing	0.67	81	25,626	24,570	96%
Hotel	0.57	69	50,000	20,981	42%
Community Use	0.49	59	50,000	17,851	36%
Entertainment Venue	0.49	58	23,000	17,778	77%

DEPICT allows the user to determine the minimum amount of batteries required to minimize the amount of electricity purchased from the grid. In the scenario where 25% of the roof area is covered with monocrystalline panels, **24,702 kWh** of batteries would need to be installed. Figure 17 shows what the average hourly electrical consumption would look like for the entire district. More options for PV panels, areas and batteries capacity can be explored using DEPICT.

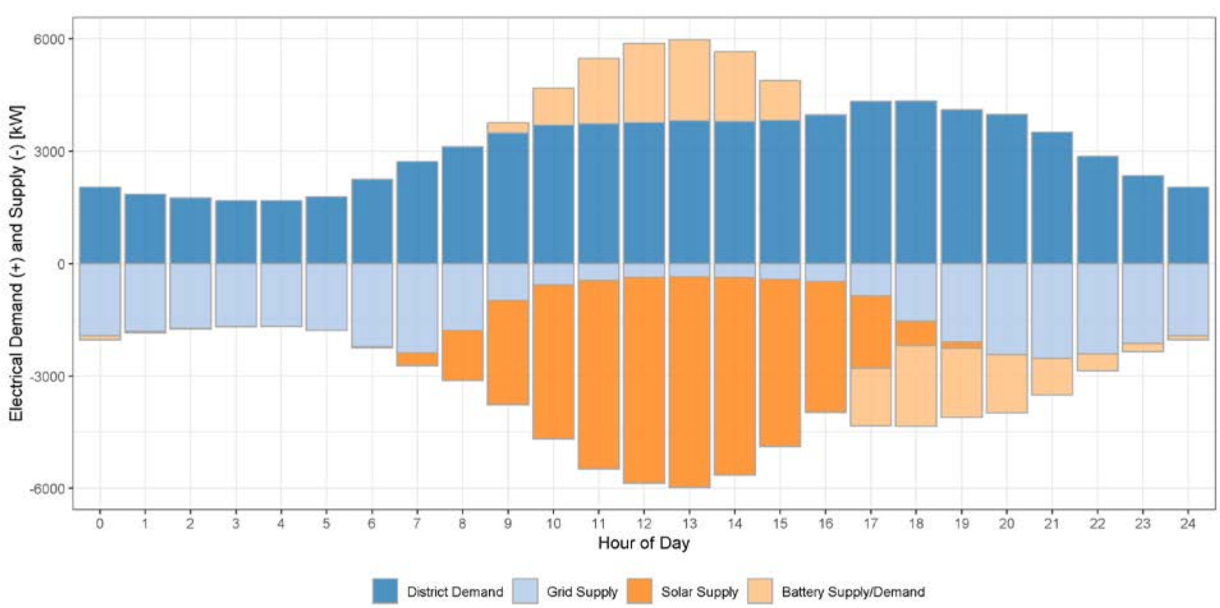

Figure 15 : DEPICT results: District B Hourly Average Electrical Consumption - PV covering 25% of rooftop areas

Total Emissions

Unmitigated emissions

District B has unmitigated CO_2 emissions of **88,112 MT CO_2 / year** after full buildout, which corresponds to **4.4 MT CO_2 / capita**. Figure 16 is showing the breakdown of emissions by sector. Construction emissions only play a small role in the district emissions and are absent after 2036. In 2036, it is estimated that 87% of emissions are due to vehicles.

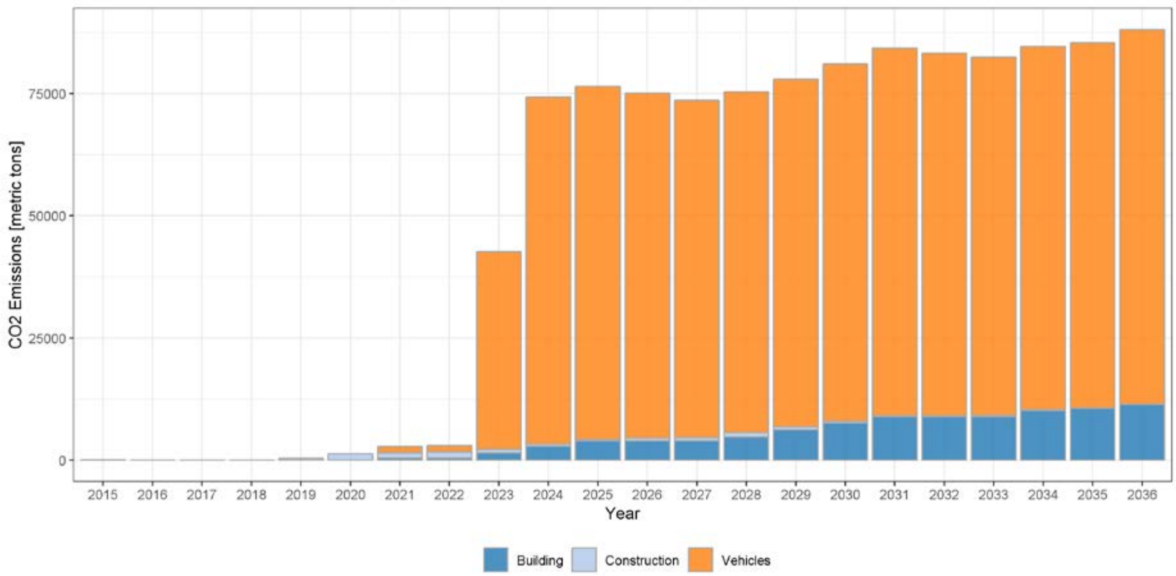

Figure 16 : DEPICT results: District B Unmitigated Emissions

Mitigation packages proposed

The different measures that may reduce emissions for District B are summarized in Table 19.

