Stockholm:

An Environmental Leader

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Executive Summary

As the earth approaches a 2°C increase in global temperature, it is imperative to look to global leaders in climate change mitigation to influence action. To halt the current warming trend, we must bend the projected curve of anthropogenic warming by reducing emissions and achieving carbon neutrality [1]. If we continue with "business as usual" we will emit 4 trillion metric tons of carbon in our atmosphere within the next 12 years, resulting in a 2.8°C global temperature increase [1]. The University of California's *Bending the Curve* details the multidimensionality of combating climate change. The report, published in 2015, describes ten scalable solutions that fall into six clusters: Science, Technology, Governance, Societal Transformation, Market-Based Solutions, and Ecosystem Restoration. Bending the curve immediately requires the use of existing technology to halt the emission of short-lived climate pollutants (SLCPs), such as diesel filters, anaerobic wastewater treatments, and degasification methane pumps. This will cut black carbon by 90%, methane by 50%, and hydrofluorocarbons (HFCs) completely [1]. Staying below 2°C requires the collaborative, genuine efforts of all countries involved in the degradation of the planet and its natural resources.

Stockholm is one of the most environmentally conscious cities in the world and one of the leading players in the effort to bend the curve of projected global warming. The solutions Stockholm utilizes are a great example of the potential of implementing all 10 scalable solutions presented in *Bending the Curve*. Stockholm's *Environmental Action Programme* addresses several goals, accomplishments, and timelines that can be broken apart into 9 of the 10 different solutions. The final solution that Stockholm must address is reducing methane and black carbon emissions by utilizing existing technologies. This report explores Stockholm's climate action as one of the most comprehensive and ambitious efforts in the world, setting the groundwork for national emission reduction and encouraging the complete shift to renewable energy. Stockholm proves to be a living laboratory from which we can learn and model plans for the future in other major cities.

Sweden's Path to Sustainability

Sweden's long history of environmental consciousness and action has allowed the country to set the global standard for climate change mitigation and international cooperation.

Activists have been working since the 1940s to introduce environmental ideas to the public by holding public demonstrations and organizing large scale community service events. The years between the late 1960s and early 1970s have come to be known as "the ecological turn" and "environmental breakthrough." This period marked the emergence of modern environmentalism and a new global attitude encompassing issues such as climate change, industrial development, hunger, and war. Climate scientists became environmental activists as they took to print, radio, and television to warn people of the looming threat of climate catastrophe and the collapse of global society. The most effective scientists were able to mobilize the public through urgent, relevant messages while remaining positive and hopeful.

A major turning point of Swedish and global interests was in 1972 when Sweden hosted the first United Nations Conference on the Human Environment in Stockholm. This conference was the first of its kind, bringing countries together to present shared global responsibilities and problems that must be solved in the near future. It set a precedent for national environmental action and international cooperation.

Stockholm's Past and Current Emissions

Before 1960, Stockholm faced several environmental problems such as declining biodiversity, harmful chemicals in water, and air pollution [2]. These threats to Stockholm's quality of life and natural resources prompted leaders to address the underlying issues head-on.

Stockholm has reduced its greenhouse gas emissions from approximately 73.2 billion carbon equivalent metric tons in 1990, to 54 billion metric tons in 2015 [3]. Per capita, Stockholm reduced its emissions from 5.4 metric tons in 1990 to 3.7 in 2009 and aims to reach 2.3 by 2020 [4]. Currently, 80% of Stockholm's energy comes from renewable sources and the city is on track to achieve 100% renewable energy by 2030 [4]. Stockholm plans to become one of a handful of cities to reach carbon neutrality by 2050 and continues to strive to be a green city [5]. The success of Stockholm, and Sweden as a whole, is unprecedented and prompts the questions: Why Stockholm? What can we learn?

Stockholm's Mitigation Actions

One of the first major changes Stockholm made was introducing a ban on several chemicals and materials that were harmful to human and environmental health. Stockholm has since banned the

use of pesticides such as dichlorodiphenyltrichloroethane (DDT) and toxaphene, as well as polybrominated biphenyls (PCBs), which are used as coolants [6]. Sweden was also the first country to ban the use of cadmium, a toxic heavy metal commonly used in batteries [6]. This prompted more change as Swedes began to realize the impact of their actions on the environment.

