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Sustainability Analytics: Meeting Carbon Commitments Most Efficiently

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Sustainability Analytics - Meeting Carbon Commitments Most Efficiently

by

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Abstract

What makes a sustainable company a sustainable company? More and more companies are setting seemingly ambitious net-zero targets for their greenhouse gas emissions, with the dirty secret being that the path to achieving these targets is largely met with little to no actual emissions reductions from the company itself. These targets are being met through financial instruments, where renewable energy credits are purchased from a renewable energy plant in a different corner of the world and applied against a company's operational emissions to counteract them on paper. So what can be done differently?

We build a prescriptive optimization framework, looking at how a major telecommunications company consumes energy, and output specific and actionable upgrade decisions that have been optimized to both save money and reduce emissions. Applying this framework resulted in a >10% reduction in operational emissions and energy spend. Furthermore, we look beyond operational emissions, and instead at embedded emissions of how a telecommunication network has been designed, and ask questions on what can be done to optimize this architecture. This included investigating the financial and environmental implications of reducing the real estate footprint of the company's telecommunications network, finding billions of dollars of savings in energy spend just in the baseline location of New York City for the company.

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Acronyms

BMS Building Management System. 40

CO Central Office. 16, 19, 23–27, 34, 35, 38, 39, 41, 44, 63, 64, 69, 70, 72–75, 78, 80, 81, 84–89, 91

ESG Environmental, Sustainability, and Governance. 29

GHG Greenhouse Gas Emissions. 12, 49, 50, 60, 66, 85

KPI Key Performance Indicator. 37

LL97 Local Law 97. 10, 16, 34, 35, 46, 50, 54, 58, 60, 66, 68, 76

NPV Net Present Value. 74, 78, 85

NT Network Transformation. 43, 49, 74, 86

REC Renewable Energy Credit. 30, 78

ROI Return on Investment. 45, 51, 65

RPS Renewable Portfolio Standard. 22, 31, 66, 80–82

TDM Time-Division Multiplexing. 41, 73

TEC Total Energy Cost. 67, 70, 75, 76

TOC Total Operating Cost. 45, 49, 85

VFD Variable Frequency Drives. 40

VPPA Virtual Power Purchase Agreement. 30, 37, 65, 78, 79

VZB Verizon Business. 49, 84

VZT Verizon Domestic Telecom. 49, 84

Chapter 1

Introduction

Verizon Communications Inc. was founded as Bell communications in 1983 and operated primarily in the northeast of the US. Bell re-branded as Verizon in 2000 upon the acquisition of GTE, a nationwide telecommunications operator. The company now operates in more than 150 countries and has 118 thousand employees. The company is a publicly traded telecommunications conglomerate (VZ; NYSE Nasdaq) and ranks twenty-third on the Fortune 500 list with a revenue of $137 billion in 2022. [1]

Through acquisitions, and the growth of network demands over time, Verizon maintains a huge real estate network. Verizon's Real Estate division manages a 100 million square feet portfolio with an operating budget exceeding 1.7 Billion in 2019 [26]. It is this real estate network that is coming into focus through a sustainability lens with the introduction of environmental compliance laws and building portfolio standards over the coming years. These laws will set Greenhouse Gas Emissions (GHG) limits on buildings that will get more stringent over time, and fine the building owner if not in compliance through a carbon tax. The most immediate version of these laws that are coming into effect is through Local Law 97 in New York City, where Verizon maintains its largest network. It is through this law that many large real estate owners in the city are examining their portfolios to reduce emissions ahead of when fines start in 2024.

This project attempts to unpack what drives emissions in Verizon's real estate

[1] https://www.verizon.com/about/our-company/verizon-fact-sheet

portfolio, build a prescriptive optimization model that outputs what projects should be undertaken to minimize the financial impact of this carbon tax and connect the high-level sustainability goals of the company to the performance metrics at the individual contributor level. When looking at how to reduce the energy consumption of a large real estate portfolio we had to look at:

1. Reducing energy consumption at each building through:
    - Increasing building energy efficiency. What upgrades can be performed to the building itself so that it carries out its operations as energy efficiently as possible?
    - Reducing operational equipment energy usage. Separate from the building, how can we reduce the energy consumption of the network equipment operating within the building?
2. Reducing the number of buildings. As mentioned above, Verizon has built out a vast network of real estate, but with the advancements of technology in telecommunications, Verizon does not need nearly as many of these buildings to maintain today's network requirements. However, with ever-increasing bandwidth demands, it gets more and more difficult (and expensive!) to scale back the portfolio.

1.1 Problem Statement

At a company the scale of Verizon, it is easy to get lost in the amount of data that is available. Looking too at how broad and deep a company it is structurally with well over 100,000 employees; it is difficult to connect the dots between how data being collected from one team on the real estate division could be used to effect change on the network team's operations and vice-versa. It is this distillation of data that the work presented aims to do by asking three questions - (a) how do we optimize building upgrades to minimize financial and energy costs, (b) how do we connect a line between sustainability goals at an executive level and individual performance metrics at a team level, and (c) how do we use sustainability as a metric to support decision making in Verizon's real estate portfolio strategy.

Firstly, organizations with large real estate holdings are facing difficult decisions to minimize the negative financial effects of upcoming carbon taxes. Which upgrades, of the thousands possible across a portfolio, gives the most bang for the buck? It is also not clear what the metric is that quantifies which upgrades are best. Are we optimizing for minimizing emissions, minimizing carbon tax, or minimizing total costs?

Secondly, there is a fundamental problem across corporate sustainability where large companies set lofty net zero emissions goals often with little to no intention of reducing their own energy usage, instead using renewable energy credits to offset operational emissions. A major contributor to this is that outside of a dedicated sustainability team, individual working teams do not have performance metrics that drive them towards projects that move the needle for the company's sustainability goals. How can we use data to draw a line between executive sustainability goals and individual team performance metrics?

Lastly, if we ignore building upgrades to reduce energy, and instead take a macro-level view of what Verizon's real estate portfolio looks like we realize that the real estate network has evolved to what it is today out of necessity, but it is by no means how a new real estate network would be designed if Verizon could start from a blank slate. How can we use data to analyze what options there are in beginning to shift the company's real estate network towards what it could be in an ideal situation?

1.2 Overview of Proposed Approach

The approach taken to carry out the work in this research was to understand what the need was from the company in this work, and creating a process to accomplish this. This project is rooted in sustainability, but importantly, was proposed by the real estate team within the company. It was first important to gather as much information as possible, which meant understanding Verizon's energy consumption

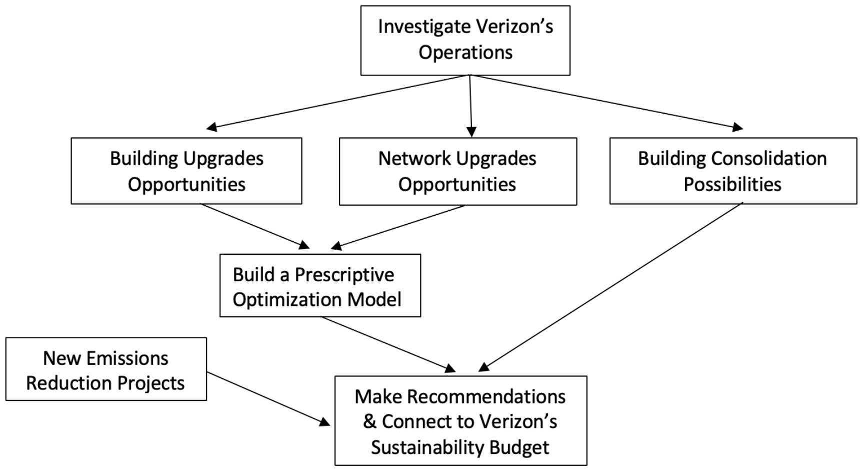


Figure 1-1: Illustration of how research areas presented relate to one another.

and sustainability targets, how the company's real estate portfolio impacts these, and building out a robust stakeholder map to understand the complete value chain that could be impacted by this project. This stakeholder mapping proved to be a critical component of this research as it led to engagement with not only the groups within Verizon who managed the real estate but also the groups within Verizon who utilized the real estate, most notably those who managed the network infrastructure. Engaging with the network team developed a broader picture of how pulling different levers in the real estate portfolio could impact their operations.

Initially, the project was intended to solely look at optimizing building upgrades to both save money and reduce emissions, but having spoken with the network team and understanding the company's operations more holistically we were able to look at upgrading network equipment and begin to rethink the network's architecture. These strategies are fleshed out in more detail in Chapter 5.

To pull all strategies together we look at how they would impact Verizon's total emissions if scaled on a national level, and compare that with the company's existing plans to meet their sustainability targets.

1.3 Thesis Organization

The sequence in how this thesis is presented follows a rough chronology of how the internship timeline of discovery progressed. That said certain stages of the internship, and in turn chapters of this thesis, represent the findings over varying durations.

Firstly, in Chapter 2, we show that using optimization models to improve operations at companies is not new or novel and much can be learned from past work, in combination with findings from modern energy policy, to shape an optimization model for Verizon.

In chapter 3, we take a deeper dive into Verizon and the telecommunications industry and how this evolving industry has shaped the sustainability challenges we face. We also look at Verizon's current plan for sustainability and how they will meet their net-zero goals, discussing the pros and cons of this.

Chapter 4 takes us to the reason why this project first came to light, carbon taxes, or environmental compliance laws. We look at how these policies have taken shape across the US, the timeline of how they will impact Verizon and the nuts and bolts of how NYC's Local Law 97 (LL97) will work.

Into the meat of the internship is Chapter 5, which discusses the different strategies for how Verizon will reduce its energy footprint. This specifically looks at the company's network of Central Office (CO)s, which are the buildings that handle the network traffic and represent the real estate portfolio's largest consumer of energy.

Chapter 6 walks through the different data used for the project. This looks at how the data was sourced, its format, and how it was organized for use in an optimization model.

How the optimization model was designed and built is discussed in chapter 7, showing all objective functions, decision variables, and constraints and how they were determined.

We then look at the results from the optimization model in chapter 8, where we present visual interpretations and provide discussion points. This section also holds results from analyses not directly outputted from the optimization model, specifically related to the real estate portfolio strategy point from our problem statement.

Lastly, chapter 9 is where we conclude overall findings from the work and discuss future opportunities to continue this study to help drive Verizon towards sustainability nirvana.

Chapter 2

Literature Review

We began by surveying past work at the host company from similar project types to identify if any common themes on what the company was trying to achieve would prevail. Following this, we took a broader approach and surveyed any types of optimization work undertaken at large companies to influence operational decisions. The next section of the review was to more specifically review how carbon taxes are designed and implemented and how they affect individuals and corporations. Lastly, we looked at the existing energy landscape and how a "greening" grid will effect change on business decisions for sustainability.

2.1 What types of projects do Verizon value?

Past masters theses where Verizon was the host company to the research vary in subject matter from design the future of hybrid work [26], to optimizing distribution center logistics management [9], to applying analytics to solve inventory management[8]. A common thread through each of these theses is Verizon's commitment to using analytics and optimization to drive the growth of their business, and how this work can be integrated into the day-to-day operations of the company. In [26] we see that as new operational challenges arise for Verizon such as COVID-19, they are quick to try to address these challenges by applying analytics to maintain company growth. In this case, Verizon created a trial hybrid work scheduler as an output of the thesis, which has since been implemented company-wide. Verizon has continued to expand its analytics department in recent years to identify new areas in the company can find value using data and optimization.

One example of work this team has completed more related to sustainability is seen in [15] where the company used analytics to optimize the locations of their work centers to minimize installation and repair operational costs of their service technicians. This work compares well to research conducted in our study on telecommunication Central Office location optimization.

The major takeaway from this review on analytics work performed at Verizon is that the company values operational and actionable results from its analytical models. This realization helped frame that outputs from our research had to be discrete and actionable in order to maximize impact as a piece of work for Verizon.

2.2 Operational Decision Making using Optimization

Taking a broader view at means by which optimization research has been used to dictate operational decision-making at large companies can be found in [29], [2], and [16]. Firstly, in [29] we see how a past MIT masters student used optimization to show opportunities for decarbonization of the electric vehicle manufacturing process, and how an implied value of carbon internal to a company can alter decisions in operations. This is particularly applicable to our work as we have a known price of carbon, but can use the optimization model setup approach taken to advise ours.

[2] and [16] both present work on applying optimization models to decide on building upgrades in both residential[2] and commercial office[16] settings. While not the same high energy intensity type buildings as we will be studying as part of our research, it validates Verizon's decision to want to apply optimization in this fashion. These pieces of work also provide outlines for how an optimization model could be constructed for this type of decision making which was drawn upon during the research. Conversely to our work both [2] and [16] use energy sustainability as the primary metric for decision-making for retrofits, contrary to the multi-optimization

approach we would recommend finding the best solution for both a financial business case as well as sustainability.

2.3 Do Carbon Taxes Work?

A carbon tax works to disincentivize emitting carbon dioxide into the atmosphere by applying a price on each ton of CO2 emitted. Similar to companies or individuals paying an electricity bill based on their electricity consumption leading to actions such as turning the lights off when we leave the room to save money, setting a price on carbon is an attempt to affect human behavior to limit emissions from activities and operations.

Carbon pricing can be implemented using either of two instruments – a carbon tax or a GHG emissions trading system (ETS). With a tax, the government sets the tax rate and specifies the sources subject to the tax. The emission reduction achieved depends upon the response of the affected sources to the imposition of the tax. With an ETS the government sets a limit on GHG emissions by specified sources and distributes allowances approximately equal to the limit. [14] This "cap and trade" ETS policy is in effect in the wholesale electricity market in Europe and has had many attempted introductions in the US where 13 states currently have ETS carbon pricing policies for their electricity markets.[23]

Carbon pricing is not exclusive to electricity markets, however. In a New York Times article[22] chronicling the economic and environmental effects of a point of purchase carbon tax on fossil fuels (e.g. petrol, diesel, kerosene, etc.) in British Columbia, it is shown that a 15% reduction in emissions can be accredited to the introduction of a broad carbon tax, with no negative effects on economic output. This highlights the major benefit from carbon pricing, although the article also highlights some downsides in the price being so high that local industries are losing market share to imports, and the price being so low that sustainability-driven industries such as electric vehicles can still not compete on price with internal combustion motors due to the cost of batteries. As such, it would appear that while the introduction of a carbon

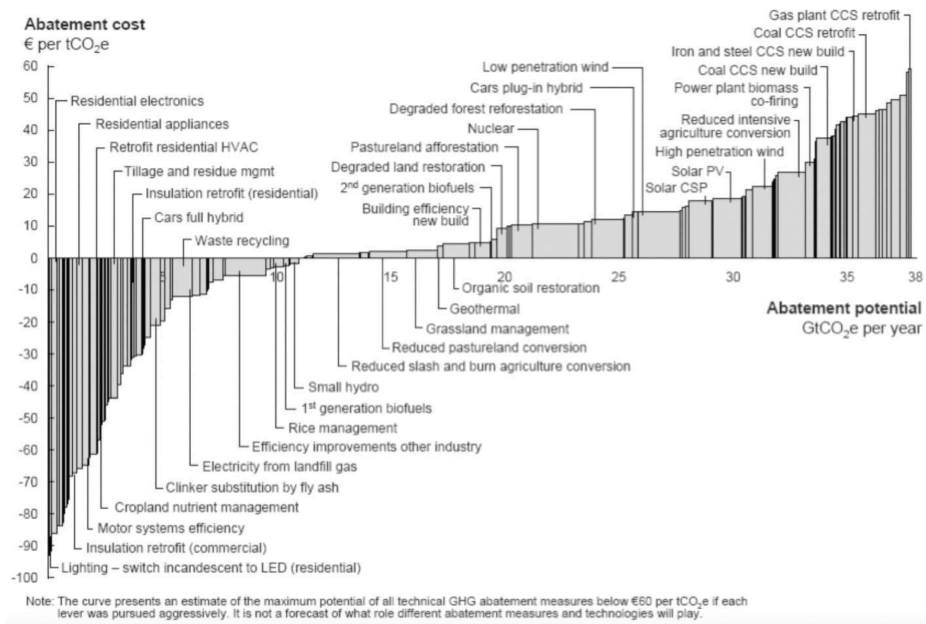


Figure 2-1: Greenhouse Gas abatement cost curve developed by McKinsey (v2, 2009)

price has largely positive results, what that price is set to can vary sentiment from constituents. We see this price sensitivity in our results.

2.4 Cost of Abatement

The carbon abatement cost curve developed by McKinsey is one of the most recognizable and used diagrams in climate change policy change discussions [12], see Figure 2-1[10]. What this diagram identifies, and perhaps oversimplifies [11], is that there are categories of carbon abatement projects that have a negative cost. What this means is that the cost of carrying out these emissions-reducing projects is outweighed by the financial gain in the long run of carrying them out. This concept is evident throughout our results as an optimization model is essentially selecting what abatement cost of carbon offers favorable enough returns to determine whether or not a project is recommended; this basically draws a horizontal line on Figure 2-1 and proposed all projects below that line. Deciding how, where, and when to place the line is the role of the optimization model.

2.5 Our Future Energy Mix

Making financial investments to meet sustainability goals cannot be performed in a vacuum, in the sense that the emissions output from our electricity, our vehicles, or from our fossil fuel burning equipment is reducing as new sources of energy come online. As more and more states in the US sign into law Renewable Portfolio Standards (RPS), there is a growing commitment to clean the electricity on the country's utility grid. This cleaning of the grid, while not yet fully realized, is something that businesses should consider taking into account when installing building energy efficiency upgrades[1]. This evolution of the grid will nudge more companies towards electrification of their operations in an effort to limit any effect of new carbon taxes being imposed. This will limit the effect of carbon taxes, as the amount of CO2 emitted per unit of electricity from the grid will decrease over time as more renewable come online, meaning the emissions generated from a company's electricity usage will decrease without any additional capital required from the company, just by leveraging the state's commitment to a cleaner grid. This will lead companies to invest money in converting their operations to take advantage of this cleaner electricity at no additional cost. As battery energy storage systems become more cost-effective, they will see a sharp increase in use due to this cleaner grid, as building owners will want to charge batteries at times of higher renewable penetration, to discharge when renewable energy is not present.[1]

It seems like a matter of time before such RPSs are in effect nationwide as public acceptance of renewable energy projects and transmission line projects are increasing nationally, matched with declining public sentiment for coal and biomass plants[24]. This makes clean energy legislation easier to pass into law. Such a national transition to cleaner electricity is something that should be planned for and taken into account when designing strategy sustainability investments for corporate sustainability.

2.6 Conclusions from Literature Review

Verizon is a company committed to leveraging data analytics to drive business decisions across all aspects of the company. The company values actionable results, which we have taken into account in the building of our model. This willingness to rely on analytics will be applied towards optimizing building upgrades spend on the company's portfolio of Central Offices, something that has been proven successful at residential and commercial office scale elsewhere. This model will be determining the carbon abatement cost threshold for the company which must be fluid enough to futureproof for evolving climate policy.

Chapter 3

Verizon Background

Verizon operates in fixed line, mobile, and internet communication services and has evolved its strategic growth in parallel with that of new telecommunications technology. This is highlighted by the fact that they are the first company in the world to launch commercial 5G communications.

