Framework and Analytics for Emissions Forecasting and Planning

by

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Submitted to the MIT Sloan School of Management and
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Abstract

Amgen has recently committed to achieving 100% carbon neutrality, 40% water reduction, and 75% waste reduction relative to its 2019 baseline by 2027. To help reach these goals, Amgen has taken a science-based approach and has assembled a Sustainability Analytics Team to develop tools based on analytical insights that site leads and executives can use to work towards the 2027 Sustainability Goal. A key business gap identified was the ability to precisely forecast future emissions growth stemming from long term growth of the company.

This thesis presents a methodology to develop a framework that breaks down Amgen's emissions profile and utilizes analytics to understand key emissions drivers for long term growth within a vertical of the framework. The key emissions drivers are then incorporated into an excel model to build upon and supplement Amgen's current forecasting methods. Using the framework and analysis, drug substance (DS) production within the manufacturing vertical in the framework is used as a case study to demonstrate the validity and value of this approach. The initial hypothesis was that increases in DS production will not materially increase Amgen's carbon emissions. Conducting regression analysis on four facilities with DS plants to find correlations between emissions drivers and energy usage revealed that (1) energy usage with respect to DS production was largely insensitive to changes in production volume for sites with large building areas and (2) as DS production intensifies and requires less space, increases or decreases in DS production may materially impact a site's energy usage.

These learnings were incorporated into an excel tool to forecast Amgen's carbon emissions versus current sustainability plans to help executives better understand whether Amgen was on pace to reach carbon neutrality by 2027 despite expected business growth and to make strategic decisions to ensure the sustainability goals are met. Moreover, these learnings can help Amgen prioritize sustainability initiatives that would help meet business needs while limiting or even reducing environmental impact. Examples include but are not limited to increasing cleanroom efficiency to reduce fixed energy usage, debottlenecking current processes before building new plants to limit increases in carbon emissions, and utilizing more energy efficient equipment or processes to reduce variable production energy usage as production intensifies and requires less space.

Beyond helping Amgen reach their sustainability goals, the methodology to developing a framework and conducting analysis can be utilized by all companies in different industries to meet their sustainability goals. The framework and type of analysis can be adjusted for different business activities and needs respectively to develop a holistic model to forecast a company's emissions and drive strategic decisions to minimize environmental impact.

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From MIT, I would like to thank my thesis advisors, Karen Zheng and Jung-Hoon Chun, for the wisdom and guidance they have provided throughout this journey. In addition, I would like to thank the LGO staff who have worked tirelessly behind the scenes to source projects, organize trainings, and help with all the logistics to make this possible. Also, I would like to thank my LGO peers, especially The Gemba, for pushing me to become stronger personally and professionally throughout my time at LGO.

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Lastly, I would like to thank my family for their love and support. Without my parents providing the opportunities to learn and grow throughout my life, I would not have had the privilege to attend UCLA and now MIT. Without my brother, I would not have had a friend to push me and a role model to emulate throughout my childhood. Finally, I would like to thank my fiancé and soon to be wife, Holly Young. She has made many sacrifices to make this opportunity possible. I am forever grateful for her selflessness, patience, and unwavering support throughout this journey.

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Chapter 1

Introduction

Amgen is a major, multi-national biotechnology company that develops, manufactures, and sells therapeutics which help treat oncology/hematology, nephrology, inflammation, bone health, and cardiovascular diseases. Within these areas of focus, Amgen targets illnesses that have limited treatment options [5].

In addition to focusing on their core business of developing and manufacturing therapeutics, Amgen has been focusing on reducing their environmental footprint. From 2008 to 2020, Amgen has reduced carbon emissions by 33%, water usage by 30%, and waste disposal by 28%. To continue down this journey, Amgen announced its 2027 Sustainability Goal in 2020. The goal aims to achieve carbon neutrality for Scope 1 and Scope 2 carbon, reduce water usage by 40% relative to its 2019 usage, and reduce waste disposal by 75% relative to its 2019 numbers [6]. To help tackle this goal in a data-driven approach, Amgen formed the Sustainability Analytics team to develop a suite of analytical tools to address various business problems. Below are a few tools developed and the business problems they resolved.

- Real-time Sustainability Trending - to visualize Amgen's energy usage over time with resolution up to a single day and down to specific sites and buildings. This will enable troubleshooting and optimization to reduce energy usage.

- Normalization Site Benchmarking - to normalize each site's energy usage for major drivers such as the facility's total building area in square feet and weather to compare each site's energy efficiency and identify sites with additional opportunity for improvement.

- Project Tracking - to track and verify expected project outcomes and to aggregate types of projects and the amount of energy reduction realized to help highlight types of projects that other sites can also implement.

The problem focus in this thesis is around strategic planning, specifically how to forecast Amgen's future emissions to inform and guide executives to make the right strategic decisions to meet Amgen's 2027 Sustainability Goals.

1.1 Project Motivation

Accurate forecasts of Amgen's future emissions allow Amgen executives to properly plan and allocate resources to meet the company's 2027 Sustainability Goals. Moreover, proactive planning and execution will allow Amgen to implement changes that achieve true emissions reductions rather than purchasing Renewable Energy Credits (RECs) or Offsets to help reach carbon neutrality.

The ambition to reach the 2027 Sustainability Goal could be complicated by the anticipated increase in drug supply needed in the future years. This is driven by price erosion (i.e., long-term decay in prices due to market and regulatory factors) seen in the market along with Amgen's growth as a company in different geographic regions. With the increase in drug supply, many parts of Amgen's business will need to scale to support these operations. Consequently, Amgen's 2027 sustainability plan will need to account for and counteract emissions growth due to this expansion.

1.2 Problem Statement

Amgen's current emissions growth forecasting ability is based on projects that go through their capital project funding process; a process in which projects that need funding and have been fully vetted are presented to leadership for final approval and funding. Here, the projects are evaluated for their sustainability impact and can be tracked to understand if this will increase or decrease Amgen's emissions footprint.

A few issues arise with the current method. First, there are many different operational changes that will lead to increased emissions and will not require a capital project. For example, increasing production with underutilized equipment will lead to increased emissions but would not require project funding. Another flaw with the current method is that the capital project funding process has a short-term outlook (1-5 years) and will not flag emissions changes further out in the time horizon. The new method developed to forecast Amgen's emissions will build off the current method but also address the gaps described here.

1.3 Potential Business Impact

The work from this thesis will help Amgen develop a framework to break down their emissions and a new methodology to understand key emissions drivers, incorporate the key drivers into an emissions forecasting tool, and plan accordingly to meet the 2027 Sustainability Goal. The work will also propose a business process and owner to ensure the tool is updated and continues to provide value. Furthermore, the analysis aims to help Amgen understand key emissions drivers within each vertical of the emissions framework that will help the company strategically focus its sustainability efforts and investments to proactively mitigate emission increases and drive further reductions.

These business impacts were kept in mind and helped drive decisions on how the tool was developed, what kind of advance analytics to use, and who was involved for feedback throughout this process.

1.4 Thesis Overview

Given the wide scope of the current problem, this thesis will focus on a framework and methodology to systematically analyze and model a company's emissions footprint.

Amgen's carbon emissions increase within the framework's manufacturing vertical will be used as a case study to demonstrate the value and process of the proposed methodology. Further analysis can be done on other framework verticals if desired in the future. Moreover, similar frameworks and analysis can be developed and conducted for other emissions (water and waste).

The thesis is organized in the following manner. Chapter 1 provides an introduction to the project, the project's motivation, the problem to be solved, and the thesis overview. Chapter 2 discusses background information regarding the biotechnology industry, sustainability, and Amgen's contribution to both. Chapter 3 introduces a framework and methodology to help break down, analyze and forecast Amgen's future emissions. Chapter 4 presents a case study using Amgen's manufacturing carbon footprint as a practical application of the framework and methodology and showcase the value. Chapter 5 provides recommendations for Amgen based on work done for the case study. Finally, Chapter 6 presents next steps to complete the framework and takeaways from the work accomplished so far.

Chapter 2

Background

This chapter provides background into the biotechnology industry and sustainability as well as Amgen's impact to both. The information provided is not exhaustive but provides enough information to understand the main emission drivers for a company like Amgen. Having a high-level understanding of this information will help with understanding the framework and analysis used to tackle the problem.

2.1 Biotechnology

Biotechnology can be defined as "the use of living organism(s) or their product(s) to modify or improve human health and human environment" [7]. This can be found in many industries including genetically modified crops for agriculture, bio-fuels for energy, and therapeutics for medicine. Since Amgen is focused on therapeutics, the remainder of this chapter will focus on this aspect of biotechnology.

2.1.1 Medicine: Therapeutics

Biotechnology is used for therapeutics through two processes: bio-molecular or cellular. Drugs produced through bio-molecular processes are also known as small molecule drugs and are considered pharmaceutical drugs. Drugs produced through a cellular process are known as biologics. The key differences between these two types of drugs are their administration routes, manufacturing steps, and interaction with the body [8].

Small molecule drugs are chemical compounds that are chemically synthesized. These compounds often act as inhibitors or promoters for various functions within the body. In addition, these drugs are often orally ingested [8]. Biologics, on the other hand, are typically proteins, carbohydrates, nucleic acids, cells or tissues that are manufactured using a host cell [9]. These drugs are introduced into the host cell via genetically modified vectors which carry the drug's DNA sequence. Once ready, the cells will begin to produce the drug. These drugs are then collected, purified, and diluted to the correct concentration [10]. Figure 2-1 is a graphic illustrating a typical biologics manufacturing process.

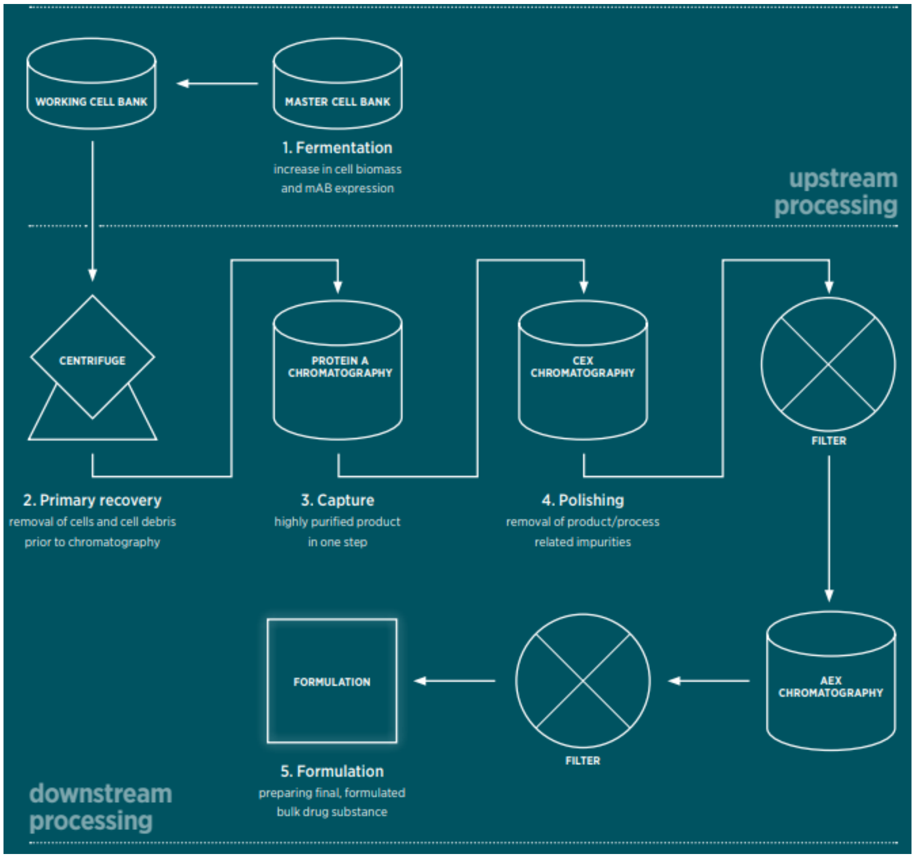


Figure 2-1: Process flow of a typical biologics manufacturing process [1]

Biologics are typically administered parenterally (injecting directly into the body) and not orally because these drugs degrade quickly when passing through the human digestive system [9]. Although biologics are more complicated and costly to manufacture, they generally provide higher efficacy and consequently are also more costly for patients [11].