Stockholm's major sources of greenhouse gas emissions are waste, electricity, heating, and transportation, which is why the *Environmental Action Programme* focuses on improvements in these areas [4]. Stockholm has lowered its overall waste in kilograms per inhabitant by 16% from 2006 to 2015 and aims to reach a reduction of 26% by 2026 [7]. The city has also updated how its waste is processed. In 2006 only 1.24% of the waste was separated as food waste, but in 2015 that number increased to 7% [7]. This increase of proper processing has led to more facilities that use anaerobic digestion to produce biogas for energy use and fertilizer for crops. Since electricity use accounts for 30% of emissions, some of Stockholm's top priorities are to switch to renewable energy by increasing the number of power plants that run on biofuels, transitioning to a public transit system that runs on renewable energy, and utilizing solar maps to install photovoltaic panels with the aim of increasing solar energy use by 50% [8]. The success of technological solutions is in part due to changes in the political arena and social thought; this is key to understanding why Stockholm has led by such a large margin.

Within Stockholm's government, the *Environmental Action Programme* has steered climate mitigation policy since 1976 [4]. The success of the *Environmental Action Programme* is reflected in recent climate studies on Stockholm. For example, since 1990, Stockholm has reduced carbon emissions by 25% per resident [5]. This amount of change is certainly substantial, and this type of progress is the result of dedicated city leaders and effectively implementing the *Environmental Action Programme*. Stockholm has also influenced climate change governance on an international scale through agreements like the C40 Alliance of Cities, where Stockholm helped facilitate climate agreements like the Paris Agreement [2]. Stockholm helped bend the warming curve through domestic and international action.

The efforts of Stockholm-based environmental organizations, city planners, and activists have worked in conjunction to shape social norms and make sustainability a way of life. It is important to consider the ways in which new forms of media and technology change how information is distributed. Stockholm-based organizations such as The Swedish Environmental

Protection Agency, the Swedish Society for Nature Conservation, and The Keep Sweden Tidy Foundation have embraced social media and internet-based communication to disseminate new sustainability strategies and information. Stockholm's rapid growth has created new challenges in environmentally friendly urban life and transportation. City planners are constantly finding new ways to directly build sustainability into Stockholm.

Economics and Environmental Initiative

Sweden's carbon tax was introduced in 1991 and is characterized by an incrementally increasing price on carbon over several years. Sweden's greenhouse gas emissions have decreased by 26% from implementing the tax in 1991 to 2016 [9]. The implementation of environmental protection policies and taxes on emissions often produce uncertainty in many sectors regarding how the economy will respond. However, since introducing several green initiatives, Stockholm's gross domestic product has increased by approximately 30% and employment has increased by 17% with a 14% increase in the green sector alone [5] [10].

Areas of Improvement

Although Stockholm has been a leader in renewable energy and sustainable living, there are several measures, in addition to addressing the tenth solution of reducing methane and black carbon, that the city and the country of Sweden must take to reduce emissions and achieve carbon neutrality.

Stockholm must improve its waste management system by halting the harmful practice of waste-to-energy (WTE) incineration and transition to more sustainable sources of energy. In order to counteract the city's reliance on WTE processes, further development in solar, wind hydropower, biogas, and nuclear energy is needed to integrate the technology into the transportation, heating, and food sectors.

Additionally, most of the official data on emissions and Sweden's carbon footprint presented by the Swedish government focuses on territorial emissions and omits total consumption-based and imported emissions. Sweden itself has a sizeable presence in international trade, importing goods from several countries that still largely run on fossil fuels. Data from the National Academy of Sciences shows that while Sweden's territorial emissions have decreased from 51 million metric tons to 48 million metric tons between 1990 and 2008,

outsourced emissions have fluctuated from 92 million metric tons in 1990, to 76 million in 2000, and rising again to 80 million metric tons in 2008 [11]. Consumption-based emissions must be incorporated into Sweden's future goals with more accurate national measurements and greater transparency in reporting. In addition to reducing territorial and imported emissions, Sweden and all industrialized countries must work to reduce the amount of imported embodied carbon by promoting local and sustainable consumption practices.

A Living Laboratory

Stockholm is an excellent example of a living laboratory from which we can learn and tailor plans for other cities looking to lower their own carbon footprint. The city uses effective communication and education to integrate sustainable living and environmental action into everyday life. Stockholm has reduced emissions by promoting technological innovation and improving the efficiency of its transportation, heating, and waste systems. Stockholm has also taken actions to revise its food system to reduce its burden on the natural ecosystem. Strong governmental organization and leadership have been integral in setting action-oriented climate goals and promoting international collaboration. Taxes on carbon and other economic incentives encourage the reduction of emissions and other detriments to the environment.