Table 19 : District B Mitigation Measures

Measure	*CO_2 Reduction* [MT CO_2]	[MT CO_2 /capita]
VMT Reduction by 10%	7,667	0.39
Geothermal plant for residential space heating and hot water	4,846	0.24
PEV penetration increase to 5%	2,064	0.10
Smart Traffic Signal (3% reduction of gas vehicle emissions)	2,009	0.10
PV on 25% of roof area	1,787	0.09
Electrification of gas appliances in residential	401	0.02
Reducing residential electrical equipment use by 10%	334	0.02

Overall, the implementation of all the measures above would reduce the district CO_2 emissions by 19,108 MT. This would bring the annual emissions on year 2036 to **69,004 MT CO_2** or **3.4 MT CO_2 / capita**.

Results – District C Development Project

District presentation

District C is a mixed-use district composed of residential, office and education buildings. An overview of the full district buildout is shown in Table 20, and the construction schedule is illustrated in Figure 17. The service population estimated from the district schedule is 32,500 residents and 21,574 workers for a total of **54,074 people**. A different estimate calculated by a transportation consultant determined the service population to be composed by 34,061 resident and 29,120 workers for a total of **63,181 people**. This estimate will be used for normalizing CO_2 emissions for the district.

Table 20 : District Buildout Description

Building Type	*Total Area [ft²]* ***(units)***	*Residents/Employees*
Campus	2,914,000	1220
Community Use	1,048,000	1048
Condos and Townhomes	7,001,000 (4395 units)	10,988
Hotel	268,000	184
Local Retail	495,000	1,237
Office Building	4,289,000	17,855
Pads and Apartments	4,572,000 (5080 units)	12,700
Single Family Large	2,505,000 (1044 units)	2,610
Single Family Medium	5,210,000 (2481 units)	6,203

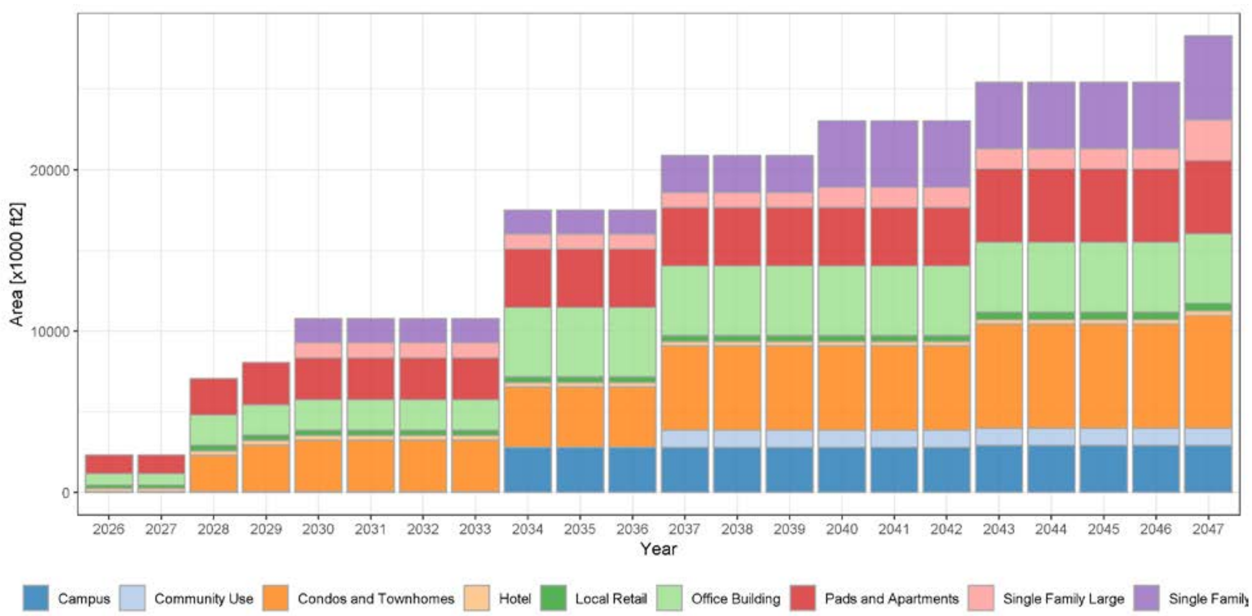

Figure 17 : District C Construction Schedule

Building Construction

The building construction modeled was developed using the later year of end of construction. Most of the building construction emission comes from on-road vehicles that are used for commute by construction worker or to carry materials in and out of the construction site. Figure 18 shows the total CO_2 emitted throughout the district construction separated by phase of construction.

Mitigation measures to reduce the emissions from construction such as alternative transportation solutions or new construction methods may reduce the vehicle miles traveled (VMT) to site, although the impact of these mitigation measures is beyond the scope of this Phase 1 study.