Because of the relatively simpler manufacturing process and compound, small molecule drugs are much easier for pharmaceutical companies to replicate. Moreover, the approval process for small molecule generic drugs is also relatively easier. Consequently, once a small molecule's patent expires, competitors can flood the market with generic drugs, creating competition and price erosion. Conversely, small changes in a manufacturing process for biologics could result in clinically significant changes in efficacy and safety [1]. Therefore, competitors who are developing a drug with similar structure or mechanism to an existing drug previously have submit a biologics license application (BLA) and go through the same rigorous Food and Drug Administration (FDA) approval process as the initial drug. This barrier to entry creates an additional hurdle on top of patents which enables companies who produce the initial drug to hold a monopoly for a longer period of time.

The Biologics Price Competition and Innovation Act (BPCIA) - includes the Patient Protection and Affordable Care Act of 2010 - created an abbreviated pathway for biosimilars to gain FDA approval through submission of data from "analytical studies (structural and functional tests), animal studies (toxicity tests), and/or clinical studies (tests in human patients)" [9]. Since the approval of BPCIA until May 29, 2019, 19 biosimilars based on nine reference drugs have been licensed in the United States [9]. As additional biosimilars enter the market, the same dynamics observed from generic drugs entering the market will occur; the innovator company will be forced to lower their price to compete, leading to lower margins. In order to maintain or grow revenues, companies are further incentivized to expand and look into new markets or discover new drugs. This is one potential reason for Amgen's outlook for increased drug production.

2.1.2 Amgen's Role

Amgen, previously known as Applied Molecular Genetics, was founded in 1980 at the start of the biotechnology industry. From the start, Amgen was a research and development company, where scientists study how diseases develop and what active ingredients could be used to treat these diseases. In 1989, Amgen founded its first drug, EPOGEN, which treats anemia [12]. Since then, Amgen has broadened its scope to include process development, manufacturing, sales, and other functions to bring the drug from discovery all the way to market.

Within process development, Amgen designs a small-scale process for clinical trials and hands off the process to Clinical Manufacturing. If the drug successfully clears the clinical trials and is approved for commercialization, process development also designs the commercial-scale process [13]. Part of the design consideration includes yield and cost which is influenced by cell selection, equipment selection, and process steps, among other things.

Manufacturing consists of three main stages which are Drug Substance (DS), Drug Product (DP), and Final Drug Product (FDP). DS is where the active ingredient for the drug is manufactured and purified. DP is where the active ingredient is diluted and mixed into the appropriate quantities for human consumption and stored in a primary container such as vials, syringes, or tablets. FDP is where the drug product is sometimes incorporated into secondary devices such as an auto-injector. This is also where the drug product is packaged for shipments.

In addition to expanding functions, Amgen has also diversified its product portfolio. Amgen currently has 25 commercially available drugs which includes a mix of biologics, biosimilars, and small molecule drugs [14]. Moreover, a continued diversification could be observed when viewing Amgen's product pipeline [15].

2.2 Sustainability

On December 12, 2015, 196 parties signed a legally binding international treaty on climate change called the Paris Agreement. This was the first time nations have come together to collectively work towards solving the world's climate change issues [16]. The agreement sets long-term goals including:

- substantially reducing global greenhouse gas emissions to limit global temperature increase in this century to 2 degrees Celsius or 3.6 degrees Fahrenheit, while pursuing efforts to limit the increase even further to 1.5 degrees Celsius or 2.7 degrees Fahrenheit;
- reviewing countries' commitments or Intended National Determined Contributions (INDCs) every five years;
- providing financing to developing countries to mitigate climate change, strengthening resilience and enhancing abilities to adapt to climate impacts [17].

The 2 degrees Celsius change limit is based on the work of many scientists who have estimated that a 2 degrees change will limit the risk of catastrophic consequences to Earth's living conditions [18].

Beyond the implications of countries working together, the Paris Agreement also set the tone for the severity of climate change and the need for everyone to work together. Everyday consumers have begun to shift habits to adopting more fuel-efficient vehicles including electric vehicles, installing solar panels on their homes, and installing smart cooling and heating systems like Google's Nest. Consumer insights company Nielsen estimated an approximate 50% increase in sustainable product sales in 2021 as compared to in 2014 [19]. This shift in behavior has also extended to how consumers view corporations. A report from Weber Shandwick, a research firm, found that 83% of consumers prefer showing support for sustainable companies by buying from them [20]. This change in behavior is also reflected in the types of investments being made. In 2020, U.S. environmental, social, and corporate governance (ESG) funds attracted $51.1 billion in new assets compared to $5.4 billion in 2019 [21]. Changes in sales volume and in investments affect corporations' bottom line and create pressure for companies to be more transparent with their ESG goals.

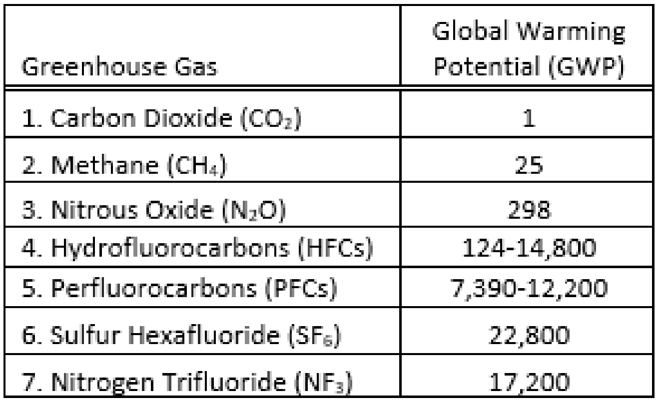
2.2.1 Carbon, Water, and Waste

Since Amgen's 2027 Sustainability Goal focuses on carbon, water, and waste, this section will focus on providing additional context for each metric.

Carbon

Carbon is measured in mass of carbon dioxide equivalent, CO_2e. Since greenhouse gases released from burning fuel are not all carbon dioxide, they are converted to CO_2e based on their global warming potential (GWP). GWP is calculated by determining the amount of warming a gas causes over a period of 100 years relative to carbon dioxide [3]. Table 2.1 shows the GWP of various greenhouse gases.

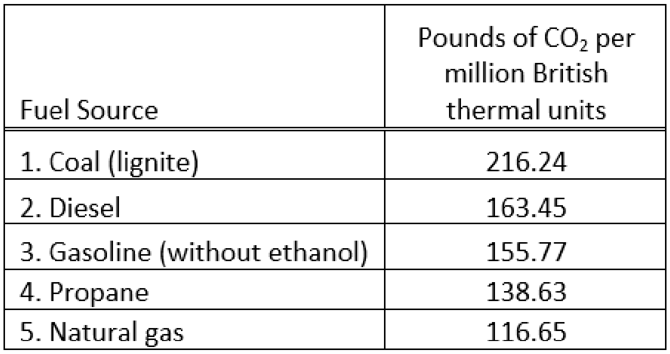
Table 2.1: Global Warming Potential for different Greenhouse Gases [3]



Greenhouse Gas	Global Warming Potential (GWP)
1. Carbon Dioxide (CO_2)	1
2. Methane (CH_4)	25
3. Nitrous Oxide (N_2O)	298
4. Hydrofluorocarbons (HFCs)	124-14,800
5. Perfluorocarbons (PFCs)	7,390-12,200
6. Sulfur Hexafluoride (SF_6)	22,800
7. Nitrogen Trifluoride (NF_3)	17,200

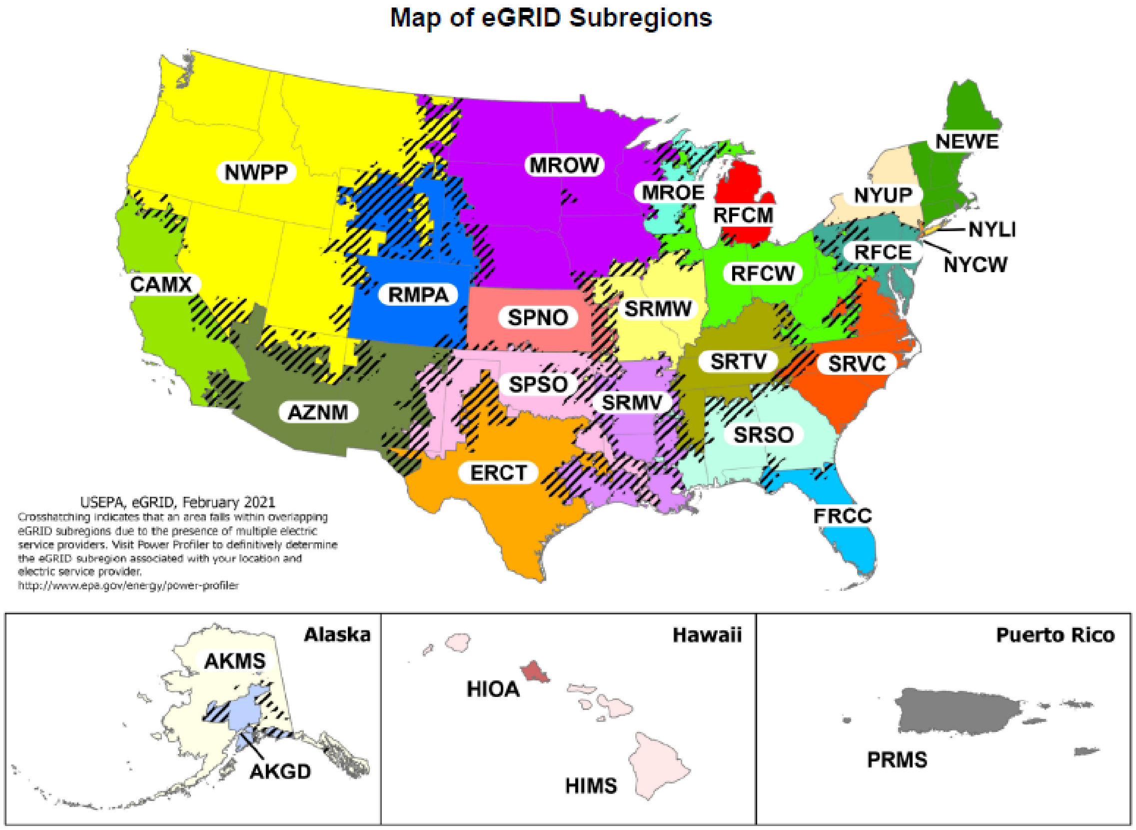
For example, releasing 1 kilogram of methane into the atmosphere is equivalent to releasing 25 kilogram of carbon dioxide. Consequently, fuels that release more methane, nitrous oxide, and other greenhouse gases will result in higher CO_2e. In particular, fuels that are dirtier and less refined result in a higher CO_2e due to the increased amount of sulfur, nitrogen, and other impurities that release greenhouse gases with higher GWP when burned. Even without factoring in GWP from the impurities, cleaner fuels release less carbon dioxide per energy produced because sulfur, nitrogen, and noncombustible elements in fuel reduce their heating value and increase their CO_2-to-heat content [4]. Table 2.2 shows various fuels and the typical pounds of CO_2 released per million British thermal units (BTU) of energy consumed.