3.1 Real Estate Portfolio

As Verizon grew alongside demand for phone and internet services, the need for an expansion of its physical footprint was needed. This is due to bandwidth constraints on legacy copper-based telecommunications networks, requiring shorter cable runs from one Central Office (CO) to another. A CO is essentially a central switching center to receive and transmit telecom data. With an increase in bandwidth demand on copper-based cabling infrastructure, these COs needed to be located closer to one another, ultimately requiring Verizon to build out sizable real estate portfolios in high population density areas, primarily cities. This can be seen in Figure 3-1, where blue markers represent locations from Verizon's legacy VZT network, and the red markers represent Verizon's VZB network. The VZT network comprises almost entirely Verizon-owned buildings and serves both businesses and consumers, and still has a high percentage of copper utilization on cable infrastructure to end users. VZT is a network that offers consumer wireline services in the United States and is the

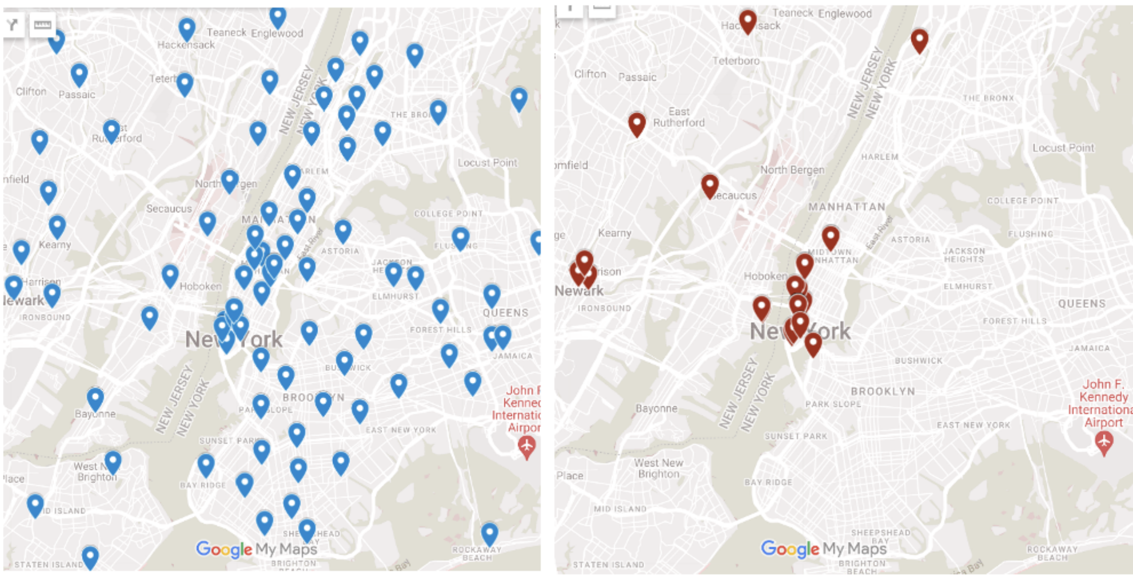


Figure 3-1: Plan view of locations of each Verizon Central Office (CO). Blue markers represent locations from Verizon's legacy VZT network (L), red markers represent Verizon's VZB network (R).

incumbent telephone operating company at the formation of Verizon. VZB refers to the Verizon competitive telephone operating companies both within and outside of the US (including MCI). The majority of VZB COs are leased by Verizon.

3.2 Network Architecture for Telecommunications Systems

The density of Verizon's CO properties in the New York City area as seen in Figure 3-1 is visibly high, particularly considering these are incredibly high energy consumption buildings by function in an incredibly high property value location. This density can be explained by a combination of an explosion in internet bandwidth demand and a legacy copper network that Verizon is building on.

A 50% annual growth in internet bandwidth has been seen in the time span from 1983 to 2023 requiring huge infrastructure upgrades to keep consumers up to speed with advancing technologies.[20] The legacy copper-based transmission network that has been built on needs to be completely overhauled with fiber optic technology to keep

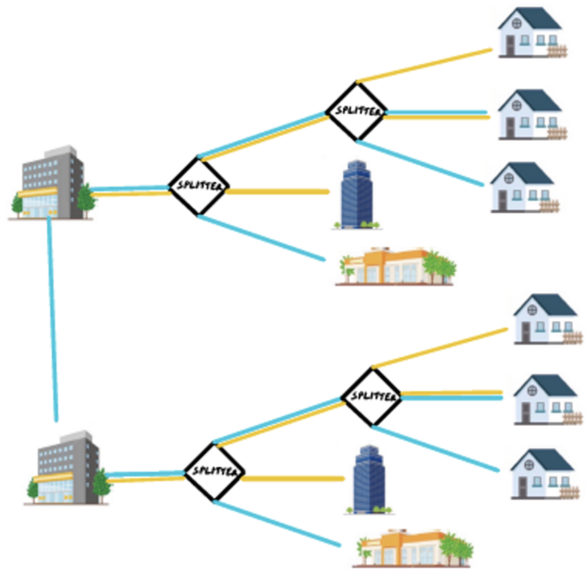


Figure 3-2: Representation of the Verizon network architecture for its VZT and VZB businesses. This shows two examples Central Office (CO)'s connected via underground high bandwidth fiber cables. These COs then transmit both copper and fiber to end users such as businesses and end consumers who are a mixture of fiber (blue) and copper (gold) users.

up with this increase in bandwidth. The reason for this need is that fiber optic cables offer orders of magnitude improved bandwidth capabilities and signal attenuation or loss over copper cables.[5] This means that in order to keep up with bandwidth demand, telecommunication companies have the choice to install more copper cable with COs closer together to handle bandwidth and signal loss issues, or to replace the copper network with a fiber-based network. Telecom companies are conservative when it comes to the latter as it is incredibly expensive to dig up streets and install equipment to serve millions of customers, particularly in high population density areas. This has all meant that the telecom industry has straddled both strategies, slowly upgrading infrastructure while minimizing cost and disruption in doing so, while building out capacity in their existing large building footprint to handle growing demand. This has led to largely maintaining an oversized portfolio of COs given the technical requirements. This network of COs are interconnected through fiber, and where they split off into end consumers is a mix of fiber and copper as upgrades continue.

GHG emissions CO$_2$e (metric tons)	2018	2019	2020	% Change 2019-2020
Scope 1	385,241	358,753	336,831	-6.1
Scope 2	4,033,579	4,006,874	3,753,660	-6.3
Total scope 1 & 2	4,418,820	4,365,627	4,090,491	-6.3
Scope 3	–	16,954,198	15,640,414	-7.7

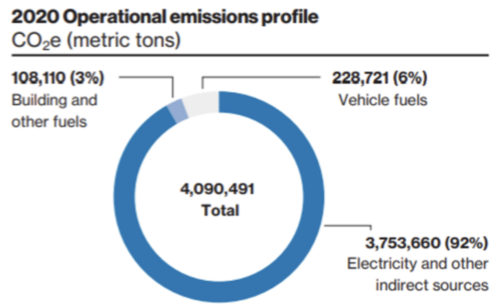


Table 3.1: Table and chart from Verizon's Annual ESG report showing Scope 1, 2, and 3 emissions from 2018 - 2020 (left), and the operational emissions profile from 2020 (right).

The incentive for this project scope from Verizon's perspective was to optimize their building portfolio's operations to limit the financial burden of upcoming environmental compliance laws in New York City, as well as help to meet the company's sustainability goals. This required investigating the portfolio from both micro and macro levels to see what reductions could be made in each building as well as what could be done to optimize the portfolio as a whole.

3.3 Sustainability at Verizon

3.3.1 Verizon Energy Consumption and Greenhouse Gas Emissions

As a major telecommunications and infrastructure company in the US, the company's carbon footprint is quite sizable. in Table 3.1 we can see the company's Scope 1, 2, and 3 emissions over time from their 2021 ESG report. The main finding from this is how much Scope 2, and Electricity in particular, affects the company's overall emissions values. the primary consumer of electricity in the company are its buildings, and of its buildings, the Central Office's are the largest contributors. The goal of the internship, targeting the emissions of these CO's seems like it has grounding and is a logical first place to look.

Looking solely at the gross emissions values from Figure 3.1 can be difficult to

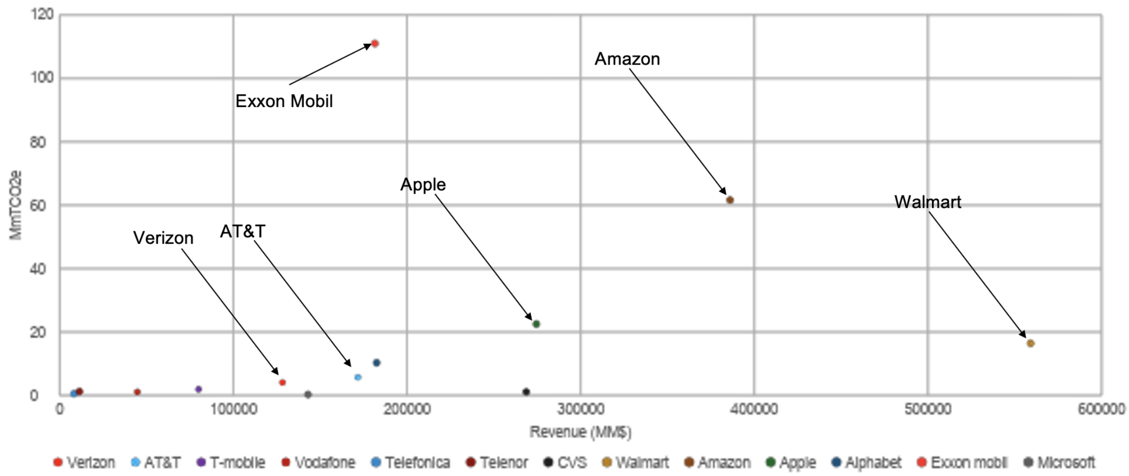


Figure 3-3: Scatter plot showing the Scope 1 and 2 emissions from a selection of Fortune 25 companies and other telecommunications companies. Annual revenue for that company is plotted on the x-axis.

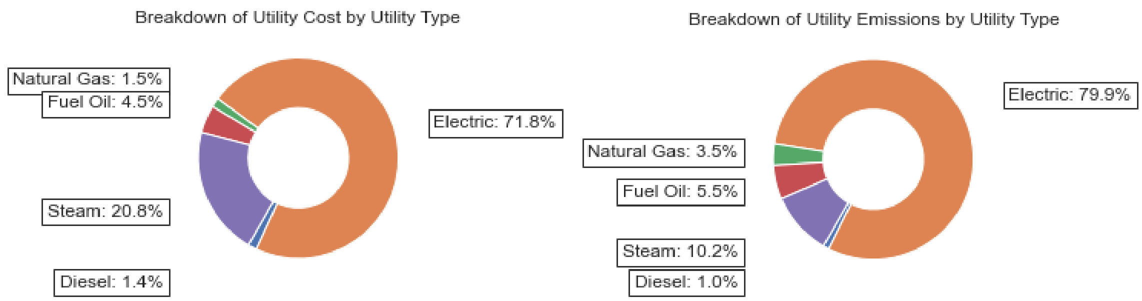
grasp whether this is a large or small amount of CO2 for a company of Verizon's scale. In Figure 3-3 a select group of fellow Fortune 25 companies, as well as some notable telecommunications companies are plotted with their annual emissions as a function of gross annual revenue.[1] The hope with this plot is to see how Verizon compares to some competitors within the same industry, or at the same financial scale. From this, we can see that Verizon's emissions are comparable with competing US telecommunications companies and fall far lower than companies with a much larger operational or manufacturing role. In companies with these larger operational functions, the contribution to emissions from electricity would be quite a bit lower than that of Verizon's, making efficiency reduction opportunities more complex but also perhaps more plentiful.

3.3.2 Sustainability Commitments and Plan to Meet Targets

As with many major corporations in the US, Verizon has set itself admirable sustainability goals, two of the most notable being:

1. 50% of total annual electricity consumption to be backed by renewable energy by 2025

[1] Data taken from annual ESG report for each company and public record revenue data for 2021



(a) Utility Cost Breakdown (b) Utility Emissions Breakdown

Figure 3-4: Comparison of utility contribution to both overall cost and emissions for Verizon's New York City portfolio of COs on the VZT network.

2. Achieve net zero carbon emissions in operations by 2035

It is important to understand what these metrics for success actually mean for Verizon as a sustainable company. Firstly, 50% of electricity being backed by renewable energy does not mean 50% of Verizon's electricity is from renewable energy. The term "being backed by" refers to using renewable energy credits purchased from offsite wind or solar farms to count against emissions being caused by your own operations. This system has a major flaw in that it does not actually reduce emissions for a company, but rather counteracts its emissions on paper by funding clean energy elsewhere. Even given this, it is the primary way that all major companies are planning on meeting their sustainability goals.

The second goal of achieving net zero carbon emissions is similar to the first, but instead of trying to offset the emissions from 50% of the company's electricity, the target is now to offset the entirety of the Scope 1 and 2 emissions we saw in Table 3.1. While adjusting its language slightly for this goal in saying that this will be achieved by both renewable energy projects and energy efficiency upgrades, it is worthwhile to look at where their sustainability funds have been directed to date.

From Verizon's annual ESG report we know that the company's primary method of achieving its sustainability goals is through its green bond initiative. A green bond is a type of fixed-income instrument that is specifically earmarked to raise money for climate and environmental projects. Verizon has announced $1 Billion worth of green bonds to be issued each year for the last four years. The first three of

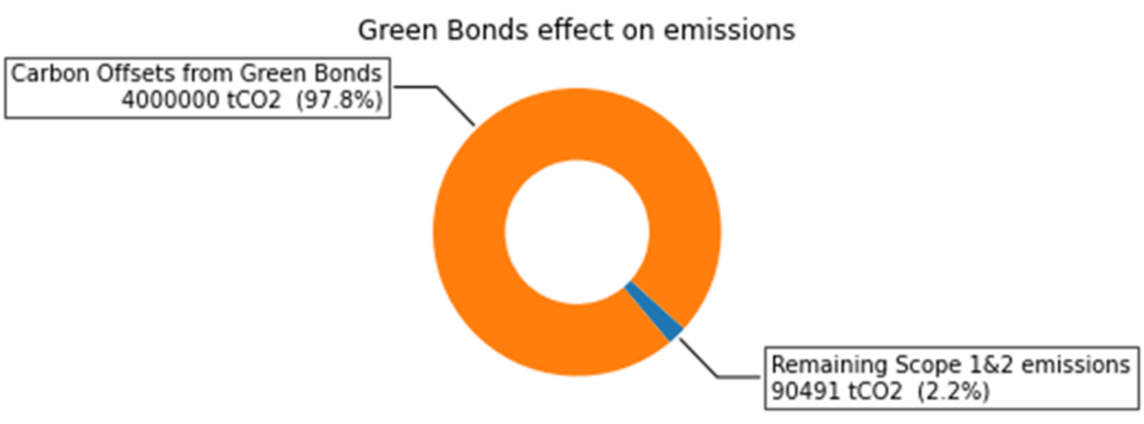


Figure 3-5: Illustration of the amount of Verizon's 2020 Scope 1 & 2 emissions that will be accounted for by Verizon's allocation of Green Bonds to Virtual Power Purchase Agreements of renewable energy. While accounting for almost all of Verizon's emissions in getting to net zero, this program does not currently move the needle in reducing Verizon's emissions.

these have already been fully allocated to renewable energy projects across the US through Virtual Power Purchase Agreements (VPPAs). How this works is that Verizon commits to being a long-term purchaser of electricity at a fixed price from a proposed renewable energy project to enable that project to be financed and developed. Once operational, the electricity generated from the plant is sold into the local utility grid, and the difference between the market price and the fixed agreed price with Verizon is Verizon's responsibility. In exchange for this VPPA, Verizon gets the Renewable Energy Credit (REC)s generated from the plant that can be counted towards the company's emissions.

The $3 Billion of green bonds already allocated from the first three green bonds have gone entirely to VPPAs. Almost all of Verizon's Scope 1 and 2 emissions from 2020 are accounted for through RECs from these projects, see Figure 3-5. While emissions from electricity are predicted to grow through electrification and increased operations by the time the fourth green bond has been fully allocated, accounting for essentially all of your emissions through projects that do not reduce your emissions seems unnecessary.

The main benefit of these VPPAs is that Verizon as a corporate leader in sustainability is providing financial support to ensure the electricity grid in the US becomes

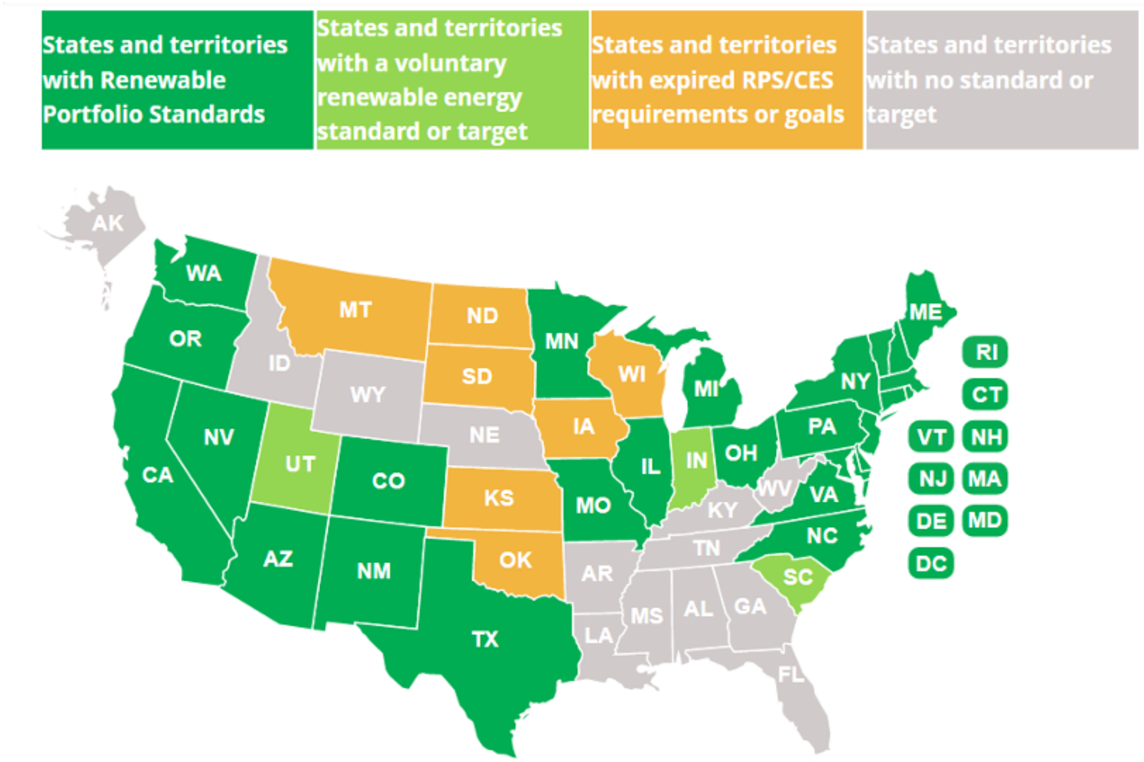


Figure 3-6: Renewable Portfolio Standards by state and territory in the US.

greener. The question here is, is this support necessary given the strong support for clean energy in the US in recent years? It is important to note that many states and territories in the US have committed to Renewable Portfolio Standard (RPS)s where a certain percentage of the electricity on the grid from renewable energy has been set for some year in the future. A map illustrating this support can be seen in Figure 3-6[2]. Essentially what this infers is that it may not be as impactful as intended by Verizon to invest money in locations where governments have already committed to large-scale renewable energy penetration in the near future. This basically begs the question of how should Verizon dedicate the funds it has committed to sustainability in this latest green bond to maximize impact.

[2]https://www.ncsl.org/energy/state-renewable-portfolio-standards-and-goals

Chapter 4

Environmental Compliance Laws

4.1 Introduction

To understand why Verizon was initially interested in this subject area we must discuss environmental compliance laws. Environmental compliance laws are laws that aim to limit greenhouse gas emissions from different sectors, by taxing the entities that are above the threshold of a compliant emission level. For the purposes of this research, we focused solely on environmental compliance laws and the built environment. These types of laws give the owners of buildings a limit to the amount they are allowed to emit from a building in a given year. Typically this limit is based on the floor area of the building and becomes more stringent over time. Verizon owns a significant number of real estate properties across the country that consume comparable amounts of energy to data centers. As such, any taxation of energy consumption of these properties will have a significant financial impact on Verizon. This section of the document serves to outline how these types of taxes work, and how that impacts how an optimization model takes them into account.