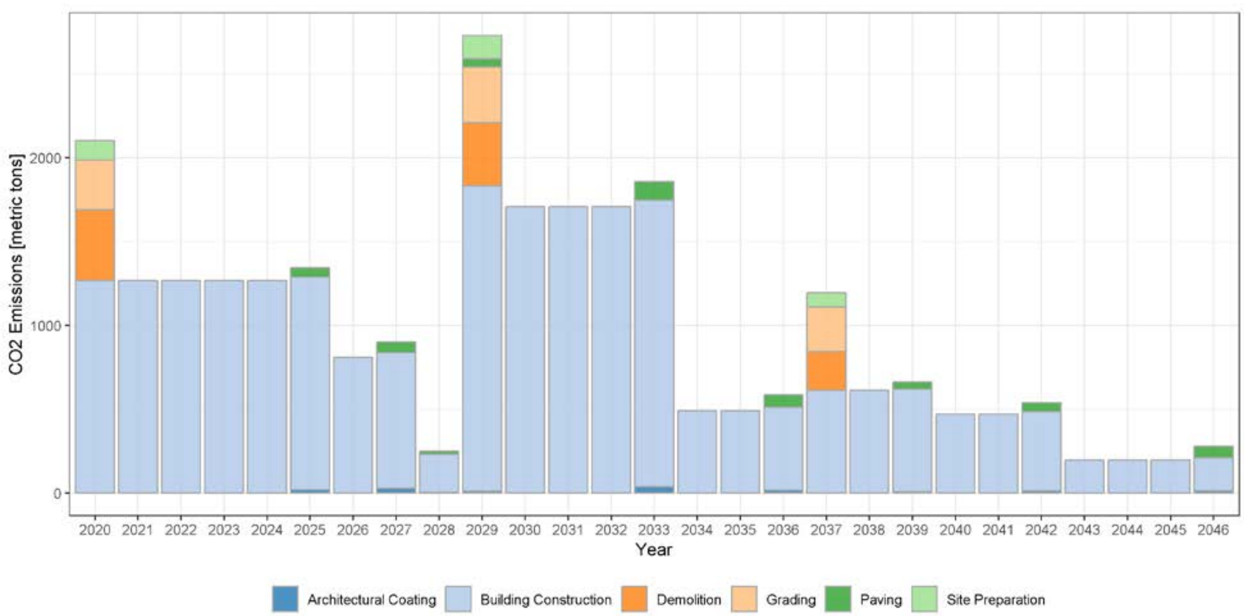

Figure 18 : DEPICT results: District C Project Construction Emissions

Overall, building construction accounts for **0.42 MT CO_2/capita** distributed over the 2020-2046 period.

Building Operations

Baseline Analysis

The detail of the reference model used for each building type in the schedule, along with the normalized electricity and gas energy use intensity (EUI) and the annual normalized CO_2 emission rate is presented in Table 21.

Table 21 : District Project Building Model Description

Building Type	*EnergyPlus Reference Model*	*Elec. EUI [kBTU/ ft²]*	*Gas EUI [kBTU/ ft²]*	*CO_2 Em. [lb./ ft²]*
Office Building	Large Office	23.53	6.99	2.70
Hotel	Small Hotel	14.37	6.25	1.89
Local Retail	Local Retail	23.11	12.91	3.38
Pads and Apartments	Multi Family Small	10.71	21.47	3.45
Campus	Large School	15.52	16.28	3.19
Condos and Townhomes	Multi Family Medium	7.29	10.01	1.79
Single Family Medium	Single Family Medium	6.49	18.84	2.79
Single Family Large	Single Family Large	6.56	18.18	2.72
Community Use	Mixed Use Space	35.76	7.39	3.71

Figure 19 shows the annual CO_2 emissions from building operation, assuming that buildings are fully operational on the year directly following end of construction.

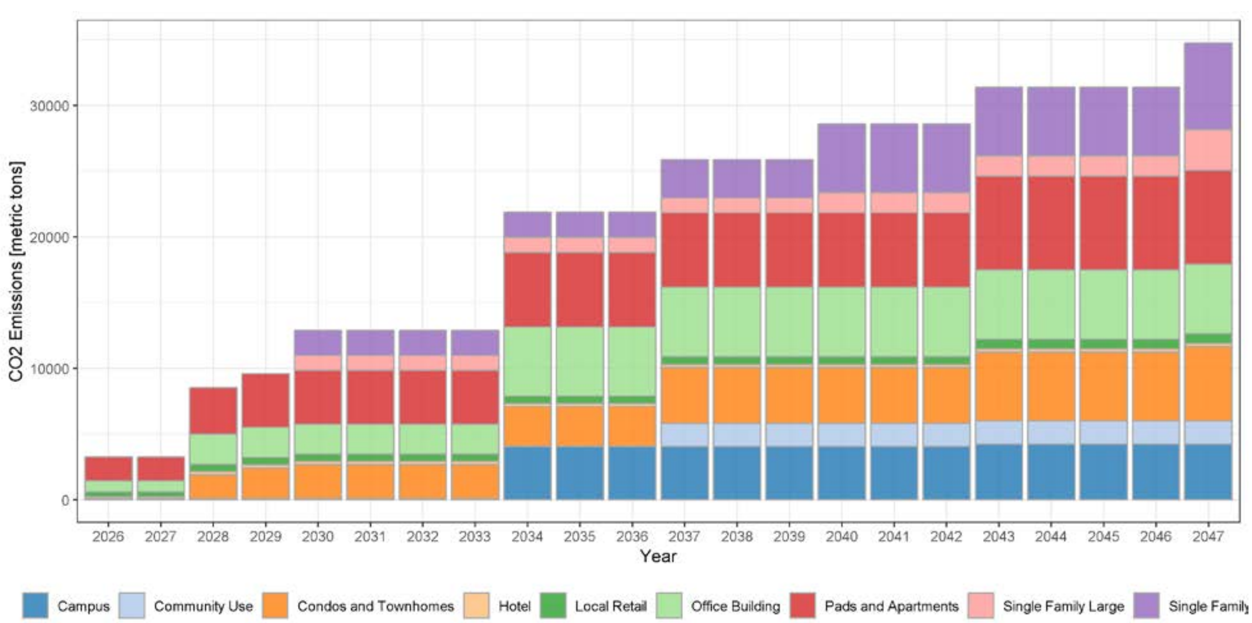

Figure 19 : DEPICT results: District C Project Building Operation CO_2 Emissions

The building operation CO_2 emissions are evenly distributed between the different building types. The four types of residential buildings combined, which represent 68.2% of the built area, accounts for 64.8% of the total CO_2 emissions. The campus and office buildings, 10.3% and 15.2% of the area, represent 13.2% and 15.1% of the CO_2 emissions respectively.

In terms of end-uses, Table 22 shows the breakdown of CO_2 emissions by end uses and energy source. The main end-use is gas heating (**29.6%**), followed by gas water heating (**27.5%**) and electrical equipment (**23.6%**).