Table 2.2: Pounds of CO_2 released per million British Thermal Unit (BTU) consumed for various fuels [4]

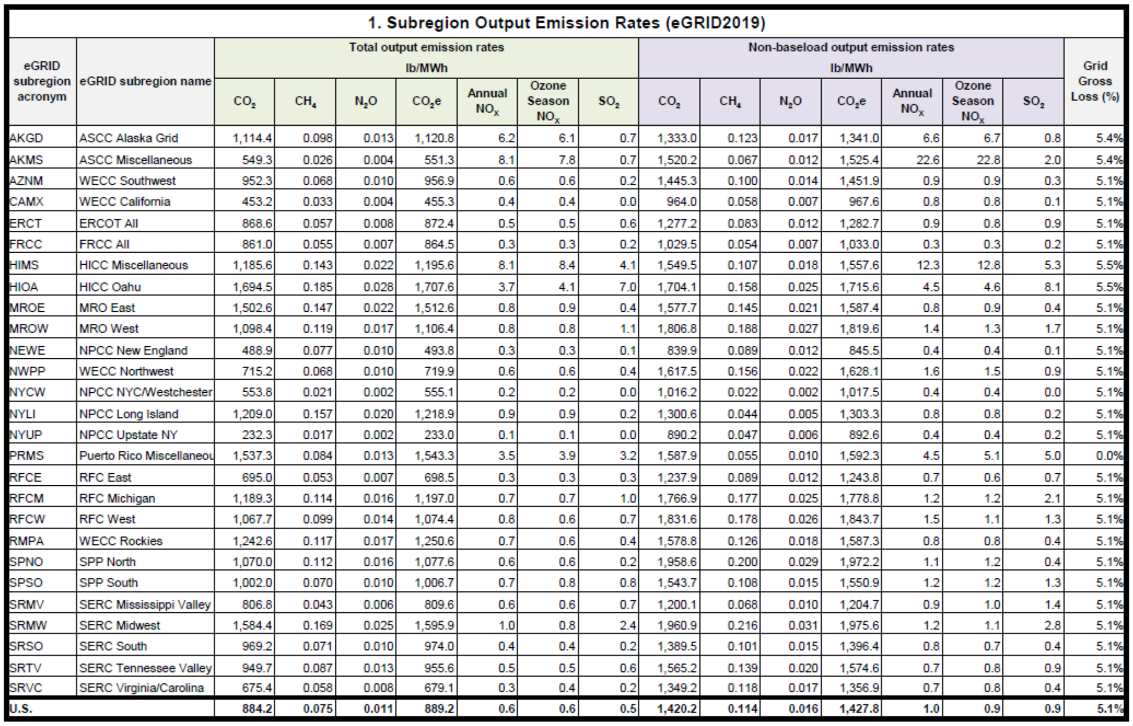


Fuel Source	Pounds of CO_2 per million British thermal units
1. Coal (lignite)	216.24
2. Diesel	163.45
3. Gasoline (without ethanol)	155.77
4. Propane	138.63
5. Natural gas	116.65

Since the chemical composition of fuel can change based on the type of fuel, region where it was sourced, and pre-treatment before burning, the resulting CO_2e will vary when burned. To a smaller degree, operational efficiency can also impact the amount of fuel burned and consequently carbon emissions. This results in different carbon emissions at different facilities, including electrical generation plants, which ultimately results in varying carbon emissions at different sites even if required energy is identical. Figure 2-2 shows the typical emission grid factor in different regions in the United States to show how widely $CO2_e$ can vary and impact a site's Scope 2 carbon emissions.



USEPA, eGRID, February 2021
Crosshatching indicates that an area falls within overlapping eGRID subregions due to the presence of multiple electric service providers. Visit Power Profiler to definitively determine the eGRID subregion associated with your location and electric service provider.
http://www.epa.gov/energy/power-profiler



1. Subregion Output Emission Rates (eGRID2019)

eGRID subregion acronym	eGRID subregion name	Total output emission rates lb/MWh							Non-baseload output emission rates lb/MWh							Grid Gross Loss (%)
		CO_2	CH_4	N_2O	CO_2e	Annual NO_x	Ozone Season NO_x	SO_2	CO_2	CH_4	N_2O	CO_2e	Annual NO_x	Ozone Season NO_x	SO_2	
AKGD	ASCC Alaska Grid	1,114.4	0.098	0.013	1,120.8	6.2	6.1	0.7	1,333.0	0.123	0.017	1,341.0	6.6	6.7	0.8	5.4%
AKMS	ASCC Miscellaneous	549.3	0.026	0.004	551.3	8.1	7.8	0.7	1,520.2	0.067	0.012	1,525.4	22.6	22.8	2.0	5.4%
AZNM	WECC Southwest	952.3	0.068	0.010	956.9	0.6	0.6	0.2	1,445.3	0.100	0.014	1,451.9	0.9	0.9	0.3	5.1%
CAMX	WECC California	453.2	0.033	0.004	455.3	0.4	0.4	0.0	964.0	0.058	0.007	967.6	0.8	0.8	0.1	5.1%
ERCT	ERCOT All	868.6	0.057	0.008	872.4	0.5	0.5	0.6	1,277.2	0.083	0.012	1,282.7	0.9	0.8	0.9	5.1%
FRCC	FRCC All	861.0	0.055	0.007	864.5	0.3	0.3	0.2	1,029.5	0.054	0.007	1,033.0	0.3	0.3	0.2	5.1%
HIMS	HICC Miscellaneous	1,185.6	0.143	0.022	1,195.6	8.1	8.4	4.1	1,549.5	0.107	0.018	1,557.6	12.3	12.8	5.3	5.5%
HIOA	HICC Oahu	1,694.5	0.185	0.028	1,707.6	3.7	4.1	7.0	1,704.1	0.158	0.025	1,715.6	4.5	4.6	8.1	5.5%
MROE	MRO East	1,502.6	0.147	0.022	1,512.6	0.8	0.9	0.4	1,577.7	0.145	0.021	1,587.4	0.8	0.9	0.4	5.1%
MROW	MRO West	1,098.4	0.119	0.017	1,106.4	0.8	0.8	1.1	1,806.8	0.188	0.027	1,819.6	1.4	1.3	1.7	5.1%
NEWE	NPCC New England	488.9	0.077	0.010	493.8	0.3	0.3	0.1	839.9	0.089	0.012	845.5	0.4	0.4	0.1	5.1%
NWPP	WECC Northwest	715.2	0.068	0.010	719.9	0.6	0.6	0.4	1,617.5	0.156	0.022	1,628.1	1.6	1.5	0.9	5.1%
NYCW	NPCC NYC/Westchester	553.8	0.021	0.002	555.1	0.2	0.2	0.0	1,016.2	0.022	0.002	1,017.5	0.4	0.4	0.0	5.1%
NYLI	NPCC Long Island	1,209.0	0.157	0.020	1,218.9	0.9	0.9	0.2	1,300.6	0.044	0.005	1,303.3	0.8	0.8	0.2	5.1%
NYUP	NPCC Upstate NY	232.3	0.017	0.002	233.0	0.1	0.1	0.0	890.2	0.047	0.006	892.6	0.4	0.4	0.2	5.1%
PRMS	Puerto Rico Miscellaneou	1,537.3	0.084	0.013	1,543.3	3.5	3.9	3.2	1,587.9	0.055	0.010	1,592.3	4.5	5.1	5.0	0.0%
RFCE	RFC East	695.0	0.053	0.007	698.5	0.3	0.3	0.3	1,237.9	0.089	0.012	1,243.8	0.7	0.6	0.7	5.1%
RFCM	RFC Michigan	1,189.3	0.114	0.016	1,197.0	0.7	0.7	1.0	1,766.9	0.177	0.025	1,778.8	1.2	1.2	2.1	5.1%
RFCW	RFC West	1,067.7	0.099	0.014	1,074.4	0.8	0.6	0.7	1,831.6	0.178	0.026	1,843.7	1.5	1.1	1.3	5.1%
RMPA	WECC Rockies	1,242.6	0.117	0.017	1,250.6	0.7	0.6	0.4	1,578.8	0.126	0.018	1,587.3	0.8	0.8	0.4	5.1%
SPNO	SPP North	1,070.0	0.112	0.016	1,077.6	0.6	0.6	0.2	1,958.6	0.200	0.029	1,972.2	1.1	1.2	0.4	5.1%
SPSO	SPP South	1,002.0	0.070	0.010	1,006.7	0.7	0.8	0.8	1,543.7	0.108	0.015	1,550.9	1.2	1.2	1.3	5.1%
SRMV	SERC Mississippi Valley	806.8	0.043	0.006	809.6	0.6	0.6	0.7	1,200.1	0.068	0.010	1,204.7	0.9	1.0	1.4	5.1%
SRMW	SERC Midwest	1,584.4	0.169	0.025	1,595.9	1.0	0.8	2.4	1,960.9	0.216	0.031	1,975.6	1.2	1.1	2.8	5.1%
SRSO	SERC South	969.2	0.071	0.010	974.0	0.4	0.4	0.2	1,389.5	0.101	0.015	1,396.4	0.8	0.7	0.4	5.1%
SRTV	SERC Tennessee Valley	949.7	0.087	0.013	955.6	0.5	0.5	0.6	1,565.2	0.139	0.020	1,574.6	0.7	0.8	0.9	5.1%
SRVC	SERC Virginia/Carolina	675.4	0.058	0.008	679.1	0.3	0.4	0.2	1,349.2	0.118	0.017	1,356.9	0.7	0.8	0.4	5.1%
U.S.		**884.2**	**0.075**	**0.011**	**889.2**	**0.6**	**0.6**	**0.5**	**1,420.2**	**0.114**	**0.016**	**1,427.8**	**1.0**	**0.9**	**0.9**	**5.1%**

Figure 2-2: Map and corresponding chart showing typical emission grid factors (lb/MWh) of CO_2e for different regions in the United States [2]

A corporation can have three types of carbon emissions and are broken down into Scope 1, Scope 2, and Scope 3 emissions.

- Scope 1 - emissions that occur from sources that are controlled or owned by a corporation such as fuel burned by heaters, vehicles, or boilers.
- Scope 2 - emissions incurred to produce electricity, steam, or other mediums for heating or cooling that the corporation indirectly is responsible for [22].
- Scope 3 - emissions from activities and assets not owned or controlled by the corporation but are the result of the corporation's impact on its value chain. For example, this could be emissions resulting from the creation of raw materials a company purchases and consumes, or from retailers who purchase the finished goods from the company and sell it in the market [23].

Amgen's current carbon neutrality goal only pertains to Scope 1 and Scope 2 carbon emissions, so the rest of this thesis will focus on Scope 1 and Scope 2 carbon emissions.

To reach carbon neutrality, a corporation must negate the same amount of carbon dioxide it is responsible for [24]. Beyond implementing projects to reduce the consumption of energy which would result in less fuel burned or utilities consumed, companies can attempt to reach carbon neutrality in other ways. For scope 1 emissions, corporations can purchase cleaner fuels, switch to a cleaner fuel type, electrify equipment (pushing emissions to Scope 2 emissions), or buy offsets. Offsets are instruments that reflect the metric tons of CO_2e a project has reduced. Companies can purchase these offsets to counteract Scope 1, Scope 2, or Scope 3 emissions. To be verified, the project must be deemed additional, emissions reductions must be real, permanent, and verified, and the offset issued must be enforceable [25]. For Scope 2 emissions, corporations can implement their own clean energy projects, work with local utility providers or government officials to reduce the emission grid factors, or purchase clean energy in the form of Renewable Energy Certificates (RECs). RECs are legal instruments that corporations can purchase and are used to account for the amount of clean electricity purchased to counteract Scope 2 emissions only [25].

Water

A McKinsey analysis of water consumption shows that by 2030, demand for water will outstrip supply by 40 percent, resulting in half of the world's population living in water-scarce areas [26]. Of the water consumed today, approximately two-thirds is consumed by corporations in producing ingredients and manufacturing their products; therefore, corporations can play a major role in shaping the world's future water ecosystem [27]. Water consumption is measured as any water corporations use from municipalities, well water, or other natural sources. The water can be used in many different ways including to cool processes, produce steam, be consumed in manufacturing process, and used in restrooms [28]. Water usage reduction can come from installation of water efficient sinks and toilets, more efficient heat exchangers, changing the formulation of a product, or changing the manufacturing process, to name a few examples.

Waste

Landfills are needed for solid waste disposal and have many benefits including reducing the amount of waste in the environment, prevent disease transmission, and keep communities clean. At the same time, landfills pose many sustainability challenges. Some of the challenges include the release of methane and other greenhouse gasses into the atmosphere, destruction of natural habitats, and leakage of leachate (liquid produced at landfills) into nearby water sources [29]. Sustainability in the context of landfills can be defined as "the safe disposal of waste within a landfill, and its subsequent degradation to inert state in the shortest possible time-span, by the most financially efficient method available, and with minimal damage to the environment" [30]. Corporations can lower their waste by trying to reuse or repurpose waste, recycle, or compost. Other ways corporations can reduce waste is changing the raw materials inputs for more sustainable alternatives and changing their manufacturing process to increase yield.

2.2.2 Biotechnology Sector and Amgen's impact

In 2020, businesses consumed 51% of U.S.'s energy, 33% of which were from industrial companies. This energy consumption doesn't include energy consumed from transporting goods and people for business needs [31]. Biotechonlogy companies typically produce at a smaller scale compared to other industrial companies that produce common goods; however, biotechnology companies have their unique challenges that require more energy input. Some of these challenges and the associated sustainability impacts will be highlighted below. This is not an exhaustive list but will provide some insights into the major drivers for environmental impact.

Carbon Emissions

One of the primary differences among biopharma manufacturing and many different industries is the level of cleanliness in the manufacturing facility. Drugs are grown with living organisms and are consumed by sick patients; therefore, maintaining a sterile environment without contamination is paramount for the ability to grow the host cells and for the safety of the patients. Cleanrooms can be defined as a room in which the concentration of airborne particles are controlled to minimize introduction, generation, and retention of particles [32]. Different parts of the manufacturing process have different cleanroom classifications based on the purpose of the room. Biopharma companies typically operate between Class 100 and Class 100,000 in their manufacturing or lab facilities. The classifications within this range are listed below with a description.