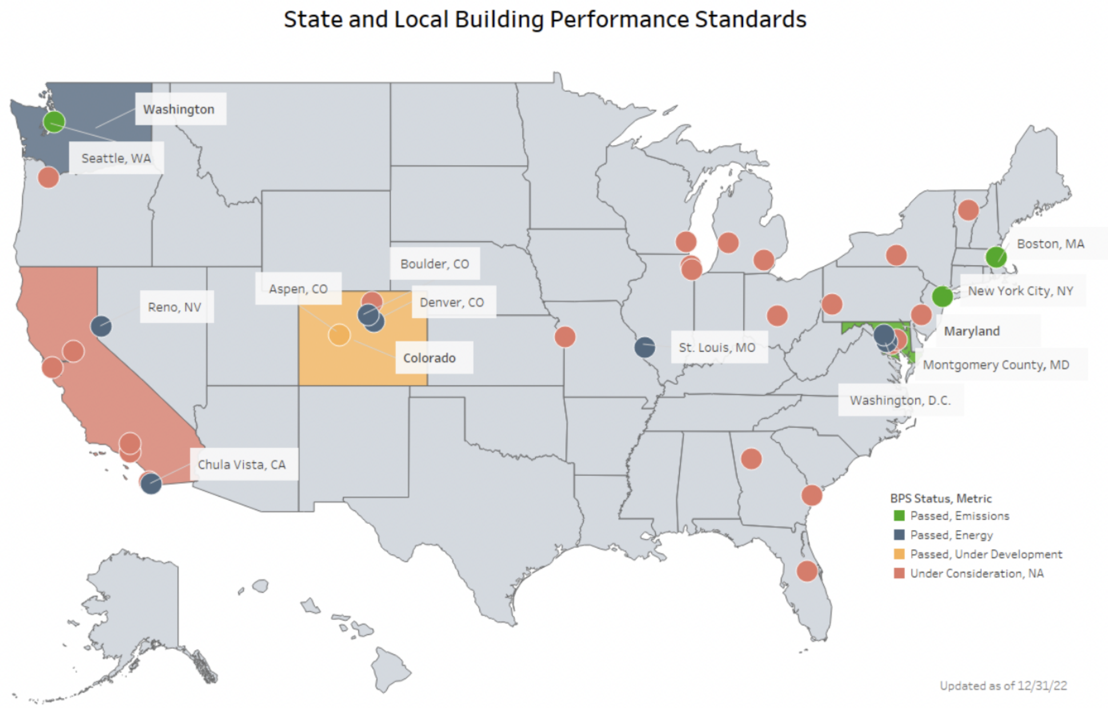


Figure 4-1: Map of US showing states and cities that have Building Portfolio Standards either in place or under development.

4.2 Environmental Compliance Laws Nationally

Environmental compliance laws for the built environment are coming into effect in over 30 cities and 4 states over the coming years.[1] This shows a drastic shift in legislation to enforce emission reductions across the country, going beyond the net offsetting of emissions discussed in Section 3.3.2. The range of when these will be enforced varies from 2024 in the case of New York City, out into the 2030s for newer legislation being proposed. As such, it is quite prudent for Verizon and other large corporations to plan for the future and devise an emissions reduction strategy now before fines kick in.

[1]https://www.energycodes.gov/BPS

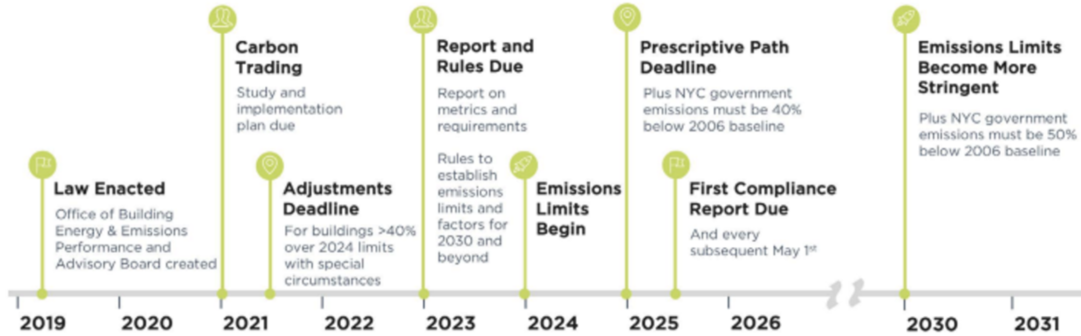


Figure 4-2: Timeline of Local Law 97 enforcement between 2019, when the law was enacted, to 2030.

4.3 Environmental Compliance Laws in New York City - Local Law 97

Local Law 97 (LL97) was signed into law in 2019 with the aim of making New York City's buildings more efficient and improving the air quality in the city for its residents. The emissions limits come into effect from the law in 2024, becoming more stringent in 2030 and every 5 years thereafter.[27] See Figure 4-2 for a complete timeline of the law up to 2030. The law applies to any building with a floor area greater than 25,000sqft, with a few exceptions. The emissions limit is dictated by what occupancy group is served within a given building, so a school or a hospital will have a different emissions limit than one of Verizon's COs.

The law dictates what the emission factor is for each emitter in a building's operations (Table 4.1), which may differ from what the actual emissions related to that energy source is as it attempts to have uniform information in each building's reporting of emissions that is traceable to a utility bill.

Table 4.2 outlines what the emissions limit is for each time period outlined in LL97. This shows that the ultimate goal of this law is to drive net emissions from each building >25,000 sqft in NYC to zero by 2050 [27] The price applied to carbon for this law is $268 per metric ton of CO2 emitted above the limits shown in Table 4.2.

Table 4.1: LL97 Greenhouse Gas Coefficients as per LL97 guidance. Coefficients beyond 2035 have not yet been defined. For all calculations used in the results section, it is assumed to continue 2034 coefficients into the future.

CO2 Source	2024-2029	2030 - 2034
Electricity (tCO2/kWh)	0.000288962	0.000145
Natural Gas (tCO2/kBtu)	0.00005311	0.00005311
#2 Fuel Oil (tCO2/kBtu)	0.00007421	0.00007421
#4 Fuel Oil (tCO2/kBtu)	0.00007529	0.00007529
District Steam (tCO2/kBtu)	0.00004493	0.0000432

Table 4.2: Local Law 97 emissions limits for Verizon's occupancy group type.

Years of effect	Emissions limit (tCO2/sf/yr)
2024-2029	0.02381
2030 - 2034	0.014791131
2035 - 2039	0.011093348
2040 - 2049	0.007395565
2050+	0.0

4.4 Impact of Laws on Verizon

The effect of these laws on Verizon is significant as these Central Office's are the backbone of the network that Verizon supports and there are thousands required to maintain the network across the country. Most immediately in NYC, Verizon owns 68 COs on the VZT network, each of which is at varying levels of compliance as seen in Figure 4-3. One of the interesting results to look at from the building out of an optimization model is, does it make sense to close each of these gaps, or is the marginal benefit in doing so dwarfed by the cost of those marginal building upgrades?

An area where LL97 affects Verizon perhaps differently to other building owners is that Verizon does not own just a handful of commercial office buildings, but instead dozens of major telecommunication Central Offices all within the confines of the city. The law is designed to force individual buildings to become more energy efficient and drive their annual emissions below a certain level, but gross outcomes could be more favorable if building emissions and emissions limits were aggregated for a

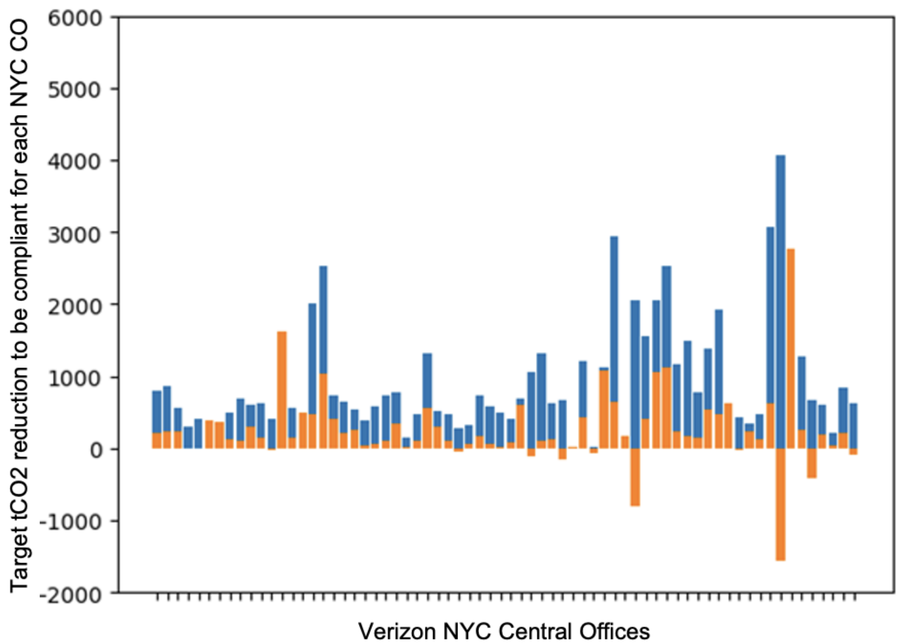


Figure 4-3: Bar chart showing each of Verizon's 68 owned NYC Central Offices and the amount reduction in tCO2 from 2006 levels needed to be compliant (blue). Also shown is the progress towards compliance in 2021 (orange). Negative orange bars indicate that the gap to compliance has grown since 2006.

company such as Verizon with so many properties. The logic behind this is that a low-cost and impactful energy upgrade could be possible in a building that is already compliant so not undertaken. In contrast, in a building that is not compliant, the only energy upgrade possible could be high cost with marginal benefits in emission reductions, this aggregate approach would reduce cost for the building portfolio owner, and reduce emissions for the city of New York. This concern was raised by Verizon with representatives from the city of New York, where the feedback was that this aspect of the law was intentional in order to improve energy efficiency and air quality equitably across all areas of New York City.

Chapter 5

Energy Reduction Strategies

At this point of the document we have a better understanding of Verizon as a company, how they consume energy, and how upcoming environmental compliance laws will impact them. This chapter highlights how we structured the approach to reducing energy consumption for Verizon and how they are all related to one another.

A company of the scale of Verizon cannot just flick a switch and reduce energy through individual measures. A likely reason that the company has focused on VPPAs as the means of achieving net zero to date is that it is a financial instrument that does not have the significant operational challenges associated with gradual reductions in energy consumption. This section will look at what those challenges are and attempt to segment them into discrete and actionable work areas. This will assist in the identification of opportunities, but importantly from an implementation standpoint will segregate the opportunities in working groups within the host company to aid in project management, budget allocation, and stakeholder engagement. One of the important lessons learned at Verizon at the beginning of this project was that there is a disconnect between the sustainability metrics being targeted from an executive level and the Key Performance Indicators (KPIs) that are being worked towards at the individual contributor level. By segregating energy reduction opportunity types, KPIs could be allocated to the individual contributors that meet the macro-level sustainability goals more clearly.

5.1 Introduction - How to Reduce Energy Consumption

The first aspect of segmenting the opportunities to reduce the energy consumption of Verizon's building portfolio is to, at a high level, designate how a portfolio of buildings could consume energy. The obvious first place to look at is through the building's operations itself. By having the lights on and the building functional towards maintaining the telecommunication network, the building will of course consume energy, primarily through electricity from the local utility grid. If we focus on reducing consumption at a building level, there is a further level that we can dive into to segment this; we can make the buildings more energy efficient so that for a given operational need the building requires less energy, or we can literally reduce consumption; reducing consumption means looking at all of the equipment being used in that building to maintain its business operations and identifying opportunities to consolidate or upgrade the equipment.

In a more perhaps basic way, the second means of reducing the energy consumption of a portfolio of buildings is to reduce the number of buildings in the portfolio. This is not exactly straightforward in Verizon's case as the portfolio of COs are all connected in a spiderweb of underground cabling that supports the national network. It is not possible to simply shut a building down, as that will shut off network availability for the thousands of customers being served from that Central Office. Any building that closes, must have its operations taken over by a different Central Office, and a new connection made from this replacement Central Office to the end customers of the now-closed Central Office. For the purposes of this research, the work has focused exclusively on Verizon's New York City Central Offices to maintain simplicity and enable eventual national build-out, but also because New York is where the first of the many environmental compliance laws will come into effect that affects Verizon so it makes sense as a logical pilot case. Figure 5-1 shows each of these options and incremental layers for reducing energy use.

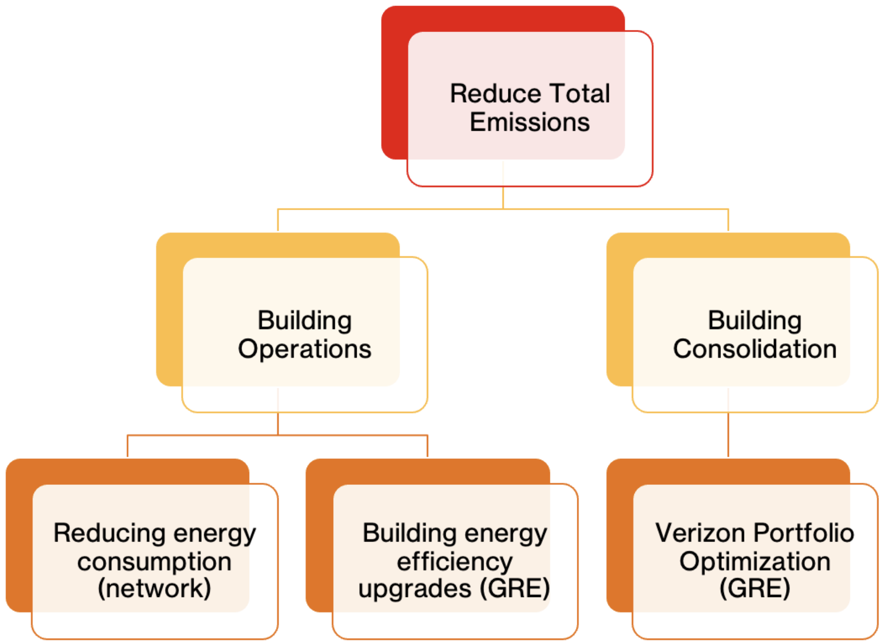


Figure 5-1: Three-pronged approach to reducing energy for Verizon's portfolio of central offices.

5.2 Building Energy Efficiency Upgrades

Building upgrades are often the first port of call to reduce your energy spend. Making incremental building improvements such as improving the thermal resistance of walls or windows by introducing additional insulation or increasing glazing respectively, can be difficult to identify the needs for and also costly and intrusive to install. Fortunately, new technologies in the past 20 years have enabled smart buildings with sophisticated controllers than can save significantly on energy costs at a lower install price.[2][16] A non-exhaustive list of commonly recommended building upgrades can be seen below, although does not represent all possible building upgrades by any means:

- Wall and window insulation improvements. As mentioned above these involve improving the thermal resistance of these shell layers by adding insulation in the cavity of a wall or external spray on insulation for walls, and adding additional layers of glazing for windows. Most newer buildings would not need these types of upgrades, but many of the buildings that are home to COs are up to 100 years old. In these instances replacing the windows or walls of a high-rise building can be cost-prohibitive.

- LED light bulbs have become the norm in many office buildings, significantly reducing energy costs for lighting compared to their incandescent or fluorescent predecessors. These have a low installation cost, and the price per unit is low compared to other upgrades. These lightbulbs use 20% of the energy of their alternatives and can last up to 25 years.[30]

- Building Management System (BMS).Similarly, low intrusive options can be to upgrade the BMS which gives a building owner more control of the building operating functions. This BMS can be used to control a heating and cooling system based on time of day or occupancy of rooms or control lighting of a segment of the building based on occupancy or time.

- Controllable louvered ducting. By installing automated louvers as part of your heating and cooling ducting network you can control the temperature of a given room or space from a single heating or cooling source without unnecessarily overheating or over-cooling a space that does not need it. This reduces the load on the heating systems and improves the comfort-ability of the space for its occupants. This system would be controlled by the upgraded BMS.

- Upgrade heating and cooling systems. Many of the older buildings in the portfolio being studied had archaic fuel oil boilers still in use. These give way to opportunities for upgrades in the plant room to gas boilers, chillers, economizers, or even heat pumps.[18] Even if the HVAC system is not an old fuel oil boiler, it can still make sense to upgrade through the different options listed to improve energy efficiency. Costs for these will vary based on the HVAC layout of a building.

- Variable Frequency Drives (VFD)'s are electronic modules that control the speed of a motor. These have been a widespread update in building plant rooms globally as they have the ability to throttle the operations of a HVAC system to partial load instead of the previous binary on/off options. This means at times of partial load, you do not need to operate your HVAC system at full capacity, and can instead match supply to demand most efficiently.[19]

Each of the upgrades listed above along with scores more were available in this project's optimization model as potential upgrades to a building to save energy. Each of these upgrade opportunities for each building was sourced from energy audits performed by external contractors for Verizon.

While no silver bullet is available in energy efficiency upgrades in buildings, layering together the most cost-effective upgrades can have a significant impact on overall emissions.

5.3 Network Equipment Energy Reduction

The next section of energy reduction opportunities falls in the category of reducing energy consumption within a building. If a building cannot perform building upgrades and is instead limited to adjusting the energy performance of its operations to reduce energy, it must look at the individual contributors that consume the most kWhs of energy within the building and investigate what can be done to reduce this energy. For Verizon COs, the primary consumer of energy from equipment the Central Office needs is from copper-based telecom switches that handle the vast network of DSL lines going to most VZT customers in NYC. At the most granular, customer-scale, level these lines were historically controlled using Time-Division Multiplexing (TDM) switches. Each of these switches handles the traffic of $<$200 individual customers and is the size of a large kitchen refrigerator (in kitchen terms). We visited a local Central Office and saw the scale of these systems and the space needed to house them, where entire floors of large buildings are taken up with rows upon rows of these large units (see Figure 5-2).

These TDMs are severely outdated (many were installed in the 1960s and 1970s), but while still functional, almost all COs still rely heavily on them, due largely to the fact that end customers being served by that CO still have a DSL line and the cost included in upgrading the in-CO unit to a fiber-based multiplexer is not seen

Figure 5-2: Picture taken showing floor of central office filled with rows of legacy TDM switches which still handle much of the copper network traffic.

as cost-effective. More modern fiber-based multiplexers use a fraction of the energy as the copper-based TDM switches (<1%) and also are a fraction of the size (about the size of a microwave if we stick to kitchen terms). Each individual fiber-based switch can maintain communications for 768 customers DSL customers. A picture of a Tellabs T1000 fiber-based multiplexer can be seen in 5-3, taken at a Central Office local to MIT.

5.3.1 Network Transformation

In 2012, Hurricane Sandy hit New York City to devastating effect leaving 800,000 people without power, and 2 million people without telecommunication services.[1] About 25,000 buildings experienced flooding to depths that likely impacted telecom equipment.[2] These people lost telecom services because of significant and historic flooding permanently damaging many of the copper telecom lines buried under NYC

[1] https://www.nyc.gov/site/sirr/about/what-happened-during-sandy-and-why.page

[2] I worked in the real estate industry in NYC during the time that Sandy hit. I stepped outside of my role as an energy performance analyst and spend the entirety of the time frame around Sandy laying sandbags and managing pumps in the portfolio of buildings owned by the company I worked for.

Figure 5-3: Picture taken showing individual T1000 fiber-based switch which can handle similar traffic as TDM switches, using a fraction of space and energy.

and managed by Verizon.

It was in the aftermath of Sandy that Verizon created its Network Transformation (NT) team, tasked with converting the inherited copper-based telecommunications network to fiber in order to future-proof its infrastructure from such natural disasters and to provide more reliable service to its customers.