Table 22 : District Project Building CO_2 End Uses Ratio

End Use	*Energy Source*	*Ratio of CO_2 Emissions*
Heating	Gas	29.6%
Water Systems	Gas	27.5%
Interior Equipment	Electricity	23.6%
Interior Equipment	Gas	7.0%
Interior Lighting	Electricity	5.9%
Fans	Electricity	3.3%
Cooling	Electricity	2.1%
Pumps	Electricity	0.6%
Water Systems	Electricity	0.2%
Exterior Lighting	Electricity	0.2%

The baseline total CO_2 emissions from building after complete buildout are **34,754 MT CO_2 annually**. When normalized by the service population (63,181 people), the value is **0.550 MT CO_2 / capita**.

GHG Reduction Measures

The following measures are suggestions to reduce CO_2 emissions coming from building operations. These measures have been selected as providing the most significant emissions reduction benefit, from a variety of potential measures analyzed through in the DEPICT model.

- Connect residential, office and education building space heating and hot water demand to a district energy system, using either geothermal or low emission sources. This measure is investigated in a following section. Alternatively, decentralized solution can be used to achieve the same results, if the production equipment efficiency is increased and/or electricity is used as the energy source.

- Equip residential units with efficient appliances and promote energy management solutions in office and school buildings to reduce electrical consumption. A reduction of the interior equipment consumption by 10% across the district would reduce CO_2 emissions by **1062.5 MT CO_2** or **0.017 MT CO_2 /capita** annually**.**

- Replace gas equipment in residential units, such as cookstoves, with electrical equipment, to make use of electricity's lower emission factor. Assuming an equivalent end-use efficiency, this could reduce up to **852.7 MT CO_2** or **0.014 MT CO_2 /capita** of CO_2 emissions annually.

On the other hand, mitigation measures aimed at reducing cooling or interior lights would not have a strong impact, considering that those loads represent a lower fraction of the CO_2 emissions and the lights requirements in Title 24 2019 buildings doesn't leave a lot of margin for improvements. Improving the envelope of building would also be inefficient since the envelope are already efficient for Title 24 2019 buildings and most of the heating load comes from ventilating outside air in buildings.

District Energy Systems

The district energy model was built over the heating, cooling and hot water hourly demand from EnergyPlus models in that district. Figure 20 provides a breakdown of the CO_2 emissions from space heating, cooling and hot water demand by building types. The main source of CO_2 is from space heating and hot water demand in the various residential buildings.

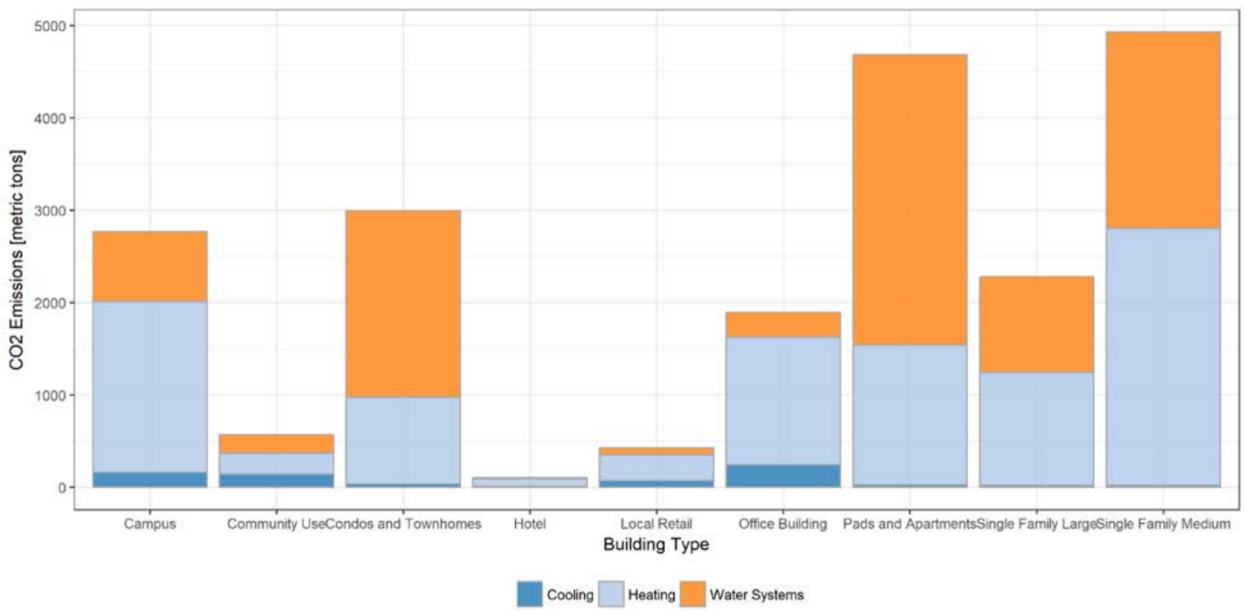

Figure 20 : DEPICT results: District C Heating, Cooling, and Hot Water CO_2 Emissions

The main benefit of district energy systems studied in this document is improving the efficiency of space heating and hot water production. The proposed mitigation measured is to connect some or all the demand to a centralized geothermal heat plant with an average Coefficient of Performances (COP) of 4.

Table 23 shows the impact on CO_2 mitigation of connecting some of the space heating and hot water demand to a centralized geothermal plant with an average COP of 4. It should be noted that the same CO_2 reduction could be achieve with a decentralized system that has the same annual average COP, but decentralized systems have generally lower annual average efficiency from being run at partial load.

The table is sorted from the highest CO_2 emission reduction potential to the lowest.