- Class 100 - less than 100 particles greater than 0.5 microns in size per cubic foot in the environment.
- Class 10,000 - less than 10,000 particles greater than 0.5 microns in size per cubic foot in the environment.
- Class 100,000 - less than 100,000 particles greater than 0.5 microns in size per cubic foot in the environment [33].

Maintaining the classification of the cleanroom is accomplished by controlling the temperature, humidity, and pressure of the room. In addition, purging the rooms air and bringing in fresh air, also known as air changes, are used to maintain a sterile environment. All of these steps are energy intensive and require heating and cooling to maintain. Moreover, the air changes require additional energy input to cool or heat the ambient air since the temperature of ambient air is further from the facility's temperature control point when compared to the temperature of the recycled air [33]. Assuming the facility does not generate its own electricity, cooling will typically consume electricity and produce Scope 2 emissions while heating will typically consume fuel and produce Scope 1 emissions.

In addition to maintaining cleanrooms, biotechnology companies need to decontaminate their equipment before each biologic lot is produced. For traditional bio-manufacturing companies, this involves steaming the equipment to remove and kill contaminants [33]. The steam is produced in boilers where treated water is heated by burning a fuel source. Consequently, using steam to sterilize equipment will produce Scope 1 emissions.

Finally, the biologics are unstable drugs at high temperatures; therefore, they require storage at low temperatures through refrigeration or freezing. The specific storage condition is dependent on the product. The purpose of storing these compounds at low temperatures is to maintain the drug's molecular structure and maintain the drug's safety, purity, and potency [34]. Consequently, any inventory that Amgen or other bio-manufacturing companies produce will likely have to be stored in a cold room, requiring additional electricity and resulting in additional Scope 2 emissions. Amgen has a commitment to ensure its medicine is available for "every patient, every time" [35]. To ensure this commitment is met, Amgen will need adequate safety stock stored in its facilities.

Water Usage

Two use cases for water that differentiate biotechnology from other industries is using water for injection (WFI) and using water to produce steam for cleaning. The latter was described above, so it will not be repeated here. Water used for injection goes through many steps of filtering and distilling to purify and significantly lower the microbial activity level. This water is used to clean manufacturing equipment, mix into cell culture media, and dilute active ingredients to produce drug products that humans can consume. Beyond the consumption of water, WFI is stored at 65-80 degrees Celsius (149-176 degrees Fahrenheit) to minimize chances for microbial contamination [33]. This will require additional energy consumption to maintain the desired temperatures.

Waste Generation

Biowaste is the more obvious waste that is unique to biologic manufacturing. Once the protein or active ingredient is separated from the host cell, the cells and culture media must be disposed of. Another source of waste comes from the form of single use plastics. This is a more recent technology that enables bio-manufacturers to line their reactors and equipment with plastic to produce a lot of drugs. Once the lot is finished, they can remove the plastic and dispose of it while quickly moving on to starting the next lot production. Studies have shown that the energy consumption for single use plastics are half of the energy required from stainless steel systems when factoring in sterilization and cleaning [36]. Companies have also experienced reduction in facility size without sacrificing production volume as showcased by Amgen's Singapore facility which is 75% smaller than a traditional facility would have been [37].

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Chapter 3

Problem Solving Methodology

Forecasting carbon, water, and waste changes for projects that did not go through the capital expense funding process is a broad problem. This section will focus on the approach and framework developed to help methodically narrow down the scope for further investigation.

3.1 Approach

The approach taken was to break down Amgen's activities into a few buckets that were mutually exclusive and completely exhaustive (MECE). Mutually exclusive means that the buckets and associated activities in these buckets do not overlap with other buckets or activities. Completely exhaustive means that combining all the buckets will capture all of Amgen's activities. By doing so, Amgen's activities can be broken down and grouped into more manageable sizes for analysis without the risk of overlooking certain parts of the business.

3.2 Amgen's Framework

Amgen's activities were broken down into four main buckets: manufacturing, drug development, fleet, and administration (admin). Manufacturing is meant to capture any activities associated with taking raw products and transforming them into finished goods. The more obvious activities include DS, DP, and FDP production, but this bucket also includes quality checks, storage of finished goods, and many more. Drug development is meant to capture any activities associated with discovering a drug and getting it approved by the FDA. These activities include lab experiments, pilot plants, clinical manufacturing, etc. Fleet is associated with any transport of goods or people with Amgen owned vehicles. This could include transportation of finished drugs to buyers, shuttles used to bring employees to campuses, or employees traveling to different sites. Finally, admin is related to any other activities that keep Amgen running. This could include utilities and energy for office buildings and utilities used for landscaping. These buckets follow the previous approach of being MECE and are the foundation on which this thesis's forecasting is built off.

3.3 Methodology for Analysis

Based on the above framework in Section 3.2, activities from certain buckets were used for analysis to help forecast Amgen's future emissions. Before dividing and analyzing possible activities, Amgen's forecasting accuracy needs were considered. Talking with leadership, a rough ballpark forecast was needed for the years that were far out. Since only a ballpark forecast was required, the buckets were weighed against each other to determine which one had a larger impact on emissions. Then an activity or two within that bucket that had a large impact were chosen to investigate and help understand the change in future emissions. It is important to note that this approach helps identify the primary drivers for emissions growth but may not capture it all. For a higher degree of accuracy, one can investigate another impactful bucket and its associated primary drivers. Going after additional drivers does come at a cost of diminished returns and must be evaluated against the gain from the increased accuracy. It is also important to note that this exercise should be done separately for each environmental category (carbon, water, and waste). After understanding how key emissions drivers affect emissions, the key drivers are then incorporated into an excel model to intuitively forecast future emissions.

For the thesis, Amgen's carbon emissions were chosen as the environmental impact to focus on. Within carbon emissions, the manufacturing bucket was determined as the most influential area for future emissions growth, primarily due to the need to meet the anticipated drug supply increases. Within manufacturing, DS production was deemed the most energy intensive; therefore, understanding how carbon emissions grow with increased DS production was chosen for analysis. The type of analysis will depend on the organization's need for accuracy and for use afterwards. The analysis and impact for DS production growth will be discussed in Chapter 4.

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Chapter 4

Use Case: Carbon Emissions Forecasting for Manufacturing

To help demonstrate how the framework can be utilized to enable organizations to analyze and evaluate their emissions footprint, Amgen's carbon emissions will be evaluated as a use case. More specifically, the use case will focus on the manufacturing bucket as this was determined by leaders within the organization to have the greatest contribution to emissions.

4.1 Emissions Drivers and Rationale

From discussions with leaders and subject matter experts within Amgen, DS production was determined to be a primary driver for carbon emissions growth within manufacturing. DS production is one of the more energy intensive step in a drug manufacturing process and requires energy to to maintain cleanroom standards for large manufacturing buildings [33]. Many of Amgen's sites that consume more energy have a DS plant. Moreover, increases in production should require more energy and increase carbon emissions. Some factors that would increase carbon emissions include the energy input to the process and steam needed to clean the reactors.

During the manufacturing process, cell lines are operating for many weeks before the drug substance is ready to be harvested and purified. During this period the reactors need to be held at a certain temperature. As manufacturing lots increase, the average utilization of the cell lines will increase, resulting in additional energy used for the production process.

Similarly, the increase in drug lots produced will require additional cleaning between each run. Since Amgen uses traditional stainless steel reactors in some of its manufacturing processes, these reactors, piping, and other associated equipment will need to be cleaned with steam. As discussed in Chapter 2, steam requires energy input to create.

Finally, DS production requires cleanrooms to be operated whenever a plant is running; therefore, increases in cell line utilization will not necessarily use more energy. However, they still require a lot of energy and may result in large emissions jumps if additional facilities need to be built.

4.2 Initial Hypothesis

The initial hypothesis was that the carbon emissions growth from increased DS production would not be so substantial as to materially change Amgen's current plan to meet carbon neutrality by 2027. This hypothesis was formulated after discussions with Amgen's Environmental Team and based on preliminary analysis from the Sustainability Analytics Team. Amgen's Environmental Team believed that the fixed energy required to run a DS plant was so high, that the variable energy needed to produce additional lots would not materially impact the total energy consumed. Fixed energy with respect to DS production is any energy usage that remains the same regardless of whether DS production volume increases or decreases. Examples include energy for cleanrooms, storage of DS or raw materials, and other energy used for non-DS production related activities. Conversely, variable energy with respect to DS production is any energy usage that changes when DS production volume increases or decreases. Examples include energy to clean equipment, to maintain process temperatures, and to run manufacturing equipment.

To help support their belief, the Sustainability Analytics Team had also analyzed how facility's total building area correlates with energy usage for all of Amgen's facilities through a linear regression and found a strong correlation ($R^2 = 0.88$).

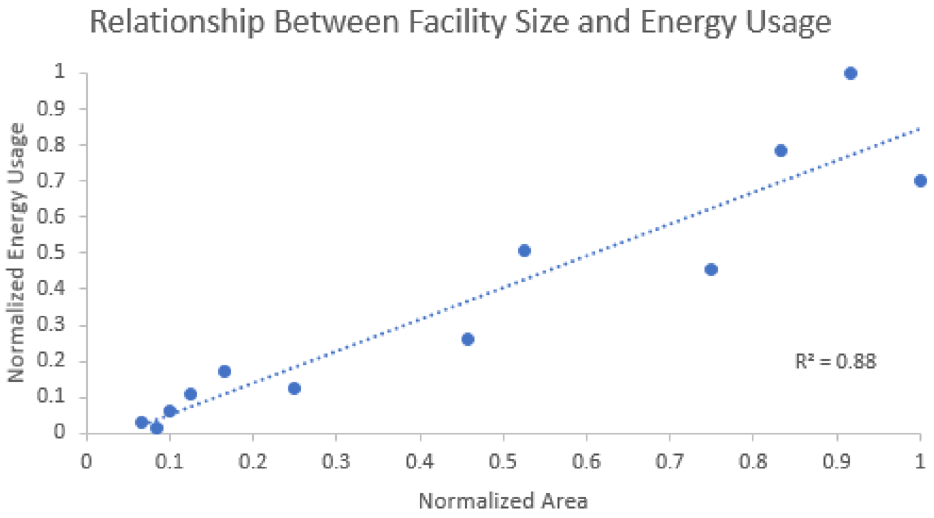


Figure 4-1: Normalized total building area versus relative energy usage for hypothetical Amgen facilities.

Figure 4-1 sends a similar message to the one created by the Sustainability Analytics Team; however, the data used was fabricated to mask potentially sensitive data. Furthermore, the facility's total building area and energy usage were scaled to between zero and one to mask the actual values of the facility's areas and emissions. Each facility's normalized energy usage, not carbon emissions, is plotted against its normalized area, and a linear regression is created to evaluate the correlation. As seen in Figure 4-1, there is a strong correlation between normalized area and normalized energy usage which further strengthens the initial hypothesis.

It is important to note that energy usage which contains Scope 1 and Scope 2 energy in kilowatts per hour, kWh, is used for this analysis. Carbon emissions are not used because each facility's grid carbon emissions factor could be different which may make certain sites seem more energy efficient than others. Moreover, Amgen has little influence or control of the grid emissions factors. Consequently, energy usage is analyzed to understand potential energy increases which can then be converted to carbon emissions.

4.3 Consideration for Types of Analysis

Desired business outcomes were evaluated to determine the best type of analysis to conduct. Amgen wanted to learn how much of their DS production energy was fixed versus variable and understand how energy usage varied across different sites. Knowing how much of the energy usage was fixed versus variable was important because it could help focus efforts regarding how best to reduce energy usage. For example, if the energy was found to be highly variable with production, Amgen can look into engineering the manufacturing process to be more energy efficient instead of focusing on efforts to reduce energy usage of the cleanroom. Understanding how energy usage varied across sites was also desired because each DS manufacturing sites had different manufacturing technologies, produced different drugs, and operated in different climates; therefore, seeing if and how these factors correlated with energy usage could help Amgen understand how to minimize energy usage when building new DS plants.

Due to the reasons listed above, the analysis chosen for this use case was to build multivariate linear regressions to fit historical energy usage for different DS plants. Each plant would have its own regression. The intercept of the regression would tell us how much of the energy is fixed relative to the independent variables chosen for the analysis. The coefficients for the independent variables indicates how much variable energy is associated with its respective independent variable. Finally, the analysis will indicate which independent variables are significantly correlated with energy usage.