The NT team is split into two teams, inside-plant, and outside-plant. The outside-plant team is tasked with replacing buried and overhead copper cables and providing landline service to customers with fiber lines. This is incredibly time- and cost-intensive work which can be held up by permitting and landlords not wanting to have their operations impacted during the work to upgrade. This work also gets pushback from customers that do not want to convert their home phone to a voice-over-IP system, and emergency services who do not want to risk changing over the emergency lines in case there are any outages in communications in the process. This outside-plant work has spillover effects on the strategy outlined in 5.4.

The inside-plant team is responsible for getting the internal equipment ready for when all of the outside-plant work is complete and the customers are ready to switch to fiber-based phone lines. One of the main roles of the inside-plant team is to allocate personnel and budget resources to specific COs that seem to be nearing full fiber adoption on the outside-plant side. The threshold that the NT team uses to trigger when to migrate a CO to fiber is when the number of copper customers reaches 768 or below. The reason for this specific number is that this is the number of customers serviceable from a single T1000 or similar fiber multiplexer. These multiplexers are needed to handle end-user copper lines, convert them to fiber for multiplexing and transmission, and then either back to copper or remain as fiber packets depending on who the customer is in communication with. As these units are only necessary for the transitional period while some but not all customers are on copper, the NT team does not want to install more than one per CO as the cost of installing more may not be redeemed in savings in the time it takes for those marginal customers >768 to switch to fiber. Why this is so important for Verizon is that a single T1000 unit requires <1% of the energy to power it compared to TDM switches and would free up huge amounts of physical and HVAC capacity by being smaller units that do not run as hot.

5.4 Central Office Consolidation

As has been discussed at length already, if Verizon could design a telecommunications network from scratch in New York City, it would look nothing like what they are currently responsible for managing. The vast nature of its nearly 70 owned Central Office (CO)s operational in the city became what it is due to requirements for more buildings to handle the explosion of bandwidth demand over the last 40 years before the fiber technology was mature enough to offload the pressure from the copper network. This meant that, as fiber line transmission and switching became available it was layered on top of Verizon's existing copper web of COs. This has led to a large fiber network that is unnecessarily complex, housing primarily equipment instead of people, operating in one of the most expensive real estate cities in the world.

This paradox of a network is what led our study to investigate opportunities to consolidate CO operations in NYC. Initially, we looked at the leased CO buildings that

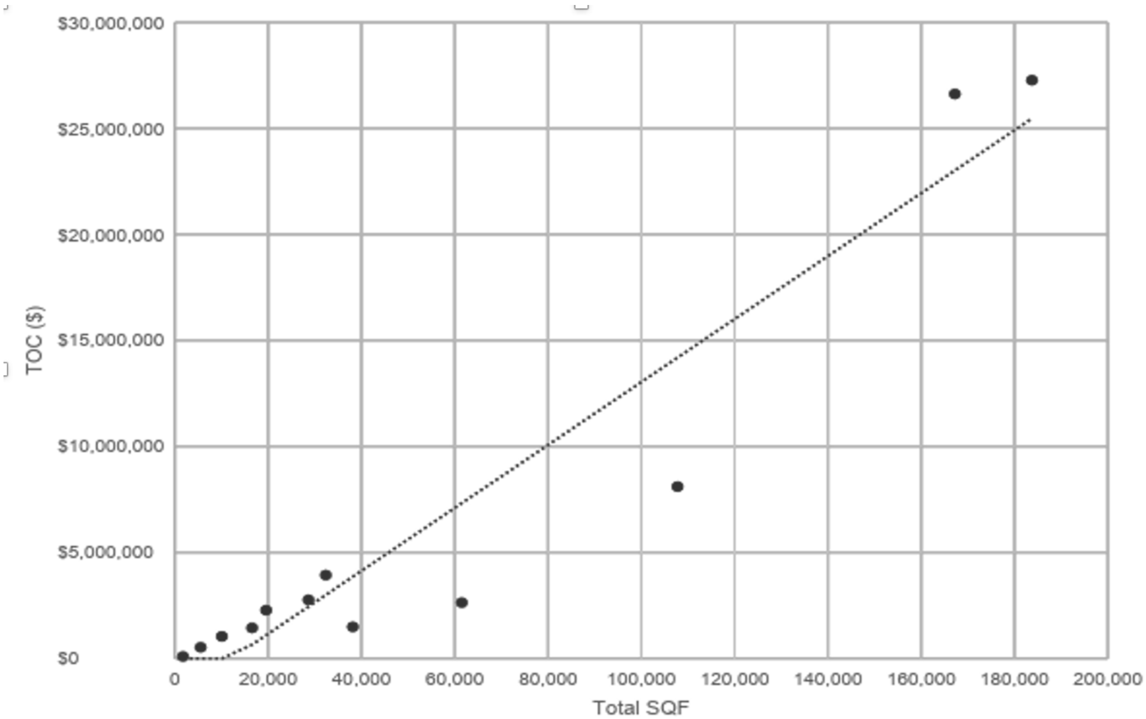


Figure 5-4: Scatter plot showing the total occupancy cost (TOC) in USD for Verizon's leased Central Offices in NYC as a function of square footage. Each of these buildings is part of Verizon's VZW network.

are primarily on the VZB network, as the value proposition of not paying exorbitant NYC rent for a CO would likely make the Return on Investment (ROI) of consolidating operations more favorable, given Verizon would not have to pay rent any longer. We collected the data shown in Figure 5-4 to see what types of cost savings could be proposed based on a building's Total Operating Cost (TOC). TOC encompasses all expenses associated with operating in that building (e.g. rent, utility bills, maintenance, etc.). While a pair of anomalous buildings stand out with incredibly high annual TOCs, the majority have TOCs below $5 million per year which would make positive ROI in any realistic timeframe.

In a similar vein to looking at TOCs of leased buildings, we performed an investigation of Verizon's owned COs in NYC 5-5 to identify the scale of potential cost-saving opportunities. While the maximum TOCs for the owned buildings are not as high as those of leased buildings, they are still incredibly high. This is likely due to property taxes taking the place of rent. Importantly for this project, it is these owned buildings

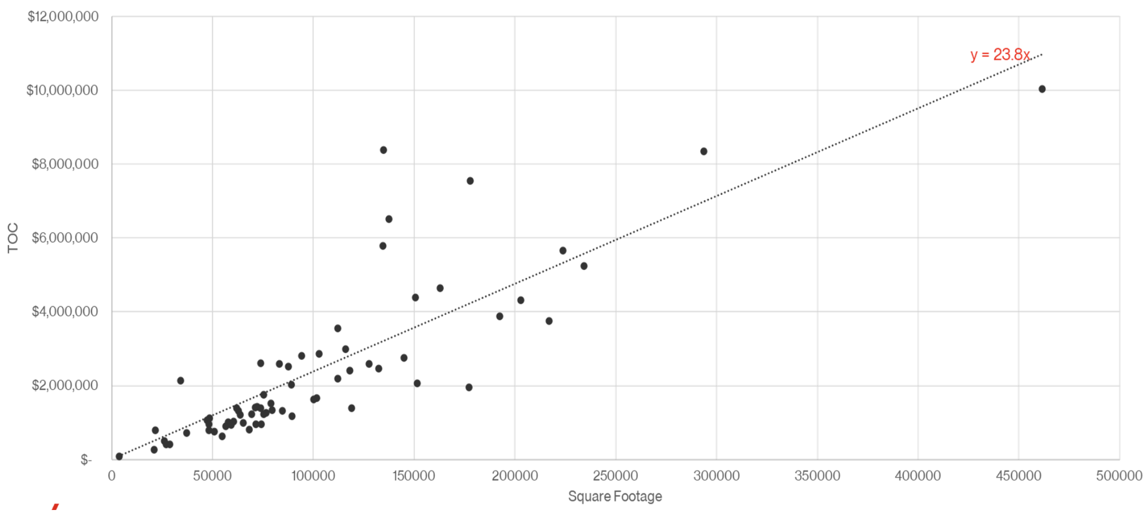


Figure 5-5: Scatter plot showing the total occupancy cost (TOC) in USD for Verizon's owned Central Offices in NYC as a function of square footage. Each of these buildings is part of Verizon's VZT network.

that would incur LL97 fines for Verizon, and so savings would be amplified even more than what is shown, which is historical data not including any future carbon taxes. Another important point is that there are additional opportunity costs embedded in consolidations such as actually selling the building, or leasing it to someone else, once the CO portion of operations has been migrated elsewhere.

It must be stressed that while this consolidation of COs may be a scenario for an ideal world, the reality is that this would be incredibly time- and cost-intensive work. While reliant on the NT team and its outside plant work for re-routing of fiber cables 3-2, it also requires a new team to replicate the internal system architecture of the CO that is being closed in the CO that those customers will now be serviced from. This effort, while certainly possible, should not be undertaken without a full understanding of the complexity of replicating network infrastructure that has slowly been growing over the previous several decades (Figure 5-6 is a picture taken at a CO local to MIT).

Additionally, the CO to which Verizon would be consolidating another CO into would need space, structural, power, and HVAC capacity for managing the network for thousands of more customers. Ideally, this type of effort would work in tandem with that outlined in Section 5.3.1 as converting internal equipment to fiber-based equipment frees up space, power, structural, and HVAC capacity. Even with each of

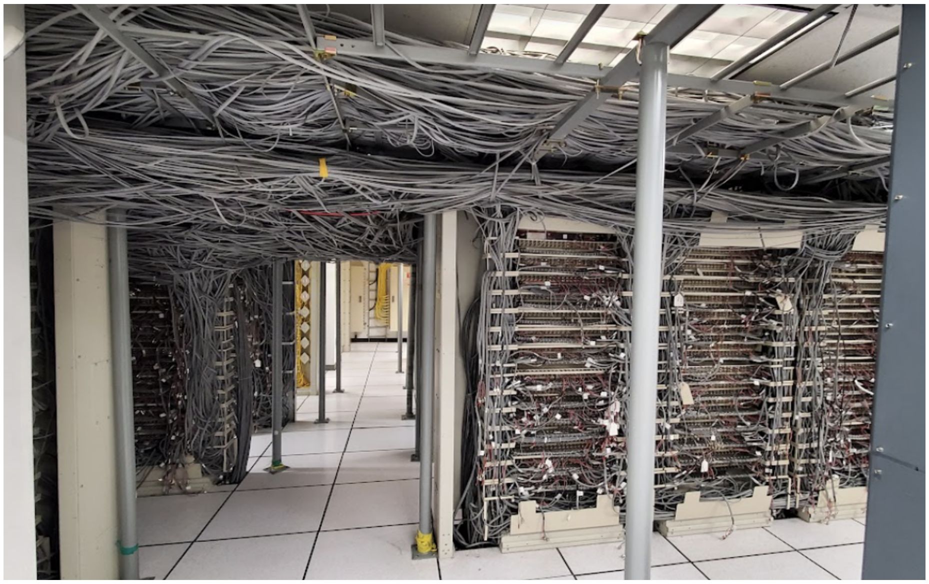


Figure 5-6: Picture taken showing extensive wiring in place across a floor of central office.

these capacities available, the floorplan or layout of a building might mean significant costs to accommodate this new equipment.

It is only when this new equipment is fully functional that any consolidation efforts can begin. This means it could be 5-10 years before any benefit of deciding to consolidate COs would be recognized, meaning that any financial gains from such decisions would need to be substantial to get approval from a publicly traded company.

Due to the less prescriptive output possible with such consolidation proposals, this internship did not look to incorporate consolidation into an optimization model. It instead aimed to gauge high-level costs of consolidation and compare with potential savings for such efforts to present to leadership.

Chapter 6

Data

For a project of this nature, the optimization model, and subsequently the results, are only as good as the quality of the data that is used to build the model. Fortunately, Verizon has significant amounts of data available, but the issue throughout the early parts of the project was finding useful data and getting the data into a usable format.

6.1 Data Available

6.1.1 Energy Audit Data

For 57 of the 68 owned CO buildings in NYC, Verizon contracted energy auditors to comprise reports on all possible building upgrades that each CO could implement to save energy. Along with the proposed upgrade, they highlighted the estimated cost of such an upgrade, the estimated reduction in CO2 emissions from that upgrade, and the utility bill line item that the upgrade would have an impact on. Each of these reports was collated into a shared spreadsheet. While attempts to standardize the spreadsheet were made, and improved throughout the project, it was quite difficult to work with as a live document with human input data. The data was the foundation of the optimization model as it was home to all of the decision variables that would later be implemented. This data showed what upgrades were possible to implement, the model would show what upgrades should be implemented.

6.1.2 Utility Bill Data

We had access to utility bill information for all of Verizon's buildings nationally from a central server which was accessed using EXASOL. The primary use for this information was to identify all utilities that were used in a single building and track the consumption of each on a monthly, and annual basis. This data was ultimately used to calculate carbon tax amount, as the same Greenhouse Gas Emissions (GHG) emission factors that were used in 4.1 were applied to calculate a baseline emission level for each building that could be reduced with upgrades.

6.1.3 Network Transformation

The NT team maintained a shared spreadsheet which contained the status of the inside plant work of each CO in the network. This showed which COs had already updated their TDM switches to fiber multiplexers, and the cost and energy savings from doing so. It also identified the COs which had not yet migrated to fiber-based switches but were in the near-term pipeline for migration so active work was taking place to install multiplexers. This left all remaining COs with no immediate plans for migration along with their copper customer count. This data would essentially be added to the building upgrade list as a possible upgrade that a building could undertake.

6.1.4 Customer Count

For each Central Office, we had access to a central repository of the quantity and type of customer being serviced from that CO. This data was in CSV format and enabled me to see how many customers a single CO served, and how many of those were copper customers.

6.1.5 Total Occupancy Costs

The breakdown of TOCs for each CO was listed in a spreadsheet for each CO in NYC on both the VZT and VZB networks. This data was used in calculating opportunities in consolidation.

6.1.6 Local Law 97

Of course, a large component of the optimization model contained data from New York's LL97 law which included fine level, emission thresholds, and GHG coefficients along a time frame up to 2050. This data was taken from the primary LL97 document and inputted directly into the optimization code.

6.2 Building Upgrade Opportunity Gaps

As highlighted in Section 6.1.1, only 57 of the 68 COs in NYC had energy audit data available. Due to this, any model built would only be able to make recommendations for 84% of the NYC portfolio, inferring that 16% of the energy and cost savings could not be realized due to lack of data. Based on this an attempt was made to develop a machine learning model that could extrapolate from the known data, what upgrades could be possible for buildings that we had no information about.

The two machine learning models considered for this were:

- logistic regression
- random forest

These models were considered as they suited the problem type, where for each possible upgrade type we wanted a binary output of whether or not that upgrade type was a likely opportunity for the building under consideration. Every upgrade in our energy audit dataset could be considered, each of which had varying levels of impact on emissions. One way of comparing the different job types was by the ratio of the cost of the upgrade to the emissions abated because of that upgrade. This data can be seen in Figure 6-1, where the bar represents the average cost of jobs in that upgrade category and the range line extend to the maximum and minimum costs for jobs in that category. From this chart, we can see that replacing steam/cooling valves is a

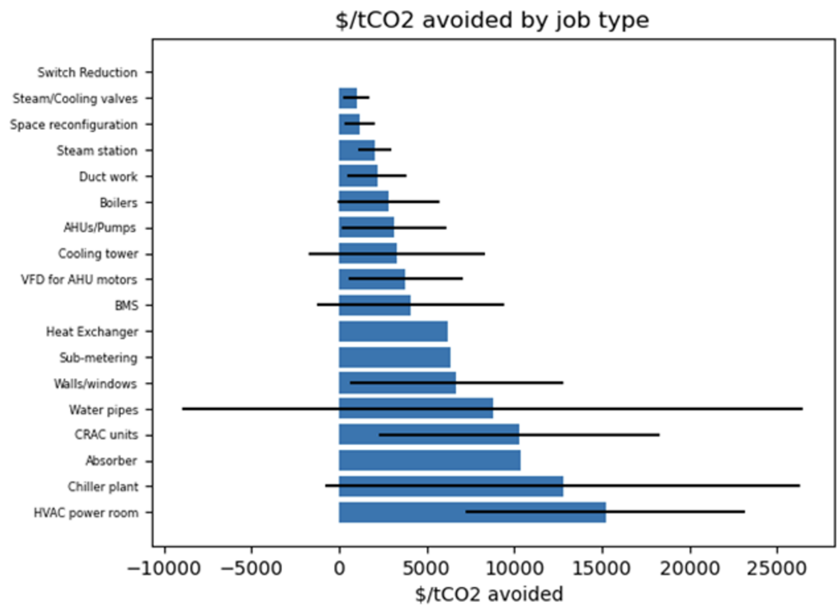


Figure 6-1: The average cost of an upgrade per annual tons of CO2 abated by that upgrade for each upgrade category, including range bars showing max and min values.

very cost-effective means of reducing emissions, whereas upgrading your HVAC power room is so expensive that it likely rules this type of upgrade out as the ROI for such an upgrade is negative in a realistic timeframe.

This graph was the incentive for trying to find low-cost emissions reduction opportunities in the buildings where we did not have any audit data. If we could accurately predict if a low-cost upgrade is possible in a building we could increase the emissions saved from the model. The input data that was used to build the model are listed below:

- Model inputs:
  - Site ID
  - Total building floor area
  - Number of customers being served
  - Annual tCO2 emitted (2018 - 2022)
  - Annual Heating Degree Days in NYC (2018 - 2022)
  - Annual Cooling Degree Days in NYC (2018 - 2022)

- Types of utilities used
- Number of maintenance alarms in the building

- Model output:
  - Binary decision variable on whether or not a category of upgrade could be done.

The intention is that the model would try to find comparable data from building metadata and energy consumption and use that to decide whether a certain building upgrade is possible or not. The point of this model would be to fill out the audit data for the entire portfolio rather than recommend carrying out that upgrade (that is what the optimization model is for). In order to figure out model accuracy we split the available data into a train and test split at an 80/20 ratio, which meant the training set was 46 buildings, and the test set 11 buildings. Intuitively this felt like far too small a dataset to get any meaningful or trustworthy results.

6.2.1 Results

Accuracies for a subset of building upgrade categories can be seen in Table 6.1. At first glance, these results look promising, with the majority of categories having accuracies greater than 80%. When diving further into the individual results it became apparent that an 80% prediction accuracy was misleading as what the model did was predict that either all or none of the buildings in the test set have that building upgrade possible. Essentially did not decipher one building from the other. This is due to the incredibly small dataset size. Ideally, this type of model would have thousands of buildings' worth of data. Based on these results, intuition was confirmed, and we continued building the optimization using the incomplete dataset.

6.3 Data Structuring

The optimization model for the project is developed using the Gurobi Optimization platform through the python environment. As all of the data sources for this project

	LR Train Accuracy	LR Test Accuracy	RF Train Accuracy	RF Test Accuracy
HVAC	**0.88**	**0.87**	**0.91**	**0.82**
Controls	**0.64**	**0.57**	**0.8**	**0.53**
Electrical	**0.97**	**0.95**	**0.97**	**0.95**
Steam	**0.91**	**0.92**	**0.91**	**0.93**
RCx	**0.89**	**0.87**	**0.95**	**0.85**

Table 6.1: Train and Test Accuracy Results from Logistic Regression (LR) and Random Forest (RF) models for five different categories of potential upgrades.

are in various different data formats, we collated all data into a single python dictionary for ease of access and programming. The below nest shows how the dictionary was organized:

- Site ID
  - Building metadata
  - Energy audit data
    - Building upgrade type
  - Utility type
    - Utility
      - Local Law 97 metadata
      - Consumption and emissions data

Chapter 7

Optimization Model

The purpose of this entire project, and the request from Verizon as the industry sponsor, was to develop and optimize a model that would output a list of building upgrades that should be undertaken to minimize the effect of the incoming LL97 carbon tax in NYC. The goal is that this model could be then extended to make recommendations nationwide as similar legislation comes into effect elsewhere across the country as discussed in Section 4. An additional benefit of this model for the sponsor is that it could be used as a project management planning tool. From early stakeholder meetings with the team responsible for project managing the physical work that is being carried out in each building, an area of inefficiency is that they do not have visibility of what building upgrade projects in what buildings are in the pipeline. This has led to resourcing constraints becoming a bottleneck when multiple projects are carried out at a building in a given year at different times when instead they could have been carried out either in parallel or one after the other which would have minimized permitting requirements, and setup and teardown times. This optimization model is a mixed integer linear program (MIP) built using Gurobi Optimization platform. The reason that it is a mixed integer linear program is that it considers both integer and continuous variables for both its decision variables and objective function.