Table 23 : District C Geothermal Plant CO_2 Reduction Potential

Building Type	Demand Type	Annual Energy [MBTU]	Unmitigated CO_2 Emissions [MT CO_2]	CO_2 Reduction [MT CO_2]
Pads and Apartments	Water Systems	44726	3145	2346
Single Family Medium	Space Heating	40103	2781	2064
Single Family Medium	Water Systems	30259	2128	1587
Campus	Space Heating	21957	1848	1456
Pads and Apartments	Space Heating	21595	1511	1125
Office Building	Space Heating	17006	1384	1080
Condos and Townhomes	Water Systems	56256	2020	1015
Single Family Large	Space Heating	17668	1226	910
Single Family Large	Water Systems	14778	1038	774
Condos and Townhomes	Space Heating	12775	939	711
Campus	Water Systems	11185	759	559
Local Retail	Space Heating	3487	277	215
Office Building	Water Systems	3845	265	196
Community Use	Space Heating	2160	226	187
Community Use	Water Systems	2433	200	157
Hotel	Space Heating	1000	80	62
Local Retail	Water Systems	996	74	56
Hotel	Water Systems	136	11	9

Connecting the pads and apartments domestic hot water load to a geothermal plant would reduce annual CO_2 emissions by **2,346 MT CO_2**, or **0.037 MT CO_2 / capita** when normalizing by the entire district service population. Connecting the single-family medium space heating demand would reduce CO_2 emissions by **2,064 MT CO_2** or **0.033 MT CO_2 / capita** annually. If all the residential building types (pads and apartments, single family medium and large, condos and townhomes) were connected to a district energy system for their hot water and space heating demand, the building operation CO_2 emissions would be reduced by **10,532 MT CO_2**, which is 30% of the total building operation emission.

Those results are assuming that the entirety of each building type is connected to a centralized plant, but the CO_2 emission reduction is proportional to the building area, therefore if only 30% of a building type is connected, the impact would be 30% of what is shown in the table, provided that the same plant efficiency can be achieved. Other production system and efficiency can be investigated using DEPICT.

Vehicles

Baseline Analysis

Gas vehicle emissions was computed using the default parameters value for the CalEEMod VMT calculation algorithm to get an appropriate ratio between the different travel type, but the total VMT was refined by using a transportation analysis provided by a transportation consultant. When fully operational, the average unmitigated daily VMT for gas vehicle estimated by the transportation consultant is **1,718,108 miles**, or **27.19 miles/capita/day**. Table 24 shows the CalEEMod land use subtype used to represent each building type in the district along with the annual VMT by area created by each building type.

Table 24 : District Project VMT Model

Building Type	*CalEEMod Model*	*VMT per area [miles/ft2/yr]*
Local Retail	Convenience Market (24 hour)	5411
Community Use	General Office Building	188
Office Building	General Office Building	188
Campus	University/College (4yr)	181
Condos and Townhomes	Apartments Low Rise	143
Pads and Apartments	Apartments Mid Rise	141
Single Family Large	Single Family Housing	114
Single Family Medium	Single Family Housing	114
Hotel	Hotel	96

The emissions factor and fleet mix were taken for each year from the District C forecast in EMFAC 2017. For electric vehicle, the baseline is assuming a 2% penetration for PEV and an even mix between PHEV and BEV. Figure 21 shows the CO_2 emissions from the first year of operation until full buildout, separated by travel type.

For the year 2047, the expected annual emissions from vehicles are **162,637 MT CO_2**. This is equivalent to **2.57 MT CO_2 /capita**, assuming default VMT calculation for the district and 2% of PEV in the vehicle fleet. PEV in the district requires an estimated annual charge of **565.60 MWh**, which accounts for **56.7 MT CO_2** of the emissions, or about 0.03% of the vehicle emissions.

GHG Reduction Measures

Reducing vehicle emissions can be achieved through three different types of measures:

- Reducing VMT by proposing alternative mode of travel or reducing the distance between residential, work and retail areas.
- Increasing the penetration of electric vehicle.
- Improve traffic flow with an efficient roadways design and using smart traffic signal.

Another source of mitigation comes from improving the efficiency of gas vehicle, but this effect is already modeled in the vehicle emission factor schedule. The original mitigation measured proposed for reducing vehicle emissions in District C was analyzed by a transportation consultant. In their report, they investigate the different aspect of District C district that would cause a reduction of vehicle emissions:

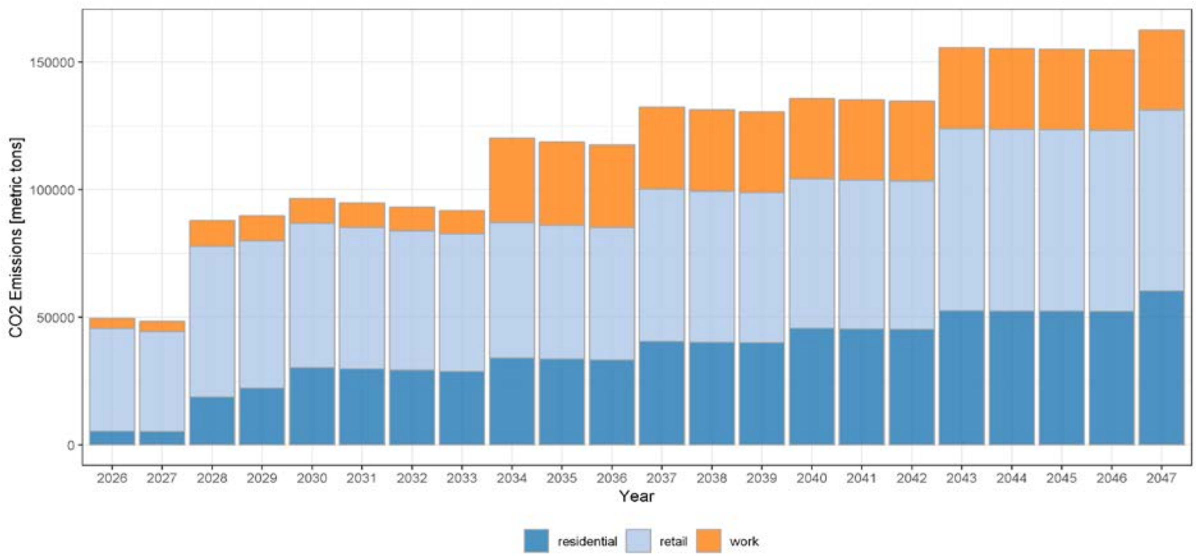

Figure 21 : DEPICT results: District Project Vehicle Emissions

- 25 percent affordable housing
- Mixture of land uses, including a variety of employment opportunities and residential types
- Mixture of community facilities, including schools and community center
- Connections to adjacent developed neighborhoods (all travel modes, or non-motorized only)
- Transit connection to BART with 15-minute headways during peak periods
- Transit only lane connection BART through site
- Grid network of interconnected streets
- Robust bicycle network with supporting bicycle infrastructure – bike parking, showers at large employers
- Small block size to promote walkability, with wide sidewalks in retail areas and frequent protected pedestrian crossings
- Reduced parking requirements adjacent to BART

The transportation consultant estimates that those factors would help reduce the district daily VMT by 14.3%, that would reduce CO_2 emissions from gas and electric vehicles potentially by **23,211 MT CO_2**.