4.4 Data Used

Data used for this analysis came from Amgen's internal databases as well as publicly available data. In particular, Scope 1 and Scope 2 energy usage came from utility bills, weather data sourced through local weather stations, and manufacturing data from internal databases. For the purposes of this thesis, the data behind the analysis presented has been altered to mask confidential information.

These data were gathered from four Amgen DS production sites and over a six year period from January 2015 until March 2021. Since the utility bills aggregate utility usage for a month, other data is aggregated to match the same timeframe. This results in only 12 data points per year for each site; therefore, the six-year timeframe was selected to ensure enough data was used to statistically understand potential correlations. One challenge that arose from this long time horizon is that Amgen has made progress in reducing its energy consumption over the selected timeframe; therefore, a new variable was created called "Time Elapsed" to capture the potential change in energy consumption over time due to reasons beyond those captured by the independent variables included.

All the data were reviewed for validity and to ensure sufficient variability to produce meaningful results.

4.4.1 Utility Bills

Amgen receives utility bills once a month for their utility usage in the previous month. The utility and waste bills capture the ground truth for electricity, natural gas (or other carbon based fuel), water, and waste usage. These bills are then entered into a software platform that Amgen calls Global EH&S Tracking System (GETS) which will convert the energy usage into carbon emissions based on the fuel type and local grid emissions factors. GETS also serves as a reporting tool and allows export of this information for analysis.

For the analysis, the raw monthly usage for carbon based fuels and electricity was gathered. These values were then converted to kWh to have the same unit. The values were then added together for each month to create the total energy usage for each site. Carbon based fuel usage in kWh was used to represent Scope 1 energy usage, and electricity usage in kWh was used to represent Scope 2 energy usage. All three variables will be used as the dependent variable for different regression analysis.

4.4.2 Weather

Weather was selected as an independent variable because it was hypothesized that the correlation between facilities' total building area and energy usage was largely driven by running a cleanroom and that weather influences the amount of variable energy a cleanroom needs to use to maintain conditions. Weather data was collected using application programming interface (API) calls to weather stations nearby Amgen's four DS production facilities. The data returned was the daily average temperature in Fahrenheit. This data was then converted into heating degree days (HDD) and cooling degree days (CDD) and summed over a month for each site.

HDD is meant to measure the amount of heating needed to maintain a base temperature of 65 degrees Fahrenheit ($^\circ F$). CDD is the opposite and measures the amount of cooling needed to maintain a base temperature of 65 $^\circ F$. Consequently, HDD for a day is calculated when the daily average temperature falls below 65 $^\circ F$ with Equation 4.1, and CDD for a day is calculated when daily average temperature rises above 65 $^\circ F$ with Equation 4.2.

$$HDD = 65 - T \qquad \text{if } T \leq 65^\circ F \tag{4.1}$$

$$CDD = T - 65 \qquad \text{if } T \geq 65^\circ F \tag{4.2}$$

Any days with an average temperature of 65 $^\circ F$ has zero HDD and CDD [38]. These daily values are then summed over a month to reflect the CDD and HDD of a site for that month. For example, if a 30-day month has half of the days with a daily average temperature of 80 $^\circ F$ and the other half with a daily average temperature of 55 $^\circ F$, then the HDD for the days below 65 $^\circ F$ is 10 $^\circ F$ and the CDD for the days above 65 $^\circ F$ is 15 $^\circ F$. Adding up all the degree days for the month results in an HDD of 150 $^\circ F$ and CDD of 225 $^\circ F$.

65 $^\circ F$ is used as the base temperature because that represents the balance point where if ambient temperature goes higher or lower, a building will require cooling or heating respectively. The base temperature does not represent the internal thermostat temperature as other factors within the building, including heat from equipment or

people, will typically increase a building's internal temperature. Although the internal thermostat temperature will vary based on building type and purpose, regions, and personal preferences, the industry norm is to use 65 $^{\circ}F$ as the base temperature [39].

4.4.3 Manufacturing Quantity

Manufacturing quantity, specifically lots produced, is another independent variable selected for this analysis. This variable is selected because increases in lot production is viewed as a potential driver for increases in energy usage. Lot production data was gathered from Amgen's internal databases. The specific data used was number of manufacturing lots run within a specific month. This was determined by using the start date of the lot production run to assign it to that month. Then the corresponding number of lots for a specific month was added up to determine the total number of lots for that month.

Some lot production did span across multiple months, especially if the lot was started closer to the end of the month. This will create a mismatch between the energy used for production and the month of production, consequently making it more difficult to determine if energy correlates with lot production. Despite this, lots spanning multiple months were not common and therefore should not make a substantial impact on the analysis.

4.4.4 Days Elapsed

To help capture the changes in energy usage over time due to other reasons not captured by weather or production, each day from January 1, 2015 is counted and the number of days elapsed from that day is used for each month. The days elapsed since January 1,2015 at a start of the month was taken as the value of the Time Elapsed variable for that month. For example, January 2015 would have 0 days elapsed and February 2015 would have 31 days elapsed. This variable is used as an independent variable in the regression analysis.

4.5 Multivariate Regression Analysis and Results

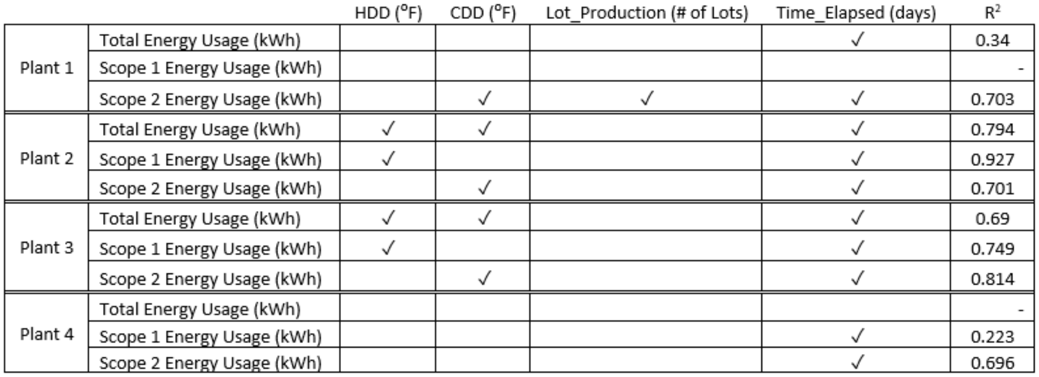
All the variables discussed in Sections 4.4.1, 4.4.2, 4.4.3, and 4.4.4 were used in the multivariate analysis. Adding additional variables was discussed and was an option if we could not determine any correlation for emissions at these sites or a higher level of accuracy was desired. After the data was cleaned and aggregated at a monthly level for the four DS plants, statsmodels' linear regression package was used to develop the models. All the independent variables - HDD, CDD, Lot Production, and Time Elapsed - were used in the initial run. Then independent variables greater than the 0.05 significance threshold were removed.

For each facility, three separate models were estimated for total energy usage (Scope 1 and Scope 2 energy usage combined) in kWh, Scope 1 energy usage in kWh, and Scope 2 energy usage in kWh. Three separate models were created for two reasons. First, Amgen wanted to understand how the increase in lot production affected Scope 1 and Scope 2 energy usage because the corresponding carbon emissions require different countermeasures to reach carbon neutrality. Second, it was possible that the total energy usage might not have sufficient variations to identify a correlation with Lot Production. By breaking the energy usage into smaller categories, there would be a higher chance of finding a correlation if lot production affected one type of energy usage more. After the models were created, the final results were reviewed with the team for validation.

4.5.1 Results

Table 4.1 shows which independent variables (HDD, CDD, Lot Production, Time Elapsed) are significant at the 0.05 significance level from multivariate linear regression analysis for the four plants and the corresponding R^2.

Table 4.1: Table representing which independent variables are significant and the corresponding R^2 for the regression model.



		HDD (°F)	CDD (°F)	Lot_Production (# of Lots)	Time_Elapsed (days)	R^2
Plant 1	Total Energy Usage (kWh)				✓	0.34
	Scope 1 Energy Usage (kWh)					-
	Scope 2 Energy Usage (kWh)		✓	✓	✓	0.703
Plant 2	Total Energy Usage (kWh)	✓	✓		✓	0.794
	Scope 1 Energy Usage (kWh)	✓			✓	0.927
	Scope 2 Energy Usage (kWh)		✓		✓	0.701
Plant 3	Total Energy Usage (kWh)	✓	✓		✓	0.69
	Scope 1 Energy Usage (kWh)	✓			✓	0.749
	Scope 2 Energy Usage (kWh)		✓		✓	0.814
Plant 4	Total Energy Usage (kWh)					-
	Scope 1 Energy Usage (kWh)				✓	0.223
	Scope 2 Energy Usage (kWh)				✓	0.696

Stemming from the understanding that facilities' emissions are strongly correlated with facility's total building area as shown in Figure 4-1, the expectation was that HDD would correlate strong with Scope 1 energy usage and CDD would correlate strongly with Scope 2 energy usage. This is based on the fact that fuel is typically burned for heating systems and electricity is used for air conditioning systems. DS plants require a lot of space and have a high cleanroom standard; therefore, the expectation was that energy usage based on weather changes would be observed.

The results revealed expected correlations for HDD and CDD when analyzing Plants 1, 2, and 3 except for Plant 1's Scope 1 energy usage and HDD; however, Plant 4 neither HDD nor CDD was significant in any of the models. It was later revealed that Plant 4 has an added layer of complexity due to the ability to generate electricity on-site by burning fuel. This effectively enables the plant to change the level of Scope 1 and Scope 2 energy usage which affects the ability to correlate the Scope 1 and Scope 2 energy usage to weather changes. Furthermore, there are inefficiencies when generating electricity which results in additional energy consumption. With changing levels of Scope 1 and Scope 2 energy consumption it also becomes difficult to correlate total energy to weather changes. Additional data to determine the level of changes could not be collected prior to the end of the internship; therefore, further analysis for Plant 4 had to be deferred to the future.

Another interesting result was that Lot Production was only significant for Plant 1's Scope 2 energy usage. The lack of correlation with energy usage for the rest of the plants supports the initial hypothesis that an increase in DS production would not materially affect Amgen's total carbon emissions. Another way of viewing this is that the amount of variable energy required to increase or decrease lot production for Plants 2, 3, and 4 are minimal. Hence, changes in lot production do not generate a sufficiently large impact on energy usage. A plausible explanation why Plant 1 has a correlation with Lot Production is that Plant 1 employs a more intensified DS manufacturing process which requires smaller building area. Plant 1 is only one-fifth the size of the second smallest area among Plant 2, 3, and 4. The reduction in size means the ratio of fixed energy usage to variable production energy usage is smaller than that of the larger facilities; consequently, there is an observable correlation between Lot Production and energy usage. Moreover, using the model for Plant 1's Scope 2 energy usage in Figure 4-2 in Section 4.5.2, Plant 1's variable energy due to lot production could be calculated and compared to Plant 1's total energy usage for that given month, revealing approximately 5-20% of Plant 1's total energy usage is due to variable production energy usage.

Figures 4-2 - 4-10 in Section 4.5.2 will illustrate in more detail the results for each plant and the breakdown in energy usage. Plant 4's results are excluded due to the reasons discussed above. Please note, for the purposes of this thesis, the data has been standardized in a way to obscure the original values; therefore the actual values shown are not relevant. Rather, the trends are more important. In addition, please note that the equations predicting energy usage is not used in the excel-based forecasting tool. The relationships learned between energy usage and key emissions drivers are modeled with the assumptions listed in Section 4.6.2.

4.5.2 Plant 1 - Energy Usage Models

Plots of Plant 1's energy usage and predicted energy usage based on the regression model for Total Energy Usage, Scope 1 Energy Usage, and Scope 2 Energy Usage are displayed in Figures 4-2 - 4-4.

Please note that some values for the predicted energy usage are missing due to an incomplete data set such as missing weather or production data. Months with missing data were ignored when conducting the regression analysis. This holds true for all the analysis in Section 4.5.3 and 4.5.4 as well.