7.1 Decision Variables

Verizon has a portfolio of central office buildings as outlined in Section 3, and each of these buildings has its own compliance targets as described in Section 4. For each building, there is a unique list of potential upgrades that can take place as outlined in Section 5. This information gives us a two-dimensional binary decision variable, where for any building in the portfolio we can decide whether or not to carry out an energy upgrade project. We must also, however, take into account the timeline of when a project may be carried out. This is because Verizon's budget is not unlimited and there is a constraint on what can be spent in a given calendar year. The visual representation of what this decision matrix looks like can be seen in Figure 7-1.

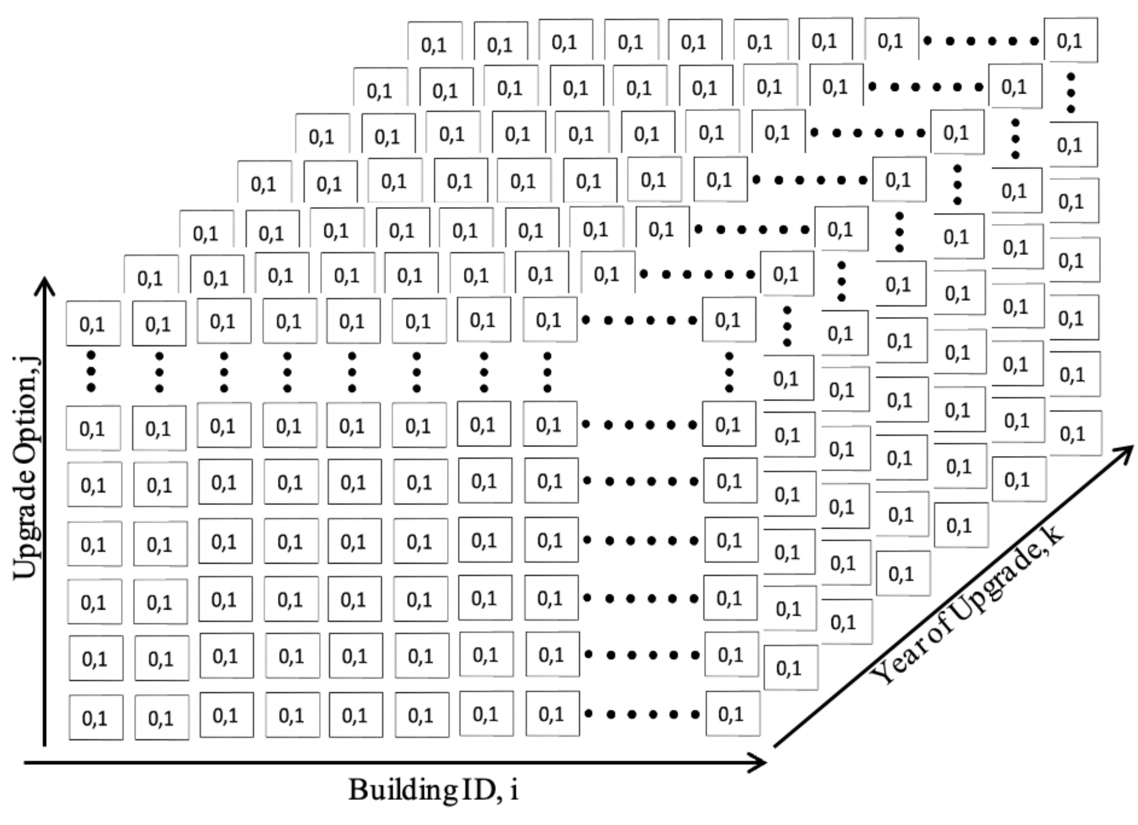


Figure 7-1: Representation of 3-dimensional binary decision matrix that is the primary decision variable for the optimization model. for each building i, for each year y, the model determines whether or not to recommend carrying out upgrade j.

Each of the options is related in some way; building out what inputs were required for each was the next logical step.

7.2 Objective Function

The next step in building the optimization model was to consider what the objective function should be. Verizon is looking to manage and optimize the company's capital project expenditure for building upgrades in New York City given the introduction of the city's incoming Local Law 97 environmental compliance laws. Eventually, this model is intended to expand nationwide as environmental compliance laws come into effect across the country (Section 4). Deciding what objective function to use is critical and played a part in how this project gained political support in the company. Several objective functions were considered and are listed below:

1. Minimize spend: This intuitively does not work for the objective function as the solution is to not undertake any projects at all as this would involve some cost. This solution does not lead to any CO2 reduction from the NYC building portfolio.

$$minimize \sum_{k=k_0}^{k_n} \sum_{i=i_0}^{i_m} \sum_{j=j_0}^{j_{lk}} CAPEX_{ijk} * X_{ijk} \tag{7.1}$$

where: $CAPEX$ = The amount it costs to implement energy efficiency upgrade j in building i in year k. Data given by energy audit

m = number of years to capture in analysis

n = number of buildings being considered in model

lk = the total number of building upgrades possible for building k; this number varies by building

X = Binary decision variable on whether upgrade j should be carried out in building i in year k

2. Minimize gross emissions: This objective function works well for the model but we must consider whether it is the best recommendation to the Verizon energy

team on how to spend their budget most effectively. This option will recommend energy efficiency projects that do not have a reasonable payback period. For example, it may recommend carrying out an efficiency upgrade with a high cost per ton of CO2 abated, which may not pay back for 30+ years. In this sense, it may make more sense to wait and see what new technologies develop in the coming years that may offer a better payback.

$$minimize \sum_{k=y_0}^{y_n} \sum_{i=i_0}^{i_m} tCO2_{ik} \tag{7.2}$$

where: $tCO2$ = Tons of CO2 emitted from building i's operations in year k

m = number of years to capture in analysis

n = number of buildings being considered in the model

and,

$$tCO2_{ik} = tCO2_{i_{k-1}} - \sum_{j=j_0}^{j_{lk}} tCO2red_{ij} * X_{ijk} \tag{7.3}$$

where: $tCO2red$ = CO2 reduction from upgrade j in building i

3. Minimize LL97 tax amount: This objective function is similar to that mentioned above for minimizing gross emissions but it differs in the sense that a building will not incur a tax if it meets compliance limits of tCO2/sqft. As such, this may give a more realistic result as the model will only aim to get buildings as close to compliance as possible, and not try to drive emissions to zero at all costs.

$$minimize \sum_{k=y_0}^{y_n} \sum_{i=i_0}^{i_m} Tax_{ik} \tag{7.4}$$

where: Tax = LL97 carbon tax amount owed for building i in year k

m = number of years to capture in analysis

n = number of buildings being considered in the model and,

$$Tax_{ik} = (tCO2_{ik} - tCO2lim_{ik}) * 268 * XC_{ik} \tag{7.5}$$

where: $tCO2lim$ = LL97 emissions limit

268 = LL97 fine per ton of CO2 in excess of limit

XC = Binary decision variable on whether the tax for building i in year k should be counted. This decision variable is to avoid negative tax values in instances where the actual emissions of a building are less than the LL97 emissions limit.

4. Minimize total energy spend: This objective function was the best holistic candidate for gaining internal support at Verizon as it focused on dollars and cents rather than sustainability measures which not all teams have as their top priority. This objective function takes into account utility rates for different fuels and energy sources and their usage, as well as capital expenditures for efficiency upgrades, and LL97 tax spending.

$$minimize \sum_{k=y_0}^{y_n} \sum_{i=i_0}^{i_m} TEC_{ik} \tag{7.6}$$

where: TEC = Total Energy Cost for building i in year k

m = number of years to capture in analysis

n = number of buildings being considered in the model

and,

$$TEC = Tax + CAPEX + \sum_{P=P_0}^{P_{ul}} UC_p * UR_p \tag{7.7}$$

where: P = Utility type (e.g. Gas, Electric, Fuel Oil, etc.)

UC = Utility consumption (e.g., kWh, Btu, etc.)

UR = Utility rate in USD

and,

$$UC_{ik} = UC_{ik-1} - \sum_{j=j_0}^{j_{lk}} \frac{tCO2red_{ijk}}{GHGcoef}_{pk} * X_{ijk} \tag{7.8}$$

where: $GHGcoef$ = Greenhouse gas coefficients for each energy source by year (see Figure 4.1

By defining what each of the potential objective functions is, we can also see how all the variables in the model are calculated as was seen in the above equations. The next stage of building out the model is to define what the constraints need to be.

7.3 Constraints

By beginning with our primary decision variables of whether or not a specific upgrade should be undertaken or not, we know that a given upgrade cannot be carried out more than once in a given building throughout the time span that model looks at.

$$\sum_{k=k_0}^{k_n} \sum_{i=i_0}^{i_m} \sum_{j=j_0}^{j_{lk}} X_{ijk} <= 0 \tag{7.9}$$

The next constraint we determined was an annual budget. As mentioned already, one of the primary uses for this optimization model is for a project management planning tool. Along these lines, the real estate and energy teams at Verizon have a set budget each year for energy efficiency upgrades in buildings that they cannot exceed. In our optimization model, we coded that as follows:

$$\sum_{k=k_0}^{k_n} \sum_{i=i_0}^{i_m} \sum_{j=j_0}^{j_{lk}} CAPEX_{ijk} <= B_k \tag{7.10}$$

where: B = Annual capital budget for energy upgrade projects in NYC

Following this, we need to examine the emissions coming from a building. The model does not know that it is not possible to remove CO2 from the air from these building upgrades. If enough projects at a given building are completed the sum of the reductions may exceed the actual total emissions, making the building appear to be a net remover of GHG emissions from the environment which we know not to be the case as we are not suggesting carbon capture equipment (yet). As such we must include the below constraint in our model.

$$tCO2_{ik} >= 0 \tag{7.11}$$

We encountered a problem with the carbon tax in the early runs of the optimization model in that LL97 was actually paying Verizon reverse tax funds according to the model when a building's emissions were below the law's emissions limit. This was countered by introducing the XC binary decision variable, whereby a tax was only counted if it was greater than zero. This was implemented by using the Big M method [6] as can be seen below:

$$tCO2_{ik} >= tCO2lim_{ik} - (M * (1 - XC_{ik})) \tag{7.12}$$

$$tCO2_{ik} <= tCO2lim_{ik} + (M * XC_{ik}) \tag{7.13}$$

The alternative to this binary decision variable would be to set a constraint where the tax had to be greater than or equal to zero, but the problem with that is then it would constrain the model such that any project that would drop a building's emissions below a certain the emissions limit could not be completed, significantly changing the output of the result.

Once each of these constraints had been set, the next step was to run the optimization model and start examining the results.

7.4 Full Optimization Model

For simplicity and ease of access, this section will present the optimization model equations in one location. For a detailed description of equations and variables please refer to sections 7.1, 7.2, and 7.3.

7.4.1 Decision Variables

$$X_{ijk} \tag{7.14}$$

where: X = Binary decision variable on whether upgrade j should be carried out in building i in year k

7.4.2 Objective Function

$$minimize \sum_{k=y_0}^{y_n} \sum_{i=i_0}^{i_m} TEC_{ik} \tag{7.15}$$

where: TEC = Total Energy Cost for building i in year k

m = number of years to capture in analysis

n = number of buildings being considered in the model

7.4.3 Constraints

$$\sum_{k=k_0}^{k_n} \sum_{i=i_0}^{i_m} \sum_{j=j_0}^{j_{lk}} X_{ijk} <= 0 \tag{7.16}$$

$$\sum_{k=k_0}^{k_n} \sum_{i=i_0}^{i_m} \sum_{j=j_0}^{j_{lk}} CAPEX_{ijk} <= B_k \tag{7.17}$$

where: B = Annual capital budget for energy upgrade projects in NYC

$$tCO2_{ik} >= 0 \tag{7.18}$$

$$tCO2_{ik} >= tCO2lim_{ik} - (M * (1 - XC_{ik})) \tag{7.19}$$

$$tCO2_{ik} <= tCO2lim_{ik} + (M * XC_{ik}) \tag{7.20}$$

7.5 Limitations of Optimization Model

The goal for the optimization model was to make it usable by Verizon, and standardized so that it could be expanded to include different locations beyond the baseline city of NYC. With these two considerations in mind, the model can be improved to offer more optimal results for Verizon to improve the incoming data to the model and identify and quantify opportunities to bundle projects in given locations to reduce operational costs.

On the first point, the model is only as accurate as the data it is being built with. As outlined in Chapter 8.1.2, several assumptions are made using the incoming data to generate our results. The model would be more robust if it included feedback of new information, such as embedding an accuracy scalar on the energy audit savings prediction as they are realized.

To the second point, several building upgrades are possible for each CO with different costs and savings associated. The model treats each upgrade independently regardless of whether or not upgrades are collocated. Ideally, the model would include operational cost savings created by undertaking two collocated upgrades simultaneously versus at different times. For example, if the model recommends two upgrades in a given building but in consecutive years, the operational and administrative cost savings associated with scheduling these upgrades simultaneously, might be enough for the model to recommend the upgrades to be carried out in the same year.

Chapter 8

Results

There are five main stages of results from this project that we will detail in this chapter. Firstly, we examine the output of a baseline optimization model using only the information available from the building energy audits Verizon conducted in its NYC Central Offices (Section 8.2). This sections highlights a **12% reduction in energy costs** and a **14% reduction in emissions** through use of this optimization model.

We will then move on to the second stage of results, examining the effect of bundling network transformation inside-plant work with building upgrades in the optimization model (Section 8.3). This sections highlights a **14% reduction in energy costs** and a **18% reduction in emissions** through use of this optimization model.

Thirdly, our final piece of results from this optimization model is to examine the price of carbon set by the city of New York (Section 8.4). Is this the best price to reduce the most amount of emissions? Is this the best price holistically from a sustainability standpoint? In this section, we find the energy gap of Verizon's operations where a **24% reduction in energy costs** and a **17% reduction in emissions** would be possible and recommended with no carbon tax introduction.

The fourth batch of results is from an investigation into the most sustainable way to achieve net zero (Sections 8.5 & 8.6). This looks at how scalable the building upgrades are nationally, and how much of a dent they would put into the company's total scope 1 & 2 emissions. This section also looks at alternative solutions to meet Verizon's net-zero goals that have a reduction in emissions, to complement both building upgrades and the existing method of financing VPPAs. This section finds that if Verizon's sustainability budget was restructured and distributed to a variety of emissions reductions projects, **a 60% reduction in emissions is possible** for the **same cost per ton of CO2** that Verizon is currently spending.

Our final set of results will highlight the financial and sustainability opportunities available from the consolidation of COs in high population density metropolitan areas (Section 8.7). These opportunities sum to **billions of dollars of savings** for Verizon, albeit with significant challenges in implementation.

The project produced significant amounts of results as can be seen throughout this section. That said, these can be condensed to the below major takeaways and recommendations:

- Creating a prescriptive optimization model to recommend building upgrades can not only reduce emissions but can significantly reduce energy expenditure, up to 24%.

- Alternatives to renewable energy credits can be utilized by companies to achieve sustainability goals at the same price, while also reducing operational emissions by up to 60%. This should be the gold standard for sustainability and energy teams at organizations. These are sometimes considered to have high barriers to entry given the operational time and expense associated with building upgrades compared to financial instruments such as VPPAs.

- Analyzing the requirements of modern network architecture can point to significant opportunities in real estate consolidation which not only saves money, but also reduces emissions, and creates a more robust network overall. The barrier for entry to any type of consolidation project however is huge, as the projects would take many years to complete at great upfront cost.

Of these recommendations, we feel most confident in the results produced from the optimization model as it was produced using real data with relatively few assumptions. This model can continue to improve by building in a feedback loop of building energy audit accuracy into the input data.

Additional modeling is recommended in recommendations for optimizing sustainability budget spend as significant high-level assumptions were made around energy storage opportunities to reduce emissions.

8.1 Setting Variables and Assumptions

8.1.1 Variables

The model has two primary input variables that can be set, namely Annual Budget, and Optimization Timeframe. These variables were set as follows:

1. Annual Budget: Initial model used an annual budget of $10 Million for building upgrades for energy reduction projects. This number is somewhat arbitrary but is useful to highlight how, under financial constraints, the optimization model works. This also is a real feature to be used for project management planning.

2. Optimization Timeframe: The optimization models throughout this project used a timeline of 15 years. As outlined in Section 7.1, the optimization model sets binary decision variables in a three-dimensional decision matrix. While building ID and building upgrade type are fixed variables, the length of the third variable, duration of time, is not. This feature is critical as the model will be selecting projects to undertake that have a positive ROI within the timeframe given. By making this time window very small, very few projects would get selected and a small impact on emissions would be seen, whereas expanding this timeline to infinity would see all projects get completed as each would have a reduction in either annual utility cost or an annual carbon tax that would be greater than the single capital expenditure needed to undertake the upgrade. The 15-year timeline was selected, as this is the project duration of the renewable energy projects that are funded through Verizon's Green Bonds and VPPAs (see Section 3.3); by using similar timeframes it would be easier to compare and contrast impact of either investment from a business perspective as well as a sustainability perspective.

8.1.2 Assumptions

There are three major assumptions embedded into the optimization model, emissions penetration on the utility grid, and utility price forecasting.

1. Emissions from electricity: Importantly, the emissions that are shown on the output plots are using the GHG coefficients set by LL97 in 4.1. This shows a step decrease in the emissions from electricity in 2030, to take into account a cleaning grid in New York State as required by the state's Renewable Portfolio Standard (RPS) (Figure 3-6). This assumption is perhaps not correct as, in reality, the decrease in emissions on the grid will ramp down rather than step, although this rate of decrease is unknown, so for the purposes of this model we used the LL97 metrics and timelines throughout for both taxes and grid information.

2. The model assumes a constant unit price of utilities over time. Intuitively, we believed that this price would decrease over time with larger renewable energy penetration in the energy mix that has lower operating costs, however, this is not seen to be the case from literature [17]. This could be due to a lack of data from regions with renewable energy capacity above a critical mass to drive price in an open electricity market. If the marginal power source needed to set the price for electricity demand for a given day is not a renewable source, then the price of electricity is not driven by the low operating cost of renewables.[28] [21]. Seasonal variations in the price of utilities have been seen in historical utility bills from Verizon. Figure 8-1 shows the price per kWh Verizon has paid for electricity at its NYC COs since 2018. An average of this price over the past 2 years was taken as the unit price for analysis.

3. Lastly, a major assumption in this model is that the predicted costs and the emissions reductions in the energy audits are correct. Engineering estimates are known to overestimate savings from energy upgrade projects [13], but without usable data from comparable building types, this study assumed accuracy in

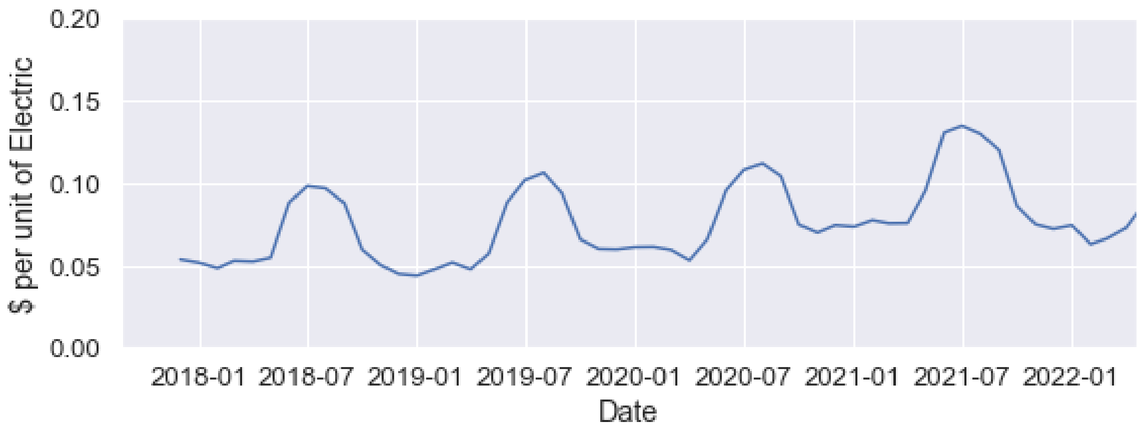


Figure 8-1: Time series representation of the unit price of electricity Verizon has paid at its NYC Central Offices since 2018.

the energy audit estimates. It has been found that in the case of residential buildings, energy audits can over-predict the actual savings by as much as three times the realized savings.