Another strategy is to incentivize the penetration of electric vehicles. Originally, it is assumed that 2% of vehicles are electric, but increasing the access to fast-charging station and other incentives might drive the penetration. Each increment of 1% increase in PEV adoption would reduce the CO_2 emissions by **1,398 MT CO_2** from previous measure estimates. 5% penetration means a reduction by **4,194 MT CO_2**.

Finally, using smart traffic signals might help reduce mobile emissions by an additional 3%, or **4,057 MT CO_2.** Researchers (Ferreira & d'Orey, 2011) have looked at the impact of smart or virtual traffic signals and found that it can reduce vehicle emissions by up to 20%, but a 3% reduction is used as a more conservative estimate to be applied in series with the other measures. Other combinations and intensity of those measure can be explored using DEPICT.

Solar and Battery

Photovoltaic panels and batteries can help reduce electricity import and cost, but have a minor impact on greenhouse gases emissions, since electricity has a low emission factor.

The solar model was run with the baseline building and vehicle electricity hourly consumption. The measures that impacts electricity use or PEV penetration would have an impact on the total amount and shape of the electricity demand but would not have an impact on the amount of electricity shed by the photovoltaic panels. After complete buildout, the building operation has an annual electricity demand of 102.33 GWh and electric vehicle have an annual charge of 0.54 GWh.

If the district uses monocrystalline 370W modules with no solar tracking, which corresponds to mid-range performance panels, covering the district electricity demand would require **211,865 solar units**, covering **3,718,834 ft^2**. This would reduce annual CO_2 emissions by **12,344 MT CO_2**, or **0.20 MT CO_2 / capita**. Using the number of stories of the reference model, we estimate the total roof area for the district to be 8,884,933 ft^2. If installed on building's roof, the PV modules would cover 42% of the area. If we look at the impact of installing PV on 25% of roof area, the annual production would reach **61.17 GWh**, and reduces CO_2 emissions by **7,340 MT CO_2** annually, or **0.12 MT CO_2 / capita**.

More PV modules would be required to bring all low- and mid-rise residential units to net-zero energy use, as prescribed by Title 24 2019, which requires producing more energy with PV than the source energy consumed. The total source energy for all single family and condos and townhomes is 104.3 GWh, which is equivalent to the production of 3,787,421 ft^2 of PV panels (assuming the performance previously established). This would reduce the building emissions by **12,725 MT CO_2**, or **0.21 MT CO_2 / capita**.

Table 25 shows the area of PV modules and roof coverage that would be required to cover each building type electricity demand.

Table 25 : District Project Electricity Consumption, PV Coverage

Building Type	*Electricity Demand [GWh]*	*CO_2 Emissions [MT CO_2]*	*Roof Area [ft^2]*	*PV Area [ft^2]*	*Roof Coverage [%]*
Office Building	29.58	3,549	635,105	1,082,909	171%
Condos/Townhomes	15.12	1,814	2,333,945	553,475	24%
Pads/Apartments	14.53	1,743	914,324	531,867	58%
Campus	13.25	1,590	485,694	485,148	100%
Community Use	10.98	1,318	349,351	402,179	115%
Single Family Medium	10.00	1,200	2,605,324	366,096	14%
Single Family Large	4.85	582	1,001,880	177,639	18%
Local Retail	3.35	402	492,664	122,787	25%
Hotel	1.13	136	66,647	41,471	62%

DEPICT allows the user to determine the minimum amount of batteries required to minimize the amount of electricity purchased from the grid. In the scenario where low- and mid-rise residential are net-zero, **513,065 kWh** of batteries would need to be installed. Figure 22 shows what the average hourly electrical consumption would look like for the entire district. More options for PV panels, areas and batteries capacity can be explored using DEPICT.