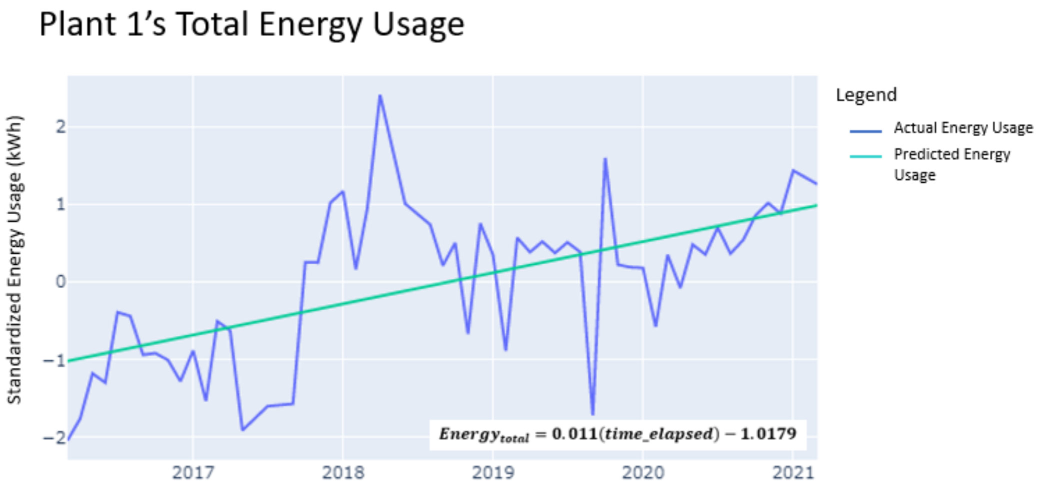


Figure 4-2: Plant 1's standardized total energy usage in kWh versus the predicted energy usage based on multivariate regression.

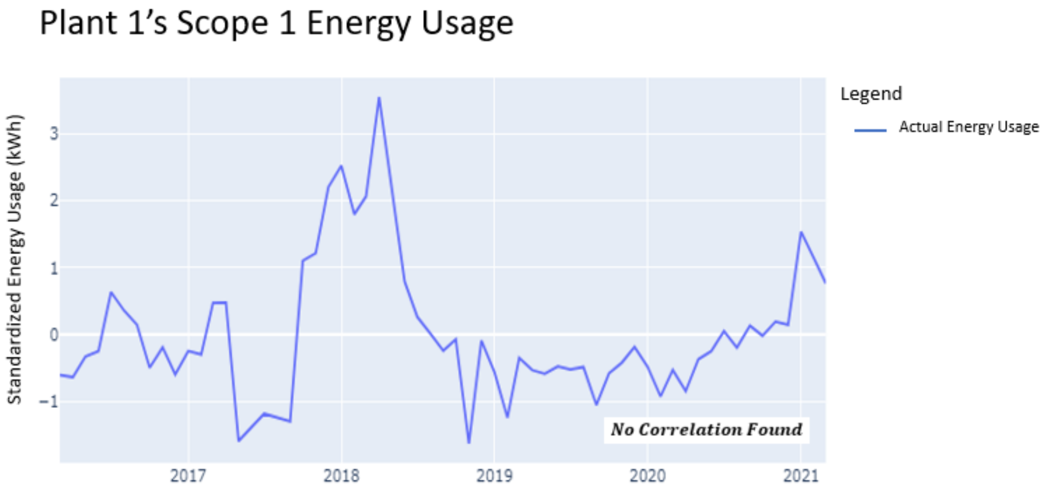


Figure 4-3: Plant 1's standardized Scope 1 energy usage in kWh versus. No predicted energy usage is plotted due to a lack of significant correlation from regression analysis.

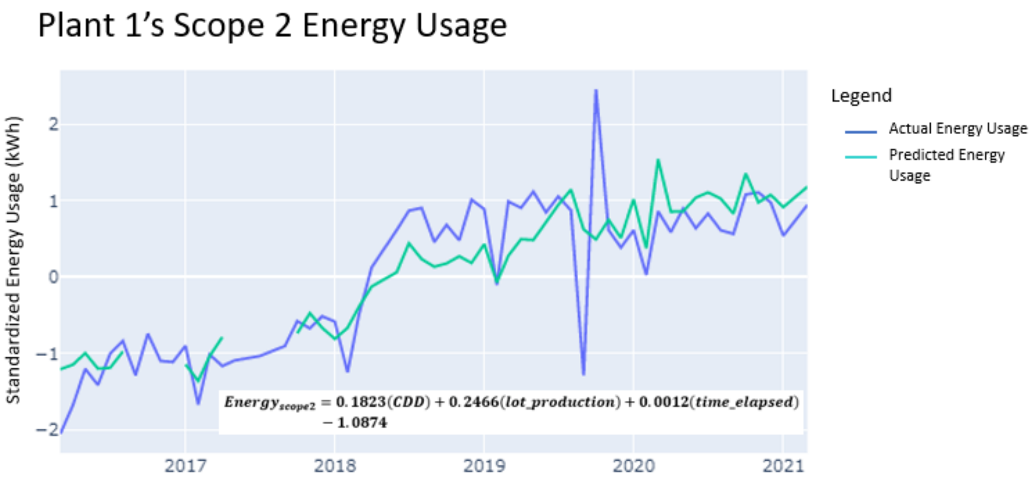


Figure 4-4: Plant 1's standardized Scope 2 energy usage in kWh versus the predicted energy usage based on multivariate regression.

Equations predicting Plant 1's Total Energy Usage and Scope 2 Energy Usage from the regression analysis are shown in Equations 4.3 and 4.4, respectively. Time Elapsed, Lot production, CDD, and HDD are represented by the variables t, p, c, and h, respectively.

$$\text{Energy}_{\text{total}} = 0.11t \tag{4.3}$$

$$\text{Energy}_{\text{scope2}} = 0.1823c + 0.2466p + 0.0012t - 1.0874 \tag{4.4}$$

As seen in Figure 4-2 and Equation 4.3, the predicted total energy usage for Plant 1 is simply a linear function of Time Elapsed. This is largely due to the fact that Plant 1's Scope 1 energy usage (Figure 4-3) constitutes the dominant component of its total energy usage and that the scope 1 energy usage is not correlated with any variables in the regression. Conversely, as shown in Figure 4-4, the model does a fairly good job of tracking with Plant 1's Scope 2 energy usage.

In addition, as seen in Equation 4.4, the slope for Lot Production is the largest, indicating that increasing production by one lot has a larger impact on Scope 2 energy usage than an increase of one unit for any other independent variable. Despite this, variable energy associated with lot production still only accounts for 5%-20% of Plant 1's total energy.

4.5.3 Plant 2 - Energy Usage Models

Plots of Plant 2's energy usage and predicted energy usage based on the regression model for Total Energy Usage, Scope 1 Energy Usage, and Scope 2 Energy Usage are displayed in Figures 4-5 - 4-7.

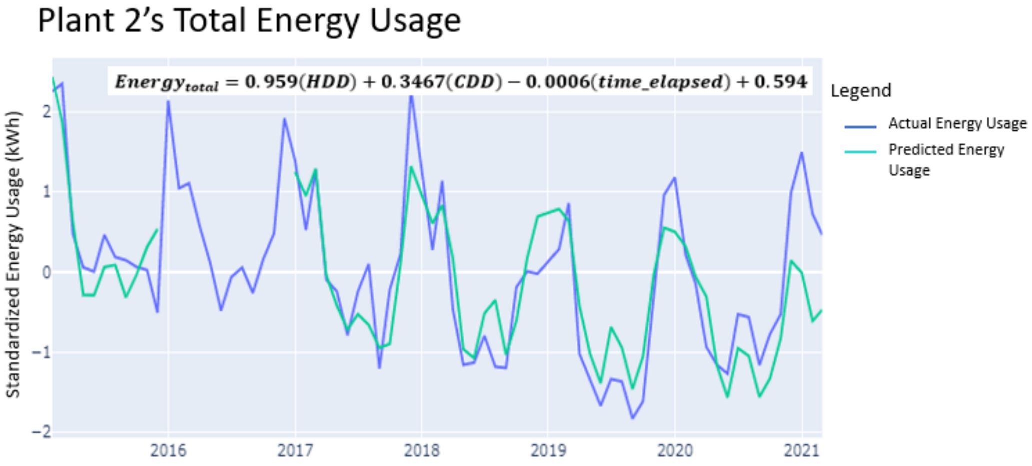


Figure 4-5: Plant 2's standardized total energy usage in kWh versus the predicted energy usage based on multivariate regression.

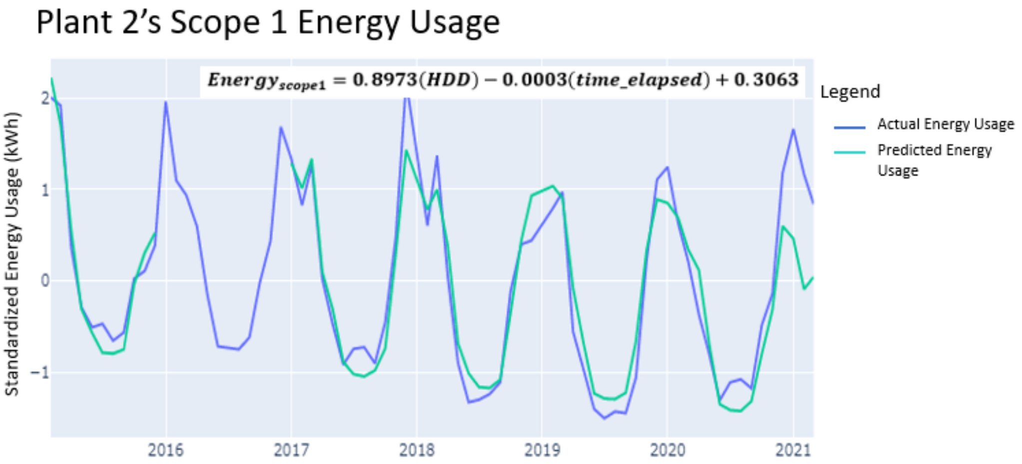


Figure 4-6: Plant 2's standardized Scope 1 energy usage in kWh versus the predicted energy usage based on multivariate regression.

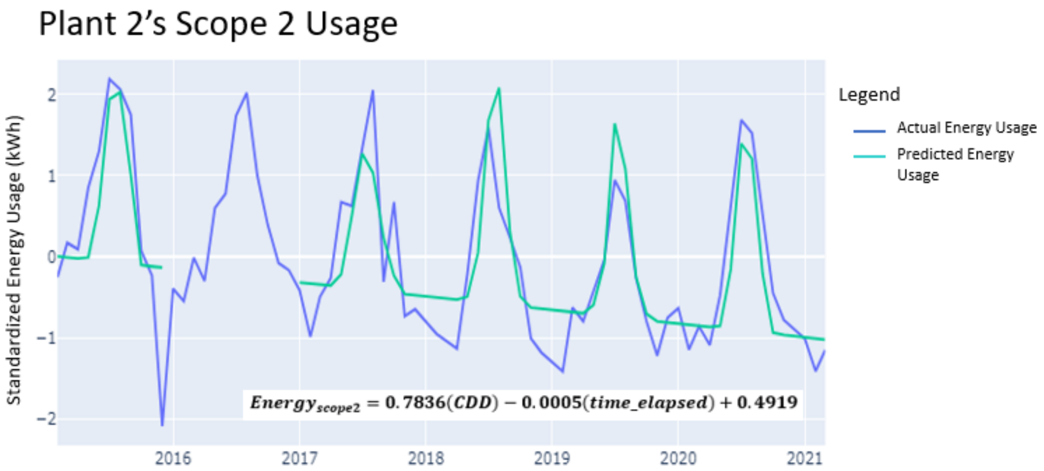


Figure 4-7: Plant 2's standardized Scope 2 energy usage in kWh versus the predicted energy usage based on multivariate regression.

Equations predicting Plant 2's Total Energy Usage, Scope 1 Energy Usage, and Scope 2 Energy Usage from the regression analysis are shown in Equations 4.5, 4.6, and 4.7, respectively.

$$\text{Energy}_{\text{total}} = 0.959h + 0.3467c - 0.0006t + 0.594 \tag{4.5}$$

$$\text{Energy}_{\text{scope1}} = 0.8973h - 0.0003t + 0.3063 \tag{4.6}$$

$$\text{Energy}_{\text{scope2}} = 0.7836c - 0.0005t + 0.4919 \tag{4.7}$$

As seen in Figure 4-5, Figure 4-6, and Figure 4-7, the variables HDD, CDD, and Time Elapsed do a very good job at capturing the energy usage trends for Plant 2. The one noticeable flaw can be observed in Figure 4-7; the model for Scope 2 Energy Usage does a poor job of capturing the oscillation during the winter months of the years (at the valley of the curve). This likely means there is another factor that influences energy usage during this period that is not captured in the model.

4.5.4 Plant 3 - Energy Usage Models

Plots of Plant 3's energy usage and predicted energy usage based on the regression model for Total Energy Usage, Scope 1 Energy Usage, and Scope 2 Energy Usage are displayed in Figures 4-8 - 4-10.