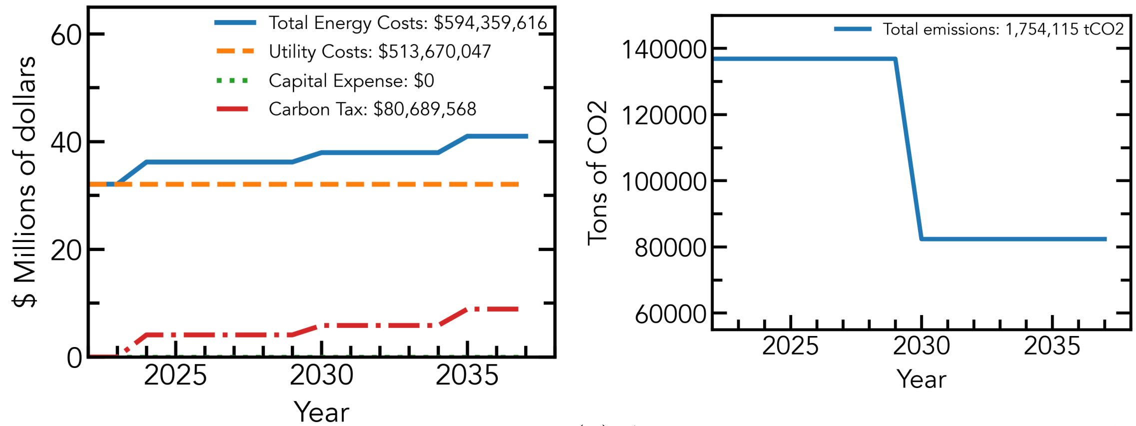
8.2 Baseline Optimization Model

The primary outputs of the optimization model are a list of upgrades by year and by building that is recommended, and two-time series plots, one showing a breakdown of Total Energy Cost (TEC) over the optimization timeline, and the other showing the emissions from the portfolio over the optimization timeline.

8.2.1 No Interference - Minimizing CAPEX

Beginning with the baseline model we ran the optimization model where we first wanted to see what the results would be with no interference - what would Verizon's Total Energy Cost (TEC) be if emissions remained constant from the portfolio of buildings using historical emissions data, while still operating under Local Law 97 legislation.

Figure 8-2 shows the no interference model results where an increase in TEC is seen over time, which is driven by the incremental increase in carbon taxes which is



(a) Annual Total Energy Cost of Verizon's NYC Central Office Portfolio to include utility expense, LL97 fines, and capital expense on efficiency upgrades.

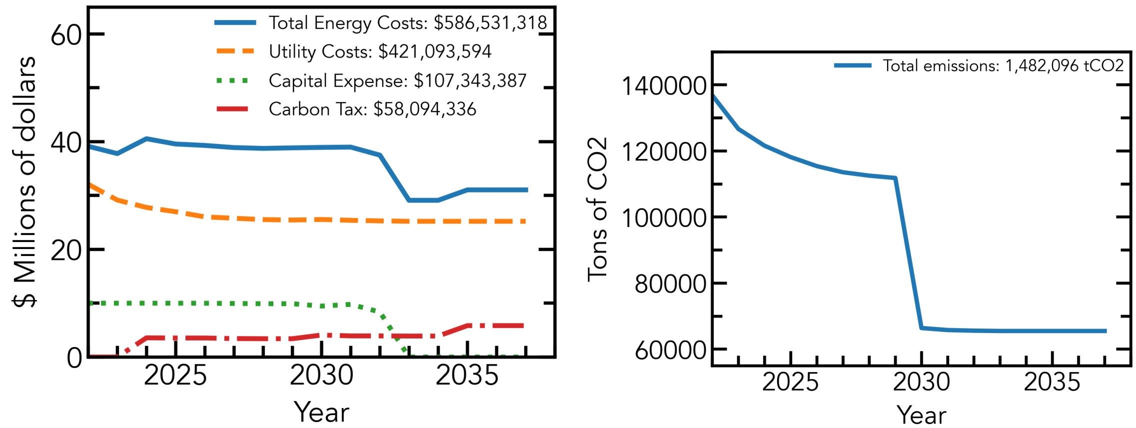
(b) Annual Total Emissions in tons of CO2 due to operations of Verizon's NYC Central Offices. Drop in 2030 due to LL97 guidelines for the predicted carbon intensity of electric grid.

Figure 8-2: Baseline optimization result where no building upgrades take place

caused by the step decreases in building emissions limits set by LL97. This is basically what the result is from a model using an optimization function outlined in equation 7.1.

8.2.2 Minimizing Emissions

If we instead set the optimization function to that outlined in equation 7.2 such that we are trying to minimize the total emissions amount summed over the entire optimization timespan we get the results seen in Figure 8-3. These results show the model recommends maxing out the annual budget for upgrades every year until there are no more projects left to complete. If we look at both the emissions reduction over time and the utility expense reduction over time we see that the effect of this high annual expenditure wanes as the more impactful upgrades are carried out earlier in the model, leaving only cost-inefficient projects in the pool of available projects near the end of the timeline.



(a) Annual Total Energy Cost of Verizon's NYC Central Office Portfolio.

(b) Annual Total Emissions due to operations of Verizon's NYC CO portfolio.

Figure 8-3: Optimization result where a $10 million annual budget is set for building upgrade projects, and the objective function is to minimize total emissions over the timeline.

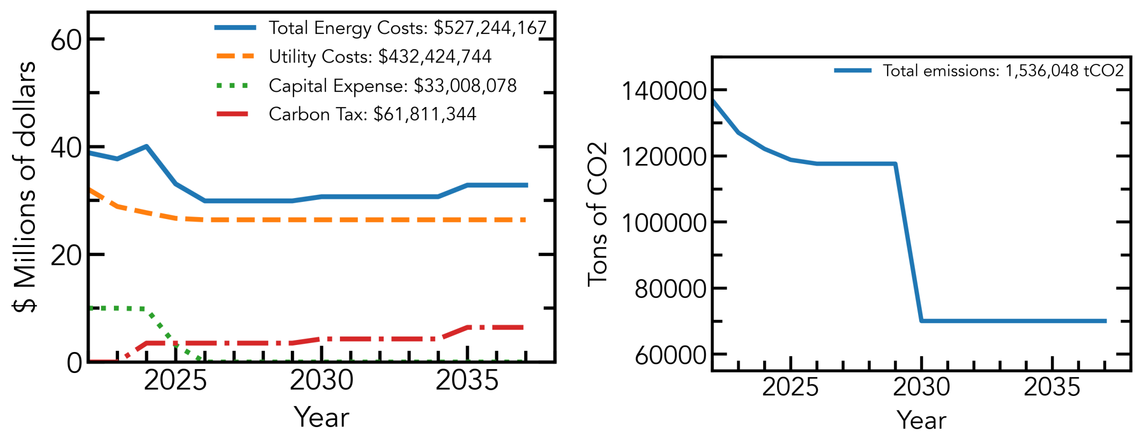
8.2.3 Minimizing Total Energy Cost

When we adjust the objective to be that of equation 7.15, we get the results shown in 8-4 which has similar characteristics to that of the minimizing emissions objective function case, but it reaches a point in the timeline where the benefit of carrying out any more upgrade projects no longer pays off in the 15-year timeline. In fact, this objective function recommends carrying out projects between years 1 - 4, as opposed to in the previous case recommending projects from years 1 - 11. This difference makes sense and is the exact type of output sought where the model presents what the best and marginal projects are to carry out.

8.2.4 Comparing Optimization Functions

When we look at each gross TEC and emissions values and calculate their percentage reduction on the baseline case, we get the results in 8.1. The major takeaway from this table is that there is an 8.7x increase % savings in TEC when optimizing for TEC vs. optimizing for emissions, compared to just a 1.23x increase in % reduction in emissions when optimizing for emissions vs. TEC.

When deciding on the best objective function to move forward with for the



(a) Annual Total Energy Cost of Verizon's NYC Central Office Portfolio.

(b) Annual Total Emissions due to operations of Verizon's NYC CO portfolio.

Figure 8-4: Optimization result where a $10 million annual budget is set for building upgrade projects, and the objective function is to minimize total energy cost.

Table 8.1: Comparative analysis of objective functions for both financial and emissions outcomes.

Objective Function	Gross TEC ($M)	% red. in TEC	Gross Emissions (MmtCO2)	% red. in Emissions
Minimize CAPEX	594.4	0%	1.754	0%
Minimize Emissions	586.8	1.3%	1.482	15.5%
Minimize TEC	527.2	11.3%	1.533	12.6%

model when making recommendations to Verizon, these results present that the most compelling objective function is to minimize Total Energy Cost. Ultimately for any set of projects that requires tens of millions of dollars worth of capital, it needs buy-in from business leaders at the company. Getting sustained support and buy-in from these stakeholders is much more likely if the proposed solution focuses on both the financial best interests of the company and the sustainability best interests of the company. For this reason, all optimization runs moving forward used an objective function of minimizing Total Energy Cost.

The output of this minimizing TEC scenario that could be delivered to a Real Estate project management planning team is shown in Figure 8-5 where for a given year, the planning team can see exactly what upgrade is being recommended, its price, and in what CO.

```
YEAR 2024
Budget:          $10,000,000
Proposed spend:  $9,999,600.8641
- CO ID: 18112 - Seal/close windows and doors.  Infiltration Reductions/limit stops: $12000.0
- CO ID: 18112 - Replace Carrier VFD: $25000.0
- CO ID: 18117 - Network Transformation: $722942.6640999999
- CO ID: 18194 - Expand/Upgrade BMS: $250000.0
- CO ID: 32130 - Damper verification: $7500.0
- CO ID: 32160 - Reduce battery room ventilation to match cell quantities rather than room area.: $75000.0
- CO ID: 32219 - Replace 6 CHW CRAC units on 3rd floor (2022): $75000.0
- CO ID: 32219 - Complete damper replacement/upgrade and automation with BMS (Round 1 of damper work, 2022
portion late invoicing): $72427.0
- CO ID: 32219 - ECM: replace old absorption chillers with new electrical chillers; new pumping and piping
systems; Cx, training: $7392991.2
- CO ID: 32219 - 2022 Lane Valente LED install work: $11740.0
- CO ID: 32219 - RCx: reduce min OA of 10 AHUs serving equipment space: $30000.0
- CO ID: 32384 - Revise Cooling Systems: $1325000.0
```

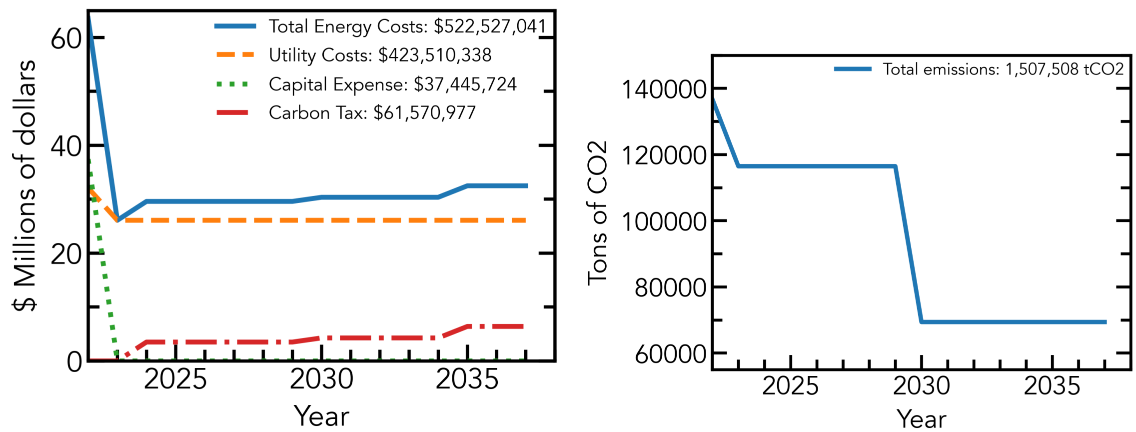
Figure 8-5: Representation of 3-dimensional binary decision matrix that is the primary decision variable for the optimization model. for each building i, for each year y, the model determines whether or not to recommend carrying out upgrade j.

8.2.5 Unconstrained Budget

Now that we have selected the objective function to move forward with, the next step of analysis is to examine the full savings opportunities of this optimization approach if budget constraints were not of concern. This method is less useful of a result for a project management planning team but becomes more helpful when comparing macro-level sustainability measures at Verizon, such as how best to allocate the billions of dollars of funds Verizon has committed to sustainability.

Figure 8-6 presents what total potential savings, both financially and environmentally, would be if unconstrained by budget, or if a budget in the region of $ 1 Billion was available similar to the Green Bonds initiative.

As we can see, all projects now take place in year 1, as expected, as the model wants to realize the cost and environmental savings for as long a duration as possible to optimize the results. Table 8.2 highlights the major takeaways in comparing the effect of a constrained budget on financials and emissions. Both results are comparable in their variation from constrained to unconstrained with both being more favorable without a constrained budget. Given this, this unconstrained budget model is what will be used to gauge the total benefit of the model going forward.



(a) Annual Total Energy Cost of Verizon's NYC Central Office Portfolio.

(b) Annual Total Emissions due to operations of Verizon's NYC CO portfolio.

Figure 8-6: Optimization result where an unconstrained annual budget is set for building upgrade projects, and the objective function is to minimize total energy cost.

Table 8.2: Comparative analysis of the effect of budget constraints on financial and emissions outcomes.

Annual Budget	Gross TEC ($M)	% red. in TEC	Gross Emissions (MmtCO2)	% red. in Emissions
$10 Million	527.2	0%	1.533	0%
No Limit	522.5	0.9%	1.507	0.98%

8.3 Optimization Model - including Network Transformation

The next stage of results builds on those from Section 8.2 but now will include network switch upgrades as potential building upgrades in the j element of the 3-dimensional decision matrix (Section 7.1).

8.3.1 Cost of Network Switch Upgrades

Unlike all other building upgrade options, which included the estimated cost of installation from the contracted energy auditors, there is no cost information for upgrading switches in COs that have not yet fully migrated to fiber operations. As such, we sought to discover a means of predicting cost from past examples of TDM switch upgrades that had been carried out at Verizon. There are three cost components of upgrading the TDM switches to fiber multiplexers:

1. TDM switch removal cost: This is the cost of labor for Verizon to decommission the legacy TDM switches.

2. Fiber multiplexer capital cost: This is the capital cost of the fiber multiplexers that need to be installed at the CO migration site.

3. Fiber multiplexer install cost: This is the cost of labor for Verizon to install and commission the new fiber multiplexers ahead of migration.

The next stage of this analysis was to examine what metrics determined the sum of each of these costs most representatively. The answer we proposed was that these costs scale naturally with the number of copper customers being served at a given CO. When plotting migrations costs as a function of copper customers we can see a linear relationship with a positive slope that inferred our assumptions were correct, and this relationship was used to populate the j element of our decision matrix with Network Transformation upgrade options, as we had access to existing copper customer counts for each CO.

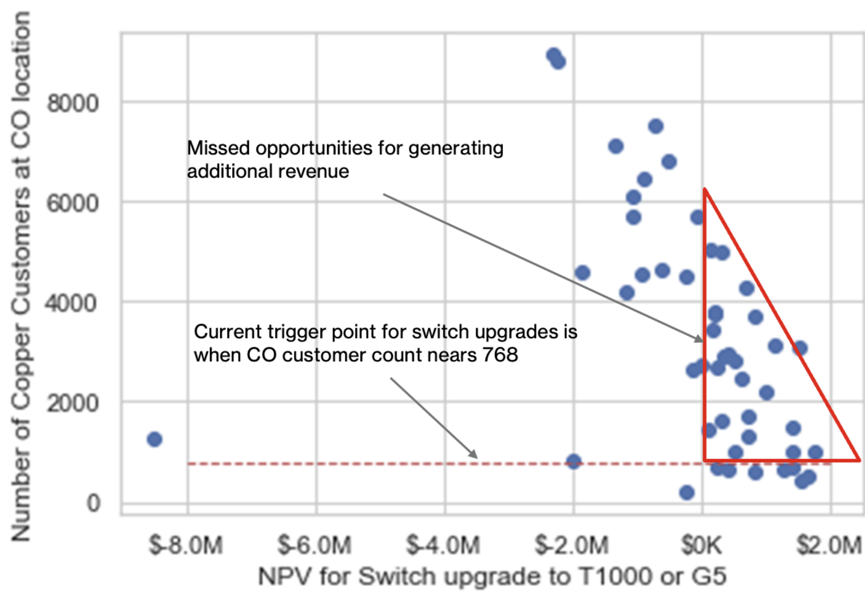
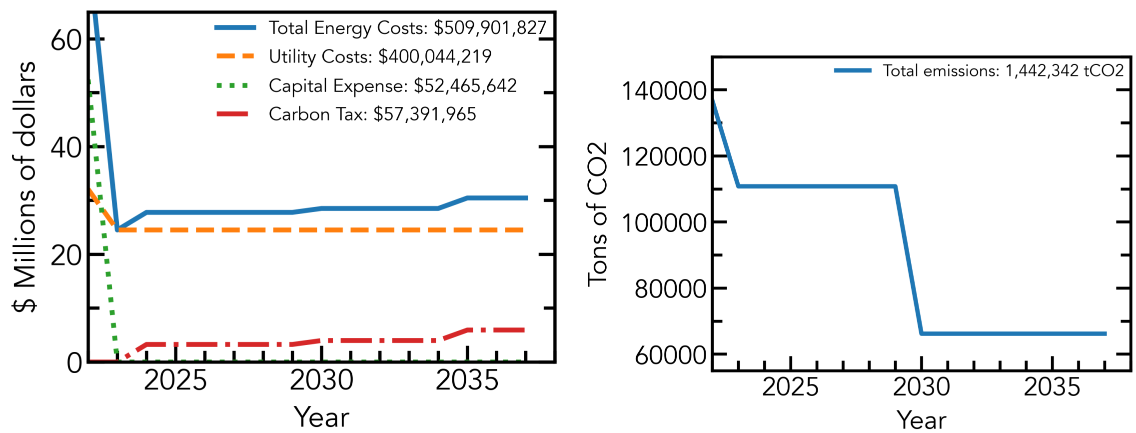


Figure 8-7: The relationship between the number of copper customers operational from a given central office and the NPV of upgrading the copper-based TDM switches to fiber-based alternatives. The dashed horizontal red line indicated the existing threshold within the network transformation team that triggers upgrades. The buildings inside the red triangle represent opportunities for both money and energy savings by upgrading switches in these buildings.

Ahead of running this new and improved optimization model, we wanted to investigate what kind of NPV was possible for migrating the 68 COs in NYC to fiber. By using a time duration of 15 years and a discount rate of 5%, we achieved the results presented in Figure 8-7, where the number of copper customers being serviced increases at a given CO, the NPV of migrating that CO to fiber decreases. The reason for the negative slope seen is that there is a step increase in capital cost for every additional 768 customers that must be migrated, and the unit cost of these fiber multiplexers ranges in the hundreds of thousands of dollars. Interestingly from this plot, when we overlay the existing threshold of copper customers at a given CO that triggers migration to fiber (768, Section 5.3.1), we see that there is a triangle of positive NPV COs that represents missed opportunities for both financial and emissions savings for Verizon. This represents an outcome that has been presented to the Verizon NT team as a possible easy lever to pull, in adjusting this migration threshold to 4000 customers instead of 768 customers.