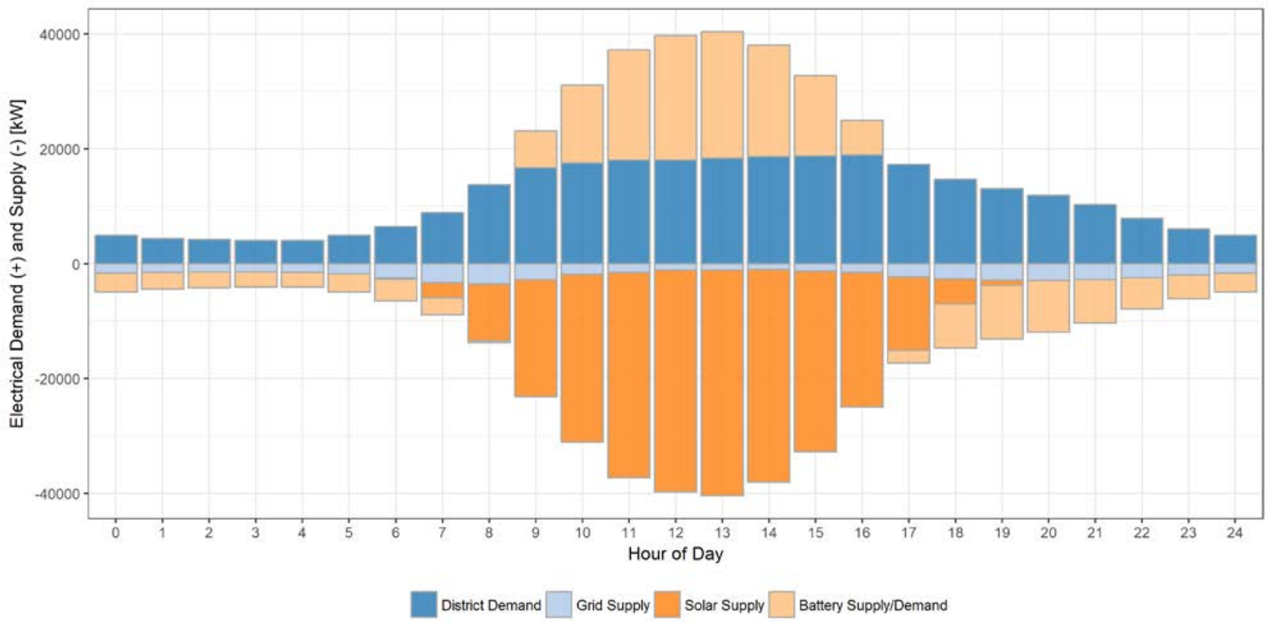

Figure 22 : DEPICT results: District Project Hourly Average Electrical Consumption – Net-Zero low- and mid-rise residential

Total Emissions

Unmitigated emissions

District C has estimated unmitigated CO_2 emissions of **197,391 MT CO_2 / year** after full buildout, which corresponds to **3.1 MT CO_2 / capita**. Figure 23 is showing the breakdown of emissions by sector. Construction emissions only play a small role in the district emissions and are absent after 2047. In 2047, it is estimated that 82% of emissions will come from vehicles.

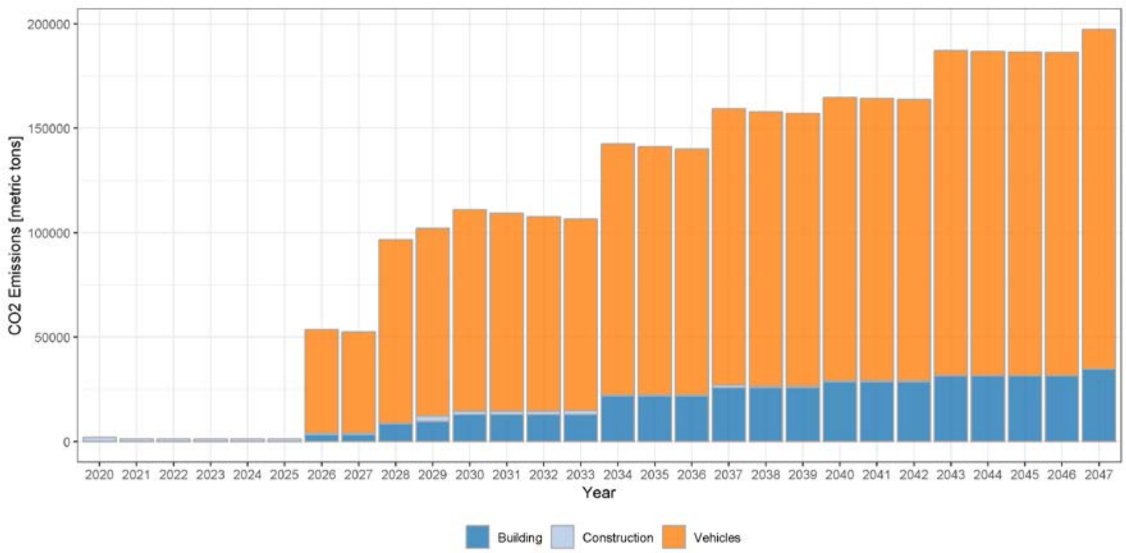

Figure 23 : DEPICT results: District C Project Unmitigated Emissions

Mitigation packages proposed

The different recommended measures for District C are summarized in Table 26.

Table 26 : District Project Mitigation Measures

Measure	CO_2 Reduction [MT]	CO_2 Reduction [MT/capita]
VMT Reduction by 14.3%	23,211	0.37
Net-Zero Low- and Mid-Rise Residential	12,725	0.20
Geothermal plant for residential space heating and hot water	10,532	0.17
PEV penetration increase to 5%	4,194	0.07
Smart Traffic Signal (3% reduction of gas vehicle emissions)	4,057	0.06
Reducing residential, office and school electrical equipment use by 10%	1,063	0.02
Electrification of gas appliances in residential	853	0.01

The implementation of all the measures could reduce the district CO_2 emissions by 56,635 MT CO_2. This would potentially bring the annual emissions in year 2047 to **140,756 MT CO_2** or **2.2 MT CO_2/ capita**.

Discussion

The results of this analysis vary between the three districts. The unmitigated baseline data shows annual normalized CO_2 emissions of 3.1 MT CO_2 /capita in District C and 4.4 MT CO_2/capita in District B. Two factors were identified to be the principal source of difference between the districts:

- For District C, the service population and VMT estimates were using the transportation consultant's calculation. This calculation resulted in lower VMT and higher service population estimates, which combined to result in lower gas vehicle emissions and lower total district normalized emissions. If we were to use the same VMT and service population used for District A and District B in District C, the unmitigated CO_2 emissions would increase to 4.1 MT CO_2/capita, which is similar to the results for District A.
- In all three districts, the main source of emissions is gas vehicle travel to retail destination. Retail buildings have a much higher VMT per built area coefficient, since they increase traffic while not creating a large impact on the service population. Local retail has the biggest impact on gas vehicle emissions with an estimated 0.18 MT CO_2/ ft^2, which is 30 times the value for an office building. Table 27 shows the emissions created by each travel destination and their ratio in the total built area. In all districts, retail is the major source of gas vehicle emissions while only representing 5-10% of the built area.

The assumption for VMT, service population and retail trip length can be adjusted in the DEPICT tool, in order to refine the numbers.