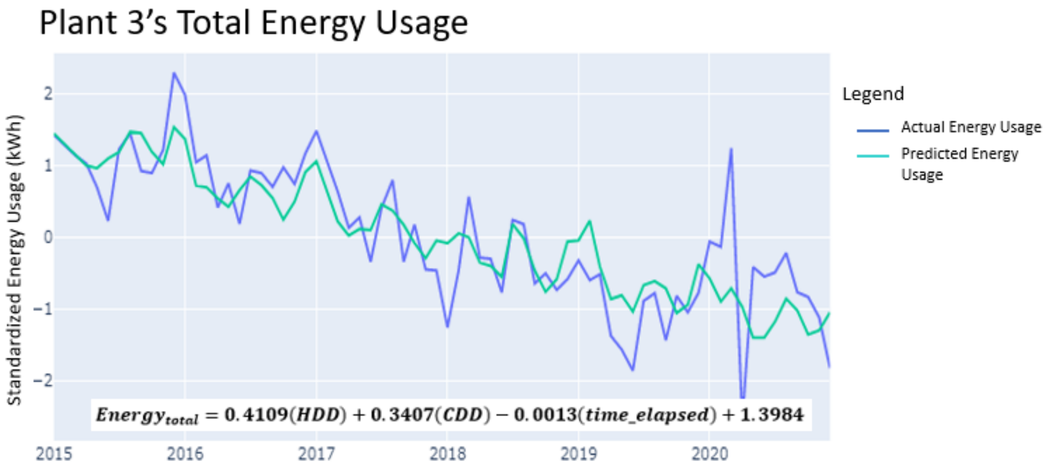


Figure 4-8: Plant 3's standardized total energy usage in kWh versus the predicted energy usage based on multivariate regression.

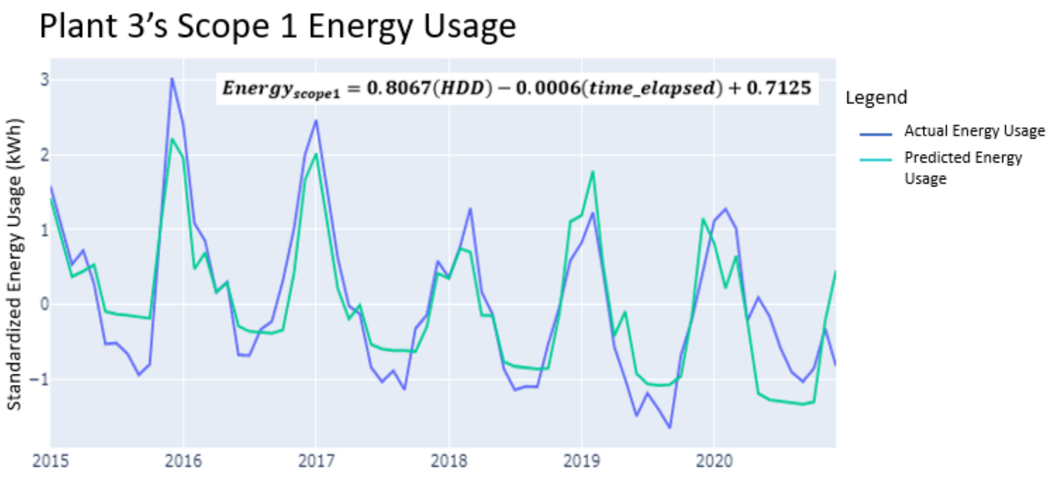


Figure 4-9: Plant 3's standardized Scope 1 energy usage in kWh versus the predicted energy usage based on multivariate regression.

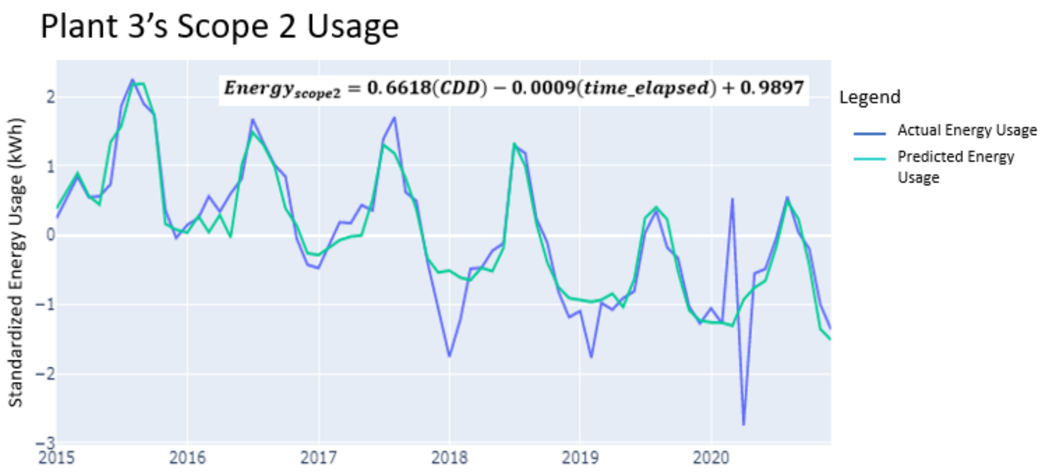


Figure 4-10: Plant 3's standardized Scope 2 energy usage in kWh versus the predicted energy usage based on multivariate regression.

Equations predicting Plant 3's Total Energy Usage, Scope 1 Energy Usage, and Scope 2 Energy Usage from the regression analysis are shown in Equations 4.8, 4.9, and 4.10, respectively.

$$\text{Energy}_{\text{total}} = 0.4109h + 0.3407c - 0.0013t + 1.3984 \tag{4.8}$$

$$\text{Energy}_{\text{scope1}} = 0.8067h - 0.0006t + 0.7125 \tag{4.9}$$

$$\text{Energy}_{\text{scope2}} = 0.6618c - 0.0009t + 0.9897 \tag{4.10}$$

Similar to Plant 2, the models developed for Plant 3 as shown in Figure 4-8, Figure 4-9, and Figure 4-10, do a great job of capturing Plant 3's energy usage with only using HDD, CDD, and Time Elapsed.

4.6 Forecasting and Planning Tool

The two main lessons learned from the multivariate regression analysis are (1) energy usage increase from production increase was negligible for larger DS plants and (2) the production energy associated with production volume could represent up to 20% of Plant 1's total energy usage. To help streamline executives' decision making, these lessons were incorporated into an excel based tool where Sustainability team, Operations Strategic Planning team, or executives could perform scenario analysis by providing inputs for a few assumptions and obtain a high level understanding of Amgen's projected carbon emissions until 2027.

4.6.1 Overview of Tool and Assumptions

The tool starts with Amgen's overall carbon emissions for the past year and breaks it down into the four buckets of the framework: manufacturing, drug development, fleet, and admin. Fleet has its own tracking of emissions, so this is easily separated out. The emissions associated with the other three buckets are split by first assigning the amount of emissions associated with each site and then estimating the amount of emissions associated with each bucket based on the percentage of the site area associated with a respective bucket in that site. For example, for a hypothetical site that has 10,000 metric tons of CO_2e emissions and 50% of the buildings are associated with manufacturing while the other 50% are associated with drug development, 5,000 metric tons of CO_2e emissions would be assigned to both manufacturing and drug development. This is the baseline upon which future projections are built off from.

Each bucket is then scaled based on different assumptions. Currently, drug development and admin carbon emissions are increased or decreased by a year-over-year percentage increase or decrease in area that the user inputs. For example, if a user inputs a 5% year-over-year increase in drug development's facility area and drug development's current carbon emissions in 2022 is 100 metric tons of CO_2e, then drug development's carbon emissions is projected to be 105 metric tons of CO_2e in 2023 and 110.25 metric tons of CO_2e in 2024. Similarly, fleet carbon emissions are increased or decreased by a year-over-year percent increase or decrease in amount of internal combustion car equivalents. These are meant as placeholder assumptions until further analysis could be conducted to understand key emissions drivers for these buckets.

Manufacturing-related emissions are further broken down into the emissions associated with each type of manufacturing technology. This is done by calculating the percent building area associated with each manufacturing technology and attributing the same percentage of the total manufacturing-related carbon emissions to that technology. The emissions are then scaled up by a variable production emission percentage for Plant 1 based on the future production plan increases. The user has the ability to also input a low and high percentage of variable emissions since the amount of variable production energy for Plant 1 does vary. For example, if the low and high variable production emission percentage inputted by a user is 5% and 20% respectively, then 5% of Plant 1's total energy will increase or decrease proportionally to production lot increases or decreases in one scenario (low case) and 20% of Plant 1's total energy will be similarly adjusted in the other scenario (high case). The fixed energy usage component for manufacturing is increased when a particular technology reaches over 100% utilization. The increase is proportional to the amount over 100% to represent the expected area increase. Once a site has been approved to be built, the expected emissions for that site can be added to Amgen's sustainability plan and the new capacity utilization can be updated in the tool.

The final piece of the tool is an import of Amgen's future projects and their environmental impacts. The sustainability impacts are accumulated for a year to indicate a net increase or decrease in carbon emissions. This is then added or subtracted respectively from the projected emissions to provide a carbon emissions forecast.

Some key assumptions to keep in mind about this tool is that much of Amgen's carbon emissions are split based on the percentage of area associated with a particular bucket or manufacturing technology. This will be updated with actual energy usage through sub-metering once the infrastructure is developed. This also implicitly assumes that weather conditions will not drastically change through 2027 and the current energy baseline energy usage is appropriate. Another key assumption for this model is that it assumes a constant grid emissions factor for future carbon emissions. This is a conservative assumption since most of Amgen's facilities are in fairly developed nations with an observed reduction in grid emissions factors over the years. Future work can be done to include user input for year-over-year percent grid emissions factor reduction to adjust the conversion from energy usage to carbon emissions.

4.6.2 Inputs from User

The intended users of this tool are Amgen Executives; therefore, the inputs required are meant to be minimal. The current inputs required are listed below.

- Manufacturing Carbon Variable With Respect to Capacity Utilization - the percentage of total emissions associated with an increase in lot production for Plant 1.

- High Manufacturing Carbon Variable With Respect to Capacity Utilization - the higher-end percentage of the total emissions associated with lot production for Plant 1.

- Low Manufacturing Carbon Variable With Respect to Capacity Utilization -

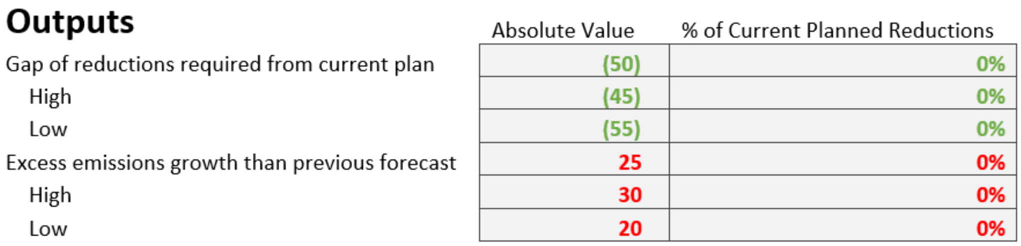
the lower-end percentage of the total emissions associated with lot production for Plant 1.

- Footprint Increase for Drug Development - year over year percentage increase in drug development area (ft^2).
- Footprint Increase for Admin - year over year percentage increase in admin area (ft^2).
- Footprint Increase for Fleet - year over year percentage increase in internal combustion car equivalents.

When the user adjusts these numbers, the model automatically updates and presents the outputs.

4.6.3 Outputs for User

There are three main outputs for the user. The first is a table with numerical values representing the forecasted carbon emissions in 2027 and the difference between this tool and the previous forecast. Both of these outputs also have a low and high range based on the low and high amount of variable manufacturing emissions the user inputs. Green values indicate that Amgen is on track to meet carbon neutrality by 2027, while red indicates a potential gap in meeting the goal. Figure 4-11 shows a sample output with hypothetical data.



Outputs	Absolute Value	% of Current Planned Reductions
Gap of reductions required from current plan	(50)	0%
High	(45)	0%
Low	(55)	0%
Excess emissions growth than previous forecast	25	0%
High	30	0%
Low	20	0%

Figure 4-11: Output from Scenario Planning Tool displaying projected carbon emissions in 2027 and the differences between the previous and current projections.

From Figure 4-11, the "Gap of reductions required from current plan" indicates how many more or less carbon emissions in metric tons need to be achieved to reach carbon neutrality. The following two rows are the high and low ranges based on the high and low variable manufacturing variables the user inputs. Since all these values are green, it indicates that Amgen is currently on track to reach carbon neutrality, which likely means Amgen can purchase less RECs and Offsets in 2027.