(a) Annual Total Energy Cost of Verizon's NYC Central Office Portfolio.

(b) Annual Total Emissions due to operations of Verizon's NYC CO portfolio.

Figure 8-8: Optimization result where an unconstrained annual budget is set for building upgrade projects that now include network transformation upgrades as an option, and the objective function is to minimize total energy cost.

Table 8.3: Comparative analysis of the effect of network switch upgrades on financial and emissions outcomes.

Annual Budget	Gross TEC ($M)	% red. in TEC	Gross Emissions (MmtCO2)	% red. in Emissions
Baseline (no interference)	594.4	0%	1.754	0%
Building upgrades only	522.5	12.1%	1.507	14.1%
Building & network switch upgrades	509.9	14.2%	1.442	17.8%

8.3.2 Unconstrained Budget with Expanded j

We will now look at the effect these positive NPV opportunities, seen in Figure 8-7, will have when included as options in the updated optimization model.

Building on the results in Figure 8-6, we again made our optimization function to minimize TEC and used an unconstrained budget to see maximum possible savings and emissions opportunities giving the results seen in Figure 8-8, and distilled for comparison in Table 8.3.

These results show the distinct opportunity available to Verizon, in not only leveraging data and analytics to achieve sustainability goals but also to capture unseen financial savings that would not have been apparent without this analysis.

8.4 What Carbon Price is Best?

We were curious as to what the effect would be from adjusting the carbon price value set by LL97 of $268 per ton of CO2 that exceeds emissions limits. The number seemed, arbitrarily precise so we wanted to examine how the model would react if we scaled it from a price of carbon of 0 to 600 dollars per ton of CO2. We re-ran the model from Section 8.3.2 only adjusting the price of carbon and arrived at the results shown in Figure 8-9 which plots the percentage decrease in both TEC and emissions caused by the models recommended upgrades over the baseline no interference case.

Interestingly, the rate of decrease in TEC reductions with an increase in carbon price is far more pronounced than the rate of increase in emissions reductions. It could be considered that if the city of New York had pushed for legislation with a carbon price resulting in uneconomical (or marginally economical) outcomes for building owners, it would have not passed through the legal framework to be written into law.

Based on the data in Figure 8-10 we can see that even with a carbon price of zero (i.e. no LL97 legislation) the model still recommends Verizon spend almost $50 million on building upgrades. It is curious to see that the vast majority of the upgrades being recommended would have been recommended without any carbon tax, but the introduction of the carbon tax is what made building owners such as Verizon perform a deeper dive study into what the optimal solution is. This is essentially Verizon closing the energy gap in their CO operations [4].

Out of curiosity, we combined the information from Figure 8-1 and Table 4.1 to form an implied cost of carbon in the electricity rate from Verizon's utility bills for its NYC COs (Figure 8-11). To our surprise, the average value was a price of carbon of $270 per ton of CO2 which likely answers the question of how the city of New York decided on its price of carbon of $268 per ton.

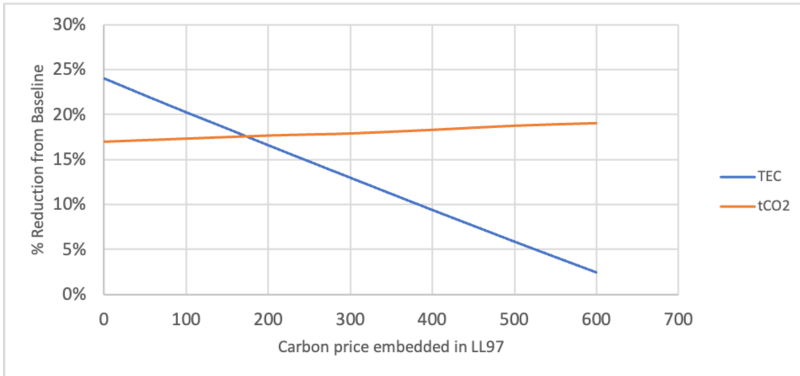


Figure 8-9: Percentage decrease in both gross energy cost and emissions as a function of what carbon price is set to in the building portfolio standard.

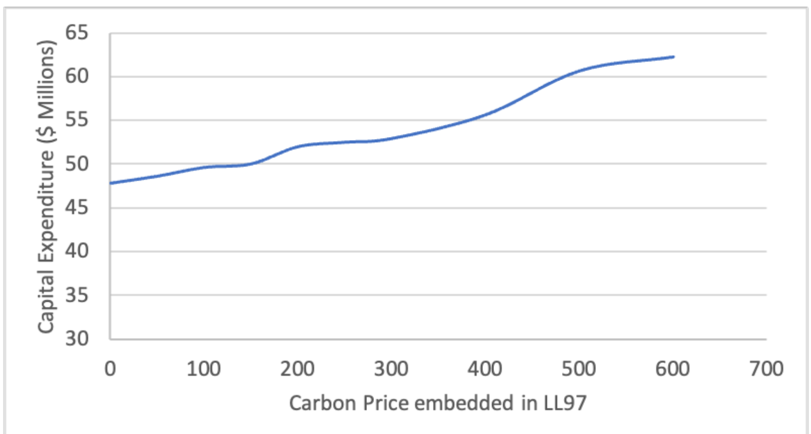


Figure 8-10: Recommended building upgrade CAPEX as a function of what carbon price is set to in the building portfolio standard.

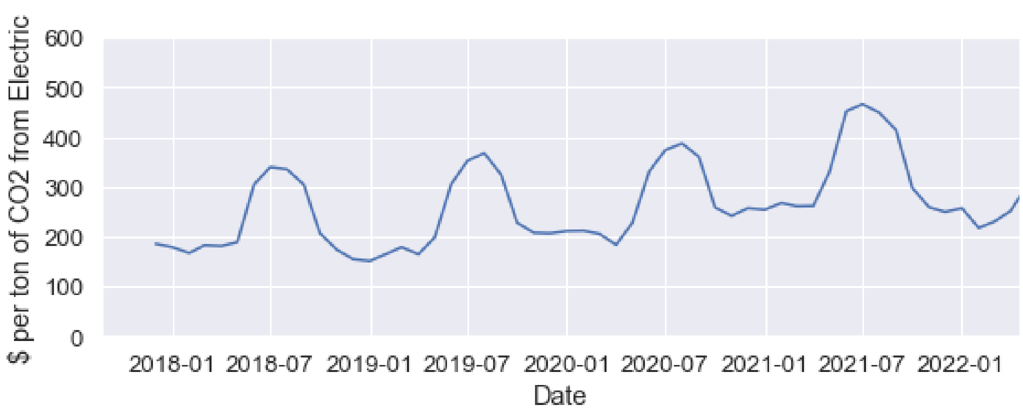


Figure 8-11: Time series representation of the unit price of CO2 from electricity based on the carbon intensity of electricity from [27] based on the electricity rate Verizon has paid at its NYC Central Offices since 2018.

8.5 Optimized Building Upgrades in Place of VPPA's to meet Sustainability Goals?

Given the positive impacts that an optimized building upgrade selection model has on the emissions from Verizon's NYC CO portfolio, we wanted to look at how this approach compared to the current approach Verizon is using to meet its net-zero goals (Chapter 3.3). We have discussed how the VPPAs that are funded through Verizon Green Bonds do not have any impact on Verizon's operational emissions, even though they do count towards the company's net-zero sustainability goals. If we look at the value of these VPPA's we see that these Green Bond investments have negative NPVs, meaning that, not only do they not reduce emissions for Verizon, they cost the company money given the premium paid in exchange for the RECs. Building upgrades, on the other hand, offer a positive NPV and also reduce emissions, a win-win. To really compare the potential impact of these upgrades to the VPPA investments, we must scale the results shown in Table 8.3 from Verizon's New York City portfolio to a national level. To do this we performed a crude scale-up, in that we identified that Verizon's utility expense for its NYC CO portfolio accounted for 7.27% of the company's CO utility expense nationally, and used this 7.27% as a scalar to extrapolate the optimization results nationally. While understanding this is an imperfect scaling method, it is presented here as a qualitative result to compare the value of building upgrades with Green Bond-funded VPPAs on a national level.

When looking at the results presented in Figure 8-12 we see the vast difference in value between optimized building upgrades and VPPAs. Based on this result it seems like an obvious decision to focus entirely on building upgrades to meet the company's sustainability goals, and cease any future financing of VPPAs. In order to see if this statement holds true, we must look at how much this nationally-scaled building upgrade regime could move the needle for the company's net-zero goals when compared to VPPAs (Figure 3-5).

Figure 8-13 quantifies this impact, which is, frankly, disappointing to see from our team. A national optimized CO upgrade project, projected to cost over $1 billion when

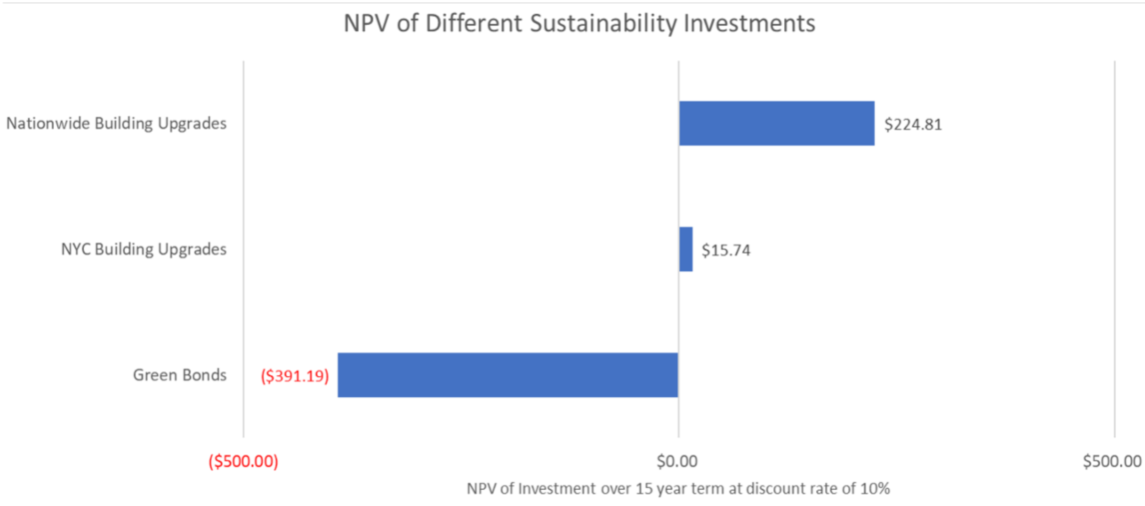


Figure 8-12: NPV of an optimized building upgrade solution using output from optimization model at both NYC and US scale after extrapolating linearly based on the energy consumption in NYC CO's as a % of Verizon's national CO energy consumption. Both NYC and Nationwide building upgrade programs show positive NPV and reduce emissions, in contrast to the existing Green Bond-funded VPPA program which has a negative NPV and no effect on emissions.

using the US scaling factor, will only reduce emissions by 7%. While obviously still more appealing than the VPPA alternative from a sustainability and value standpoint, this clearly is not the silver bullet to get Verizon to net zero by itself.

8.6 Optimizing a Corporate Sustainability Budget

As outlined in Section 3, Verizon has shown a strong financial commitment to corporate sustainability, committing four consecutive $1 billion rounds of green bonds in each of the last four years. The first three billion dollars have been fully allocated to fund VPPAs for all of their pros and cons, but the fourth green bond announcement of $1 billion has yet to be allocated and so we wanted to investigate how could Verizon optimize the allocation of these funds beyond VPPAs, into projects that move the dial on the companies emissions, such as building upgrades.

Based on the somewhat underwhelming results shown in Figure 8-13 of what a nationally scaled optimized building upgrade mandate would contribute to Verizon's net zero goals, exploring additional levers to pull was necessary. We examined what

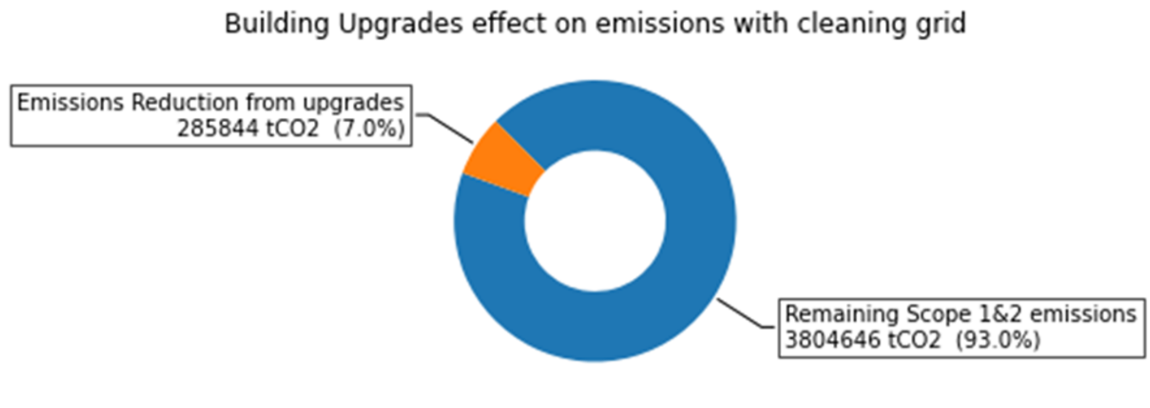


Figure 8-13: Scope 1 & 2 emissions reductions from a nationally scaled optimized building upgrade program.

additional options there are to layer on top of building upgrades to help Verizon meet net-zero goals while maximizing emission reduction.

8.6.1 Energy Storage

Certainly not a focal point of this research, we looked at the possibility of using the green bond sustainability funds to invest in on-site energy storage in COs. This technology would be favorable from a sustainability standpoint as, when paired with an electricity grid with more and more renewable penetration, such as those driven by state's Renewable Portfolio Standards (Figure 3-6), it could store energy from times of the day with high renewable energy penetration and dispatch that electricity when the renewable penetration wanes[1]. We sourced capital cost, round trip efficiencies, maintenance costs, and lifetime data from a recent government-funded technical report from the National Renewable Energy Authority (NREL)[7], to determine costing information for industrial scale energy storage systems.

To calculate a dollar per ton of CO2 abated through an energy storage solution, we calculated what the annual electrical energy requirement would be in NYC to make up the 30% of non-Renewables on the grid, based on New York states RPS goals of 70% renewable energy on the grid by 2035. Based on this gross energy amount, we calculated the CAPEX and OPEX for an energy storage system to have this type of capacity. We then divided this net present value of the energy storage investment

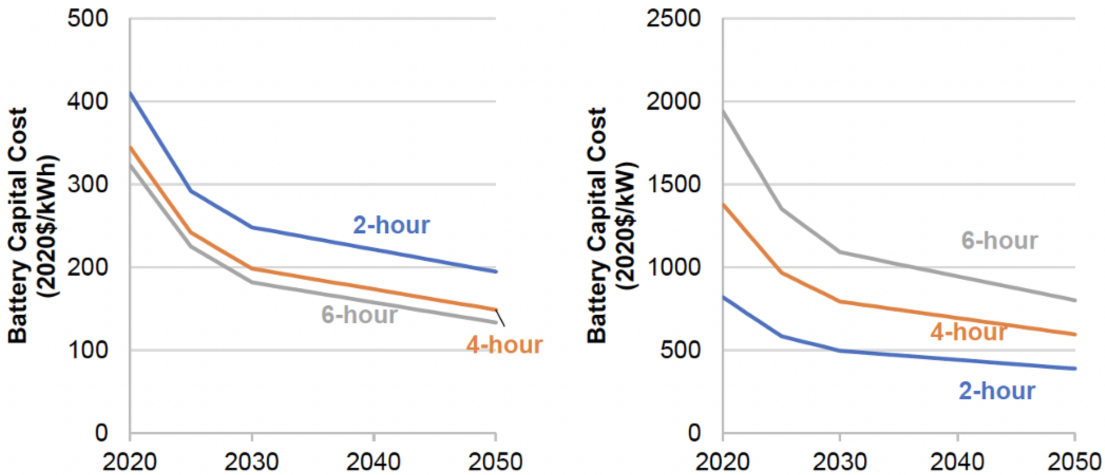


Figure 8-14: Cost projections using 2-, 4-, 6-hour duration batteries using the mid-cost projection. The Left shows values in \$/kWh, right show values in \$/kW.[7]

by the amount of energy this 30% account for. We then arrived at a cost per ton of CO2 abated figure for an energy storage solution. This analysis contains a major assumption in that the numbers presented by NREL in [7] are for an energy storage solution with a 6-hour duration battery. This assumption implies that the energy storage system will not have to discharge for more than 6 hours at a time, and therefore there will not be an instance of less than 70% renewables on the grid continuously for more than 6 hours at a time. This is a highly optimistic viewpoint, and as such some buffer perhaps should be included to require the energy storage capacity to be greater then 30% of the electrical energy need.

Based on this analysis we calculated that a large-scale energy storage installation at Verizon COs would cost Verizon \$50 per ton of CO2 abated when used as part of a smart dispatch controller to leverage 70% renewables on the grid in New York State as determined by their RPS, putting it firmly in right-hand side of the carbon abatement cost curve (Figure 2-1). This obviously is not a favorable investment by itself, but when combined with building upgrades and Verizon's existing VPPA investments, we can achieve a much more favorable impact on emissions for the same cost of achieving net zero as the present VPPA method.

Figure 8-15 shows a McKinsey style cost of carbon abatement curve for standalone options that we are considering, building upgrades, energy storage, and Green Bond funded VPPAs, as well as combinations of those strategies. This graph shows that building upgrades by themselves are hugely favorable from a carbon abatement cost standpoint, either in an existing grid scenario or in a scenario where the grid has cleaned significantly due to RPS implementation. However, we can also see that these investments marginally move the needle on emissions reduction (see mini pie charts). In contrast, investing in energy storage solutions for renewable energy dispatch can dramatically reduce Verizon's emissions with assumptions of 70% renewable penetration capacity on the grid (state of New York's RPS target). This emissions impact however comes at a cost of $50 per ton of CO2 abated, which due to the amount of capacity that would need to be installed for this theoretical emissions reduction, Verizon would be spending billions of dollars with no prospect of making that money back in energy savings due to the high capital cost of batteries. So from this analysis, we have:

- one solution that has incredibly favorable carbon abatement costs but low scalability for emissions reductions (building upgrades)
- one solution that has incredibly poor carbon abatement costs but high scalability for emissions reductions (energy storage)
- one solution that has poor carbon abatement costs and zero impact on emissions but is indefinitely scalable in meeting net-zero goals (Green Bond funded VPPAs)

What if we combine all three? If we set a target price per ton of CO2 that is equal to that of VPPAs alone as a target for determining a mixture ratio of solutions to still achieve net zero, we see that we can achieve Verizon's net zero carbon goals while also reducing emissions. In fact, for the same carbon abatement price, this mixture of solutions would have a 60% reduction in emissions for Verizon, compared to a 0% reduction in emissions from using VPPAs alone. Figure 8-16 shows what the mixture ratios of solutions are for each scenario mentioned above. This solution features a large investment in energy storage which at this point is purely theoretical. As a follow on to this work we would recommend further investigating the opportunity cost of widespread energy storage installations for Verizon. This analysis is intended to show rough possibilities on the energy storage point.