Table 27 : Correlation between built area and normalized vehicle emissions

	Residential		*Retail*		*Office*	
	Vehicle Emissions [MT CO_2/district capita]	Built Area Ratio [%]	Vehicle Emissions [MT/district capita]	Built Area Ratio [%]	Vehicle Emissions [MT CO_2/district capita]	Built Area Ratio [%]
District B	1.1	90	2.8	10	0	0
District A	0.4	41	2.2	8	1.0	51
District C	1.0	69	1.1	5	0.5	26

The key strategy for reducing CO_2 emissions in all the districts is the reduction of VMT, which can be achieved through efficient land use and transportation planning and proposing easy access to alternative modes of travel.

In theory there is no limit to how much energy use can be offset with renewable energy sources, whether from onsite solar or community choice aggregators. The most notable difference in impact is that District C, which has a larger low- and mid-rise residential mix may benefit greatly from using photovoltaic panels with the goal of making those buildings zero-net energy.

Conclusion

This work aimed at devising a new way to estimate and predict CO_2 emissions of three districts in the San Francisco Bay Area, and evaluate solutions adapted to each district. A novel *DEPICT* tool was developed to facilitate this study by integrating models across three different sectors: building construction, operations, and vehicles, as well as the models of district-wide mitigation measures such as photovoltaic and district energy plants.

In all three districts, the CO_2 emissions are unsurprisingly driven by gas vehicles, and mostly from travel to local and large retail. For this reason, District B, which has the largest retail built area (10%) out of all three districts, has the highest unmitigated CO_2 emissions, 4.4 MT CO_2/capita, followed by District A with 8% of built retail area and an annual unmitigated CO_2 emissions of 4.1 MT CO_2/capita and finally District C with 5% of retail area and an annual unmitigated CO_2 emissions of 3.1 MT CO_2/capita. Across the board, gas-based transportation is a biggest opportunity for emissions mitigation new developments followed by natural gas heating.

Even though District C would be expected to have higher per capita emissions owing to its suburban location, it exhibits lower results. This may be in part due to the use of a different model (provided by the transportation consultant) that yielded higher estimated service population and lower VMT. The main mitigation measures for all three districts aim at reducing the VMT of occupants. Some of the other solutions are inherent to the land use planning and may already be accounted for in the baseline using a hypothetical development plan. The model shows that a reduction of district-wide VMT by 10 to 15% can reduce emissions by 0.37 to 0.54 MT CO_2/capita depending on the district. Penetration of electric vehicles, such as PHEVs, e-bikes, ZEVs in this suburban district to switch out gas vehicles can also provide significant mitigation benefit. Parameters such as EV penetration can easily be adjusted in the DEPICT visualization.

Buildings are overall a less significant driver of emissions than gas vehicles since the models assume compliance to the CA Title-24 buildings energy code that helps mitigate emissions. The technical potential for electrification of buildings is large, especially for new residential buildings, where a single heat pump can provide heating and cooling, where gas infrastructure can be avoided, where winters are mild, and where heat pumps can cost-effectively displace propane or fuel oil rather than natural gas especially in new homes (Deason at al, 2018). Heat pumps for water and space heating (enclosing ground source and air-source heat pumps) are lower cost than gas-fired furnaces, improve efficiency and extend temperature range. Further, electric technologies have a potential to capture demand response revenue stream with that are not available to gas-based technologies.

In terms of building operations, the emissions profile varies slightly between the districts. District A includes 51% of built area for offices and R&D labs, which leads to the main energy end use to be space heating, and also a slightly higher electrical demand for equipment. District A might most efficiently reduce emissions by tailoring the district energy systems to cater to the space heating demand, and solutions to manage equipment energy use. District B, which is 90% residential, has most of its building emissions caused by the production of domestic hot water. A significant reduction in CO_2 emissions may be achieved by supplying this hot water with an efficient production plant, such as a geothermal district plant. District C has a more diverse building portfolio but has 52% of its area reserved for low- and mid-rise residential which are required to be net-zero energy per the Title 24 2019 code. A large portion of the district emissions may therefore be mitigated by installing PV panels to balance the source energy of residential buildings. The ZNE has a specific compliance criteria in Title 24, and using PV to balance the source energy is not a prescriptive requirement. Site PV kWh should balance site kWh electricity demand for mixed fuel homes. Parameters such as PV and energy storage size can easily be adjusted in the DEPICT visualization.

However there are significant areas for future work.

For instance, the rampant gap between design and operations is noted as a significant potential issue in districts once they are operational. Buildings can waste up to 30% of energy if not monitored and managed. In order to enable that district operations deliver the intended level of energy use and emissions that is forecasted through planning and design, conducting energy monitoring and management in commercial and residential buildings is highly recommended. Another strong recommendation is to use a district energy operations platform through which energy data from various energy generation and consumption sectors (buildings, transport, industry) can be acquired, analyzed, visualized, and the energy end-uses can be optimized and controlled. Additionally, a detailed analysis of district energy systems, a key driver of reducing CO_2 emissions, should be conducted in order to provide expert support for engineering of latest generation district heating/cooling systems. The focus would be on contributions to the basic design and specifications regarding system architecture, energy sources and modularity, and hydraulic distribution and control.

Another key recommendation is to develop quantification and analysis of key mitigation measures that are not covered in this current study, such as land use and land cover, and alternative construction methods such as the use of modular pre-fabricated building technologies that could reduce VMT from construction vehicles and construction worker vehicles, as well as demolition dust etc.

This study has led to the development of an innovative, single tool DEPICT that aggregates model input from various sectors, lets you input data in one place and present consolidated views for each scenario or mitigation. It integrates various functionalities of otherwise disparate tools that provide piecemeal analysis. Key further work could be to augment the tool with financial data (cost to implement) for feasibility analysis for each suggested measure.

In conclusion, when all measures to reduce CO_2 emissions were implemented in each hypothetical district scenario, DEPICT forecasted the annual CO_2 emissions per district to be 3.2 MT CO_2/capita in District A (22% reduction), 3.4 MT CO_2/capita in District B (25% reduction), and 2.2 MT CO_2/capita in District C (30% reduction).

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