The "Excess emissions growth than previous forecast" indicates how many more or less emissions are predicted by this model versus Amgen's previous forecasting method as discussed in Section 1.2. Similarly, there are high and low ranges for sensitivity analysis. The current output indicates that the model is estimating a higher emissions forecast compared to the previous forecast for all of the scenarios.

The column labeled "% of Current Planned Reductions" represents how much the cell to the left is relative to the current planned reductions. In Figure 4-11, the values are all 0%, indicating the values in the "Absolute Value ($mTCO_2$)" column is small relative to the total planned reductions, and represents marginal tweaks to planned reductions to help reach carbon neutrality.

The second output from this tool is a graph that shows Amgen's future carbon emissions for "business as usual" (BAU), the new forecast which includes planned reductions, and the previous forecast. For the BAU and new forecast emissions, there is a high and low line which is again set by the low and high amount of variable manufacturing emissions the user inputs. Figure 4-12 shows a sample output with hypothetical data.

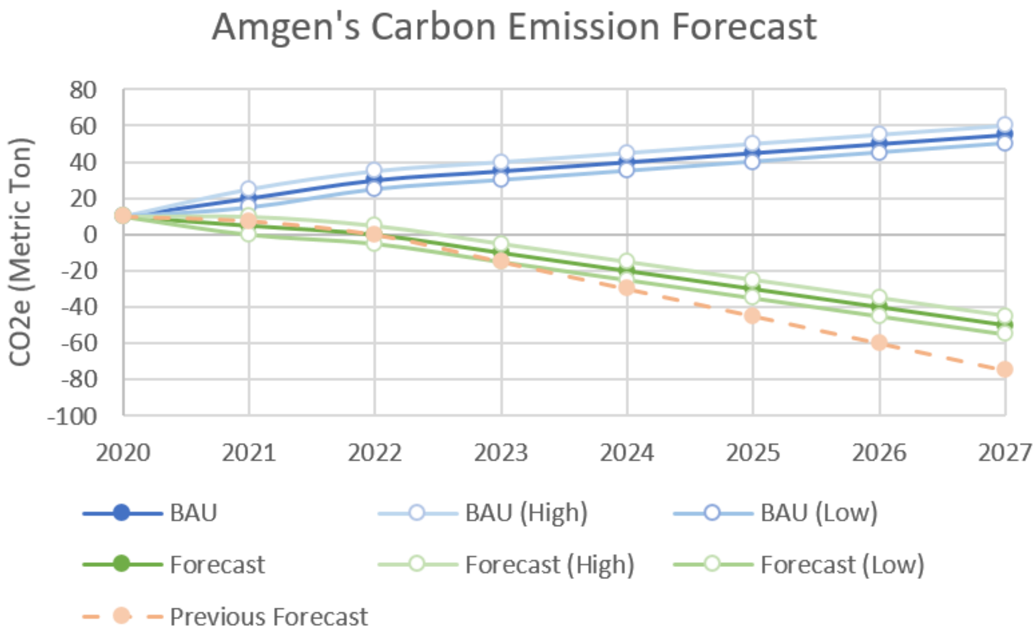


Figure 4-12: Projected carbon emissions from the Scenario Planning Tool.

In Figure 4-12, the BAU (in blue) and its corresponding high and low scenarios show and increasing projected carbon emissions. However, the forecast from this model (in green) and its corresponding high and low scenarios show the carbon emissions dropping below zero by 2027. This information is similar to the information presented in the first three rows of Figure 4-11 but in a graphical form. Finally, the previous forecast (in light orange) is plotted to show the differences between the current and previous forecasts.

Finally, there is a stacked bar graph that displays the amount of emissions increase or decrease and which bucket is influencing the increase or decrease. This will help executives understand which aspect of Amgen's business is having the biggest impact on Amgen's future carbon emissions. Figure 4-13 shows a sample output with hypothetical data.

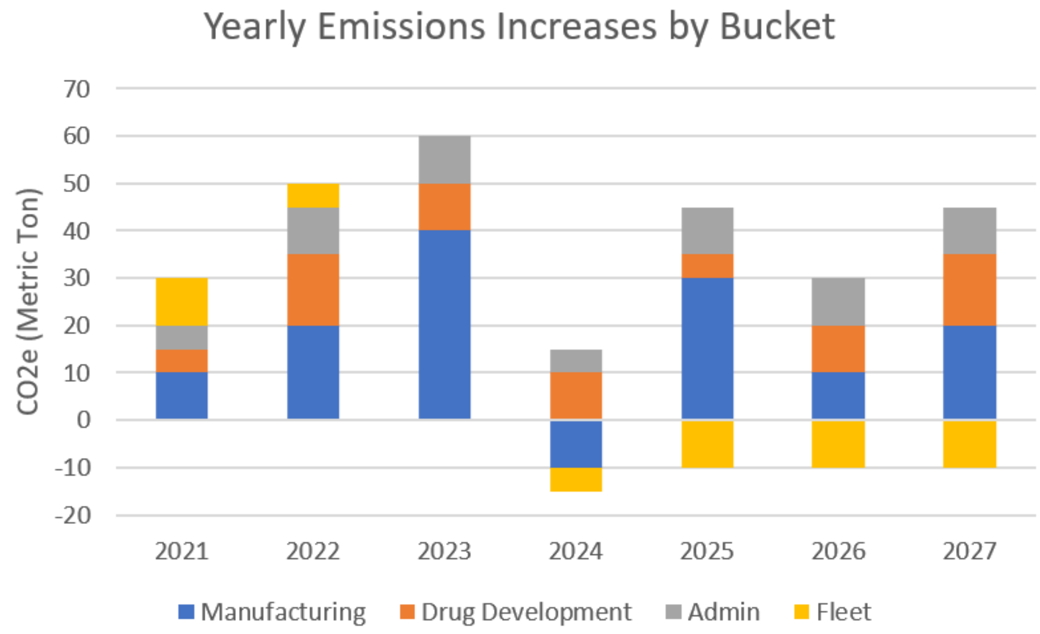


Figure 4-13: Projected carbon emissions from manufacturing, drug development, admin, and fleet through 2027 from the Scenario Planning Tool.

From these three outputs, an executive can determine whether Amgen will meet its 2027 carbon neutrality goal, understand the trend of Amgen's carbon emissions, and identify which aspects of Amgen's business (i.e., manufacturing, drug development, fleet, or admin) demonstrate the greatest increases or decreases in emissions to help guide strategic decisions. For example, Figure 4-13 shows increasing emissions in 2021-2023 of 30, 50 and 60 metric tons CO_2e of which 10, 20, and 40 metric tons CO_2e is from manufacturing related activities. From here, Amgen can narrow in on manufacturing to understand and decide how best to tackle the increasing emissions.

4.6.4 Upkeeping from Owner

To ensure this tool is maintained and functional, some business processes were proposed. The environmental group who helped advise and gave input throughout this project will own the tool. Their role is to update this tool each year by engaging the proper stakeholders and to ensure the data utilized by this tool is correct. Additional information on what needs to be updated is summarized below.

- Previous Year's Emissions - The total amount of carbon emissions before applying RECs and Offsets for the past year will need to replace the prior year's emission in the model.
- Emissions by Site - Emissions by site for the previous year will need to be updated by actual emissions. This can be determined through utility bills and the grid emission factor for each site.
- Percent Emissions by Bucket - This data is based on the percent area associated with each bucket at each site. If building usage and footprint has changed across buckets, this will need to be updated.
- Emissions by Manufacturing Technology - This is data based on the percent area associated with each manufacturing technology. If the area associated with different manufacturing technology has changed, this will need to be updated.
- DS Plant Utilization - This will need to be updated by discussing with Amgen's strategic planning team to understand future production projections and then calculating each plant's utilization based on its projected capacity.

By creating an owner and the associated business processes, the tool can remain useful for Amgen as they continue their journey to carbon neutrality.

Chapter 5

Business Impact and Recommendations

Beyond being used to generate a forecasting tool, insights and learnings from the Use Case can help prioritize different initiatives to more efficiently meet Amgen's carbon neutrality goals.

5.1 Insights to Drive Strategic Investments

The two main insights generated from the Use Case is that a facility's total building area and weather correlate strongly with a site's energy usage and that when a manufacturing process is intensified to utilize less area, variable energy from manufacturing may become an important emission driver.

From the first insight, Amgen can try to evaluate alternatives before building new facilities since area footprint increases will increase emissions. Some examples include evaluating manufacturing debottlenck projects to increase capacity in a given space, reorganize work spaces to be more space efficient, repurpose unused work spaces, develop manufacturing processes that are more space efficient, and many more. Furthermore, Amgen can first prioritize looking into ways to heat and cool more efficiently before evaluating other projects to reduce energy usage. This can include examining their current systems to find opportunities to improve heat exchange efficiencies, lower the need to heat and cool when a certain area is not in use, and many other ideas.

From the second insight, Amgen can begin to look at ways to reduce the variable energy of their manufacturing process. This is currently a relatively small portion of Amgen's energy usage, but will become a more significant portion as they continue to intensify their manufacturing with the given footprint. At that point, reducing variable energy will become more impactful. Some projects that Amgen can begin to consider are evaluating more energy efficient equipment (pumps, heat exchangers, etc.) for the process, re-engineer the manufacturing process to require less heating and cooling, or even finding a more energy efficient cell to produce drug substances.

5.2 Data Granularity and Validation Improvement

Another lesson learned was that the amount and depth of analysis was dictated by the amount and type of data available but also the quality of that data. Improving both would enable Amgen to gain more insights which in turn drive other initiatives to help meet the sustainability goals.

5.2.1 Data Granularity

Increased data granularity can be accomplished in two ways - increasing the frequency at which data is measured and increasing the layers of measurement. In the Use Case described in Ch. 4, the analysis could have benefited from increased frequency of energy usage. If metered electricity and carbon fuel data were readily available and validated, these values could have enabled the analysis to be conducted at the weekly or even daily level. This effectively increases the number of data points and enables the analysis to be conducted over a shorter time period; therefore, the results will be representative of the plant's current energy usage and provide more accurate future predictions. Moreover, the increased data granularity helps to capture variations in emissions that would allow better identification of potential correlations. A downside of increasing the frequency is that additional noise may be introduced which may skew results. Choosing the correct frequency will be imperative and should involve discussions with subject matter experts of the system under analysis.

Additionally, increased layer of data could help provide deeper insights. For example, the analysis conducted in Ch. 4, used the whole site's energy usage as the dependent variable, and a site may include many more functions other than DS production. However, if submetering or building specific utility usage was available, the analysis could have been narrowed down specifically to the building producing DS. This can be taken further by analyzing the energy usage for specific equipment within the DS production process to understand where the bulk of the energy is utilized and identify opportunities for reduction. A final benefit for additional layers of data is that it can enable real-time operational changes or anomaly detection to constantly minimize energy usage.

5.2.2 Data Validation

Data can't be used if it can't be trusted. Moreover, constant checking of raw data is cumbersome and can become redundant if many people are using the same data set. Developing an automated system would be beneficial especially for metered data such as water, carbon fuel, and electricity flows. Energy and mass balances could be examined to understand if these meters are reading correctly. For example, if electricity enters a facility through one meter and then the flow to each building is also metered, adding up the independent flows to each building should equal the main meter. If so, the meters are validated and the data can be trusted for analysis. If not, meters should be investigated and resolved. An underlying assumption here is that the main meter is reliable and can be trusted. A few methods to ensure this are regular maintenance and monitoring of the meter as well as having duplicate meters reading the main line.

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Chapter 6

Next Steps and Takeaways

This thesis presents a method for developing a MECE framework to break down Amgen's core activities that impact sustainability, a use case analyzing key drivers for manufacturing-related carbon emissions, and insights from the analysis which will help to shape Amgen's emissions forecasting and prioritization of future projects. These series of work can be taken and reapplied on the same framework in other buckets to gain further insights into Amgen's carbon emissions. Similarly, further analysis can be conducted within the manufacturing bucket to gain more depth. The framework provides the backbone from which analysis and insights can be gained to understand drivers that impact sustainability and how best to prioritize projects and efforts to minimize or reduce these impacts.

More importantly, the framework and analysis can be applied generally across different companies and industries. The framework can be tailored to a company's specific sustainability goals and activities. The type of analysis can be adjusted to reflect the companies forecasting needs and desire for interpretation to drive strategic investments. From this, companies can formulate plans based on data-backed forecasting to more confidently fulfill their sustainability goals.

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