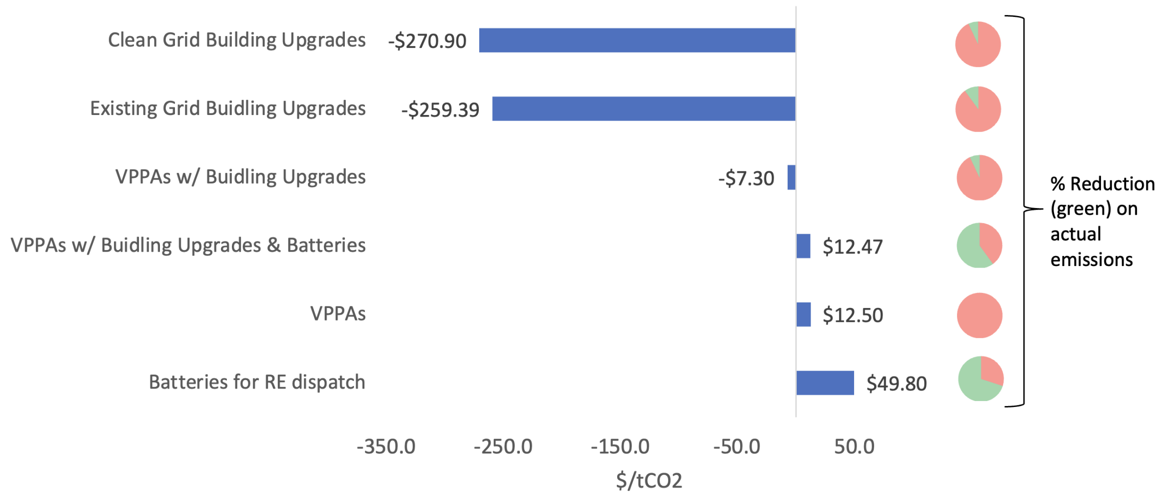


Figure 8-15: Carbon abatement cost curve showing dollars spent per ton of CO2 for different abatement solutions or combinations of solutions. Also shown in the mini pie charts are the reduction in emissions these investments cause over 2021 levels.

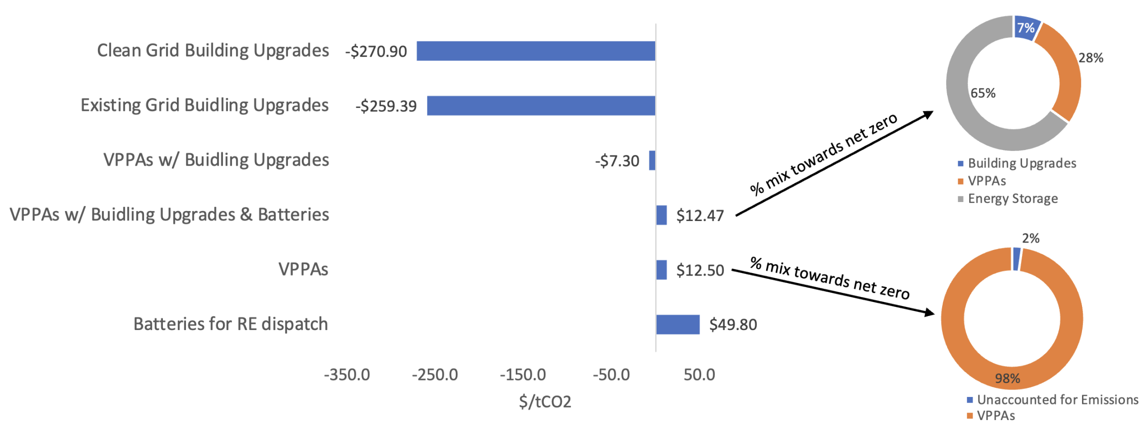


Figure 8-16: Dollars spent per ton of CO2 accounted for on Verizon's net zero goal for different solutions or combinations of solutions, including pie charts showing contribution mix towards net zero contribution for identically priced solutions of existing green bond funded VPPAs, or a mixture of building upgrades, on-site energy storage, and green bond funded VPPAs.

8.7 Central Office Consolidation

The final of the three energy reduction strategies outlined in Section 5 is consolidating the number of Central Offices in Verizon's portfolio in order to reduce emissions. The prospect of closing down a CO is not something we felt was prudent to include as an option in the project's optimization model. One of the primary goals of the optimization model was to output a prescriptive framework where the results could be handed off to real estate and energy teams for budget and project management planning. Consolidating a portfolio of Central Offices is not something that fits within the goal of a prescriptive framework. As we felt the optimization model may lose some credibility and buy-in with senior leadership if it moved to include more theoretical possibilities of redesigning the network of COs, it was decided to keep this piece of the project separate from the optimization model.

Figuring out where to begin was difficult as trying to consider all of the factors that are at play in closing one CO and moving its operations to a different CO was overwhelming and beyond the scope of this piece of work given the timeline. Instead, we focused on performing a high-level analysis that was based on an existing central office consolidation project that Verizon is carrying out. Due to an upcoming end of lease at one of Verizon's largest central offices in its portfolio, and the landlord's desire to not renew, Verizon has had to begin a project to migrate this entire CO's operations elsewhere in NYC. In this particular case, the leased building is in the VZB network, and it is being consolidated into an owned CO in the VZT network. From this project we have at least a single data point for how much one of these consolidation projects costs in an order of magnitude level, and what the breakdown of these costs by job type looks like. We then looked at the total number of customers being serviced by the CO in question and used the relationship between customer count and cost of consolidation as our scaling factor for consolidation costs in each of the 68 owned COs in NYC. While imperfect obviously as we only have a single data point for this rare type of occurrence, it is an actual data point that keeps the analysis realistic at least from a comparative standpoint.

Table 8.4: Comparative analysis of the effect of network switch upgrades on financial and emissions outcomes.

Borough	Value/SQFT
Bronx	277
Brooklyn	454
Manhattan	889
Queens	357
Staten Island	332

Armed with a total cost for consolidating a building relative to customer count, it was then necessary to gauge how much money and emissions could be saved by closing a building. For emissions, Verizon would no longer be responsible for the emissions associated with that building, essentially reducing that building's emissions from its Scope 1 and 2 total. Financially, Verizon would no longer need to pay any of the Total Operating Costs for the building and would be able to sell the building once fully moved out. For the potential sale of a building, we used the real estate valuations listed in Table 8.4 to calculate the income that would be generated from selling a CO.

We calculated what the Net Present Value (NPV) would be for closing each of the Central Offices in the NYC portfolio based on the assumption that we had made, using a discount rate of 5% and a timeline of 8 years. We were more conservative with our NPV timeline as we believed any business case of this scale would need to have a short payback period to be able gain support at senior levels. We plotted these NPV calculations against what the potential reduction in national GHG emissions would be for Verizon which can be seen in Figure 8-17. While the percentage reduction values appear small when considering them as a percentage, it is important to note that it is quite impactful for an individual building to be able to move the needle at all for a company's entire nationwide emissions. Furthermore seeing that some buildings are showing NPVs of more than $100 million in just 8 years highlight not only the sustainability opportunity from this type of work but also the business opportunity in streamlining and modernizing your network.

An important consideration when exploring this type of project is that it is reliant

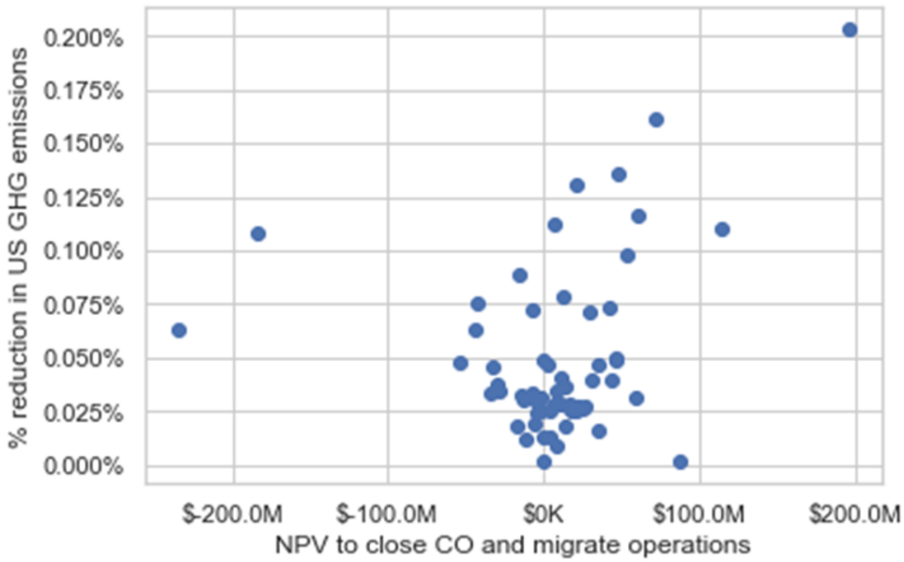


Figure 8-17: Plot highlighting the NPV of consolidating a CO in Verizon's NYC portfolio. Each point represents one of Verizon's owned CO's in the VZT network. On the y-axis, we see the % reduction in Verizon's national scope 2 emissions that would be caused by this CO closure.

on the Network Transformation (NT) team migrating operations to fiber to realize energy, space, and power savings (section 5.3.1). In order for one CO to close, space, power, and HVAC capabilities must be available in the CO that its services are moving to. Based on this we wanted to add more data to our analysis to highlight where opportunities would be not only for CO closures but for CO expansions. Figure 8-18 shows the same information as in Figure 8-17, but with each CO color-coded by location and sized based on the number of customers serviced by that CO. We can infer that a CO that services a large number of customers likely has substantial space, power, and HVAC capabilities, that would not be needed to the same extent if the NT team migrated the COs operations entirely to fiber. This migration could free up enough space to house additional services for customers from an adjacent CO. Essentially what we are looking for is COs with a large existing customer service base and identifying that as a "hub" CO. We are then looking for nearby COs that have lower customer bases (implying they would not need as much space/power/HVAC if consolidated) and high NPVs when closed. These two buildings could then be "paired" and presented to Verizon leadership as an opportunity for cost and emissions

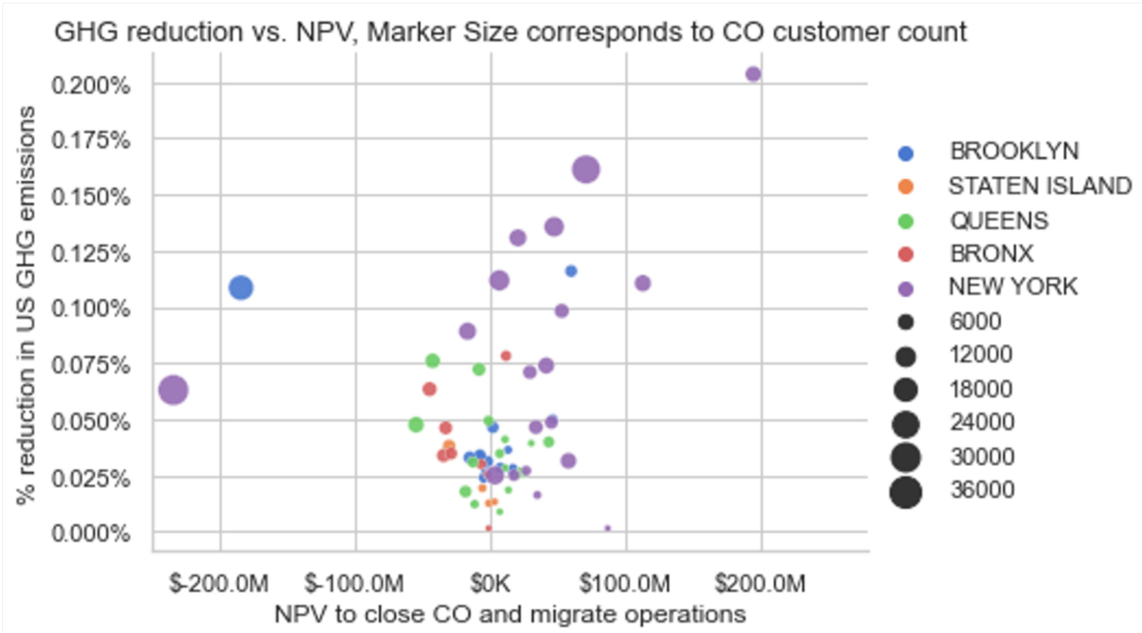


Figure 8-18: Plot highlighting the NPV of consolidating a CO in Verizon's NYC portfolio. Marker size represents the number of copper customers being served by that CO, and marker color indicates its location in NYC.

savings to then look into further and perform actual quantifiable analysis for technical feasibility.

What was most interesting when investigating the cost breakdown of the one CO that we had data for, was that 50% of the cost was allocated towards preparing the CO to which the services were being migrated from a structural, power, and HVAC standpoint to be able to accommodate the services that were being installed there. By the analysis presented in Figure 8-18 we are recommending making CO consolidation pairs where this need for major overhauls of structural, power, space, or HVAC capabilities is not required. As such, we can adjust our NPV calculations to look at what the savings opportunities could be if we could carefully select CO pairs to realize this 50% reduction in consolidation costs. Doing so gave the results in Figure 8-19. This alteration to the consolidation cost shifts almost every Central Office consolidation project to have a positive NPV in eight years. Much of this high-value opportunity is driven by properties in Manhattan which makes sense given its extremely high real estate value. Performing such consolidation work in Manhattan

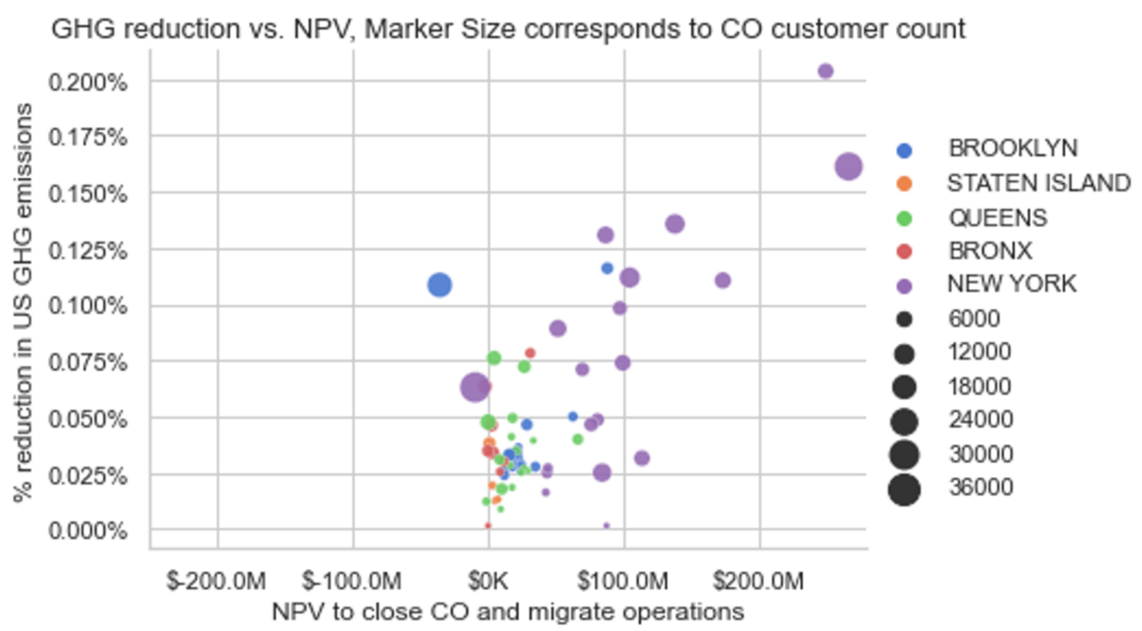


Figure 8-19: Plot highlighting the NPV of consolidating a CO in Verizon's NYC portfolio. Assumes that buildings where operations are being consolidated into do not need structural or electrical upgrades which would roughly double the cost of consolidation.

also is as complex as possible in NYC given the sheer density of real estate and infrastructure present there.

The purpose of the results for this section on portfolio consolidation is not to be prescriptive in exactly what CO should be consolidated into what CO, but instead to display the opportunities for cost and energy savings to be interpreted and investigated further by dedicated teams at Verizon. Clearly, opportunities exist to optimize the network architecture, but deciding on exactly what opportunities should be looked into further are beyond the scope of work of this project.

Chapter 9

Conclusions & Future Work

Upon compiling the findings of a 6-month internship into a single document, we saw that what began as trying to build a project management planning tool to forecast building sustainability upgrades, escalated significantly to recommending totally re-imagining sustainability investments and consolidating Verizon's telecommunications network. Our final chapter recaps the findings from our study and discusses recommendations for future work.

9.1 Summary of Contributions

What this study aims to show is that being a leader in corporate sustainability should be much more than just purchasing renewable energy credits. It should be using analytics to study and optimize your sustainability budget for both financial returns and impact on greenhouse gas emissions. The findings of this study can be separated into three different timelines of implementation.

In the near term, Verizon should invest as much money as possible into making building and network upgrades in their portfolio of Central Offices in New York City using an optimization framework to determine which projects to finance. This will stymie the negative financial implications of Local Law 97 and provide a testbed for this optimization framework for Verizon ahead of Building Portfolio Standards coming into effect beyond NYC, across the country. The immediate nature of NYC's environmental compliance law beginning fines in 2024 amplifies the near-term need for the adoption of this optimization approach. This recommendation does have significant operational implications for Verizon however. The benefit of the company's existing approach of reaching net zero, of financing VPPAs using Green Bonds, is that it is a purely financial instrument with no need to stockpile capital or allocate significant labor resources to implement work.

In the medium term, the study suggests that a reallocation of Verizon's Green Bond sustainability budget towards distributed solutions would, for the same cost per ton of CO2 towards net zero, reduce actual emission by up to 60%. This finding challenges the industry-standard method of achieving net-zero sustainability goals but results in a much more impactful path to net zero. There is some urgency in acting on these findings as Verizon actively looks to allocate its fourth round of $1 billion green bond funding. While less prescriptive in actions from its findings, it clearly indicates that further investigation into alternative emission reduction projects, such as large-scale energy storage solutions for central offices, needs to take place.

Longer term, the study challenges the status quo of how Verizon's network of Central Offices is designed. We understood why and how the portfolio has arrived at its existing inflated design - through company acquisitions, fast technological advancements in telecoms, and even faster network bandwidth demand. However, we also, know that a data point exists for downsizing the company's central office footprint, and can be learned from and applied across the company's portfolio to save money, reduce emissions, and modernize the grid. This work shares the same visions as what led Verizon to form the Network Transformation team but is admittedly highly capital and labor-intensive. Implementing widespread building upgrades and consolidation would require either re-allocating personnel to this work from projects that are core to the company's business such as expanding the 5G network or expanding the workforce - both difficult propositions to executive leadership. This result of our project is therefore deemed as longer-term strategic visioning.

Separate from these more discrete findings, a broad discovery from this project is that a company of Verizon's scale has endless opportunities for creating value if you know where to look. Asking pointed questions and applying analytics has uncovered three significant opportunities for furthering Verizon's holding as a force in corporate sustainability.

9.2 Potential Areas for Future Work

The three implementation timelines outlined previously each share a need for further work toward implementation for Verizon.

Firstly, the optimization model was built as a standalone system for this research. The next step of that would be to implement this model and its results internally on Verizon's servers such that input data could be updated, and results could be accessed by Real Estate and Energy teams for planning purposes. New York City is a natural test site for the model, in that it is the first locale with environmental compliance laws coming into force. Once tested there, the model could then be expanded nationally, and beyond just central offices.

Secondly, future work is needed on how best to spend green bond finances. This would be most useful in the area of performing a deep dive into energy storage solutions and building a sophisticated techno-economic model of such a project. This could also expand into other solutions to reduce emissions to combine with building upgrades such as hydrogen fuel cells or nuclear microreactors[3][25].

Lastly, using the CO pairing consolidation approach outlined in Section 8.7, a detailed investigation into actual consolidation costs would be beneficial in getting more accurate data on seemingly profitable business opportunities for Verizon as well as improving the accuracy of the consolidation NPV model.

The most important learning from this work is to never stop working towards reducing your carbon footprint; continue to evolve and use the most state-of-the-art tools at your disposal to determine the best paths forwards. True corporate sustainability is possible if companies are willing to dive in head first.

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