Stockholm has made it a priority to optimize efficiency; its approach to reaching carbon neutrality has focused on the intersection of solutions in several sectors of the city:

- Initiating a shift in nationwide perceptions that fosters a new culture of climate literacy and concern for global health
- Investing in further research and technological innovation to reduce emissions and integrate new sustainable technologies into city development and everyday living
- Electing officials with public and environmental interests who will introduce effective legislation and regulations
- Implementing economic incentives for industries and other financial stakeholders to reduce their carbon emissions and invest in green technology

Other cities and sub-national jurisdictions may learn from Stockholm's successes and weaknesses to build upon a universal model of climate mitigation and carbon neutrality.

I. Introducing Stockholm

Stockholm, the capital of Sweden, has been one of the most environmentally conscious cities to date, leading in innovation and paving the way toward carbon neutrality by 2050 [5]. Sweden has consistently ranked as the top country in combating climate change [5]. The city is on track to achieve 100% renewable energy by 2030 with 80% of its energy already coming from renewable sources [4]. Stockholm's success has been the point of reference for the country's environmental activity for decades and the country as a whole is an experimental model for global climate mitigation and carbon neutrality. Sweden's long history of environmental consciousness and action has set the global standard for climate change mitigation and international cooperation.

In the context of the *Bending the Curve* report published by the University of California in 2015, Stockholm can be described as a "living laboratory," where the world's most advanced climate solutions have been fine-tuned and tested [1]. Living laboratories allow researchers and community members to test technological, economic, political, and social strategies in order to evaluate the scalability and generalizability of these solutions to larger contexts [5]. Stockholm's success is important because it can be used as a model for other cities around the world.

The *Bending the Curve* report highlights six clusters embodying ten "pragmatic, scalable solutions" to clean the earth's air and bend the global warming curve to keep global warming under 2°C [5]. The "business as usual" route predicts a total of 4 trillion metric tons of carbon in our atmosphere within the next 12 years, yielding a 2.8°C increase in warming [1]. Warming greater than 2°C will result in detrimental and irreversible damage to the earth's ecosystem, human health, and the economy, which is why jurisdictions around the world must take action to bend the curve [1]. This will require the collaborative, genuine efforts of all countries involved in the pollution of our planet, meaning there is no country exempt from this mitigation effort.

Stockholm's *Environmental Action Programme* addresses several goals, accomplishments, and timelines that can be broken apart into 9 of the 10 different solutions discussed in *Bending the Curve* [1]. The city uses effective communication and education to integrate sustainable living and environmental action into everyday life. Stockholm has reduced emissions by promoting technological innovation and improving the efficiency of its transportation, heating, and waste systems. Strong governmental organization and leadership has been integral in setting action-oriented climate goals and promoting international collaboration.

Economic incentives encourage the reduction of emissions and other detriments to the environment. Stockholm has also taken actions to revise its food system in order to reduce its burden on the natural ecosystem. The final solution to address is the reduction of methane and black carbon emissions.

Science Solutions	1. Bend the warming curve immediately by reducing short-lived climate pollutants and introducing carbon neutral technologies		
Societal Transformation	2. Foster a global culture of climate action through coordinated public communication and education	3. Deepen the global culture of climate collaboration	
Governance Solutions	4. Scale up subnational models of governance and global collaboration		
Market- and Regulation-Based Solutions	5. Adopt market-based instruments to create efficient incentives for businesses and individuals to reduce CO_2 emissions	6. Narrowly target direct regulatory measures at high emissions sectors not covered by market-based policies	
Technology-Based Solutions	7. Promote immediate widespread use of mature technologies	8. Promote innovations to accelerate the electrification of energy and transportation systems and improve building efficiency	9. Utilize available technologies and regulations to reduce methane emissions by 50% and black carbon emissions by 90%
Natural and Managed Ecosystem Solutions	10. Regenerate damaged ecosystems, maximize utilization of food produced, and recover energy from food that is not consumed		

Table 1. Ten Scalable Solutions and Clusters presented in Bending the Curve, red indicates the solution Stockholm has yet to address [1]

Through this lens, we can analyze why Stockholm has shown great promise for the future. We ask: How has Stockholm transformed its citizens into avid participants of the mitigation solution? What solutions were instrumental in creating substantial change? And why should other nations follow suit?

Stockholm has assumed the risks that come with implementing new sustainable ideas and has demonstrated benefits ranging from substantial financial rewards to the improvement of our environment. Now we must solve the puzzle of replicating and customizing Stockholm's success in other cities and countries, enforcing effective solutions best suited to their situations, and converting all global citizens into climate warriors. There is no single secret to Stockholm's success; the utilization of several initiatives working in unison has created what we see today and the example is there for the taking.

II. Societal Transformation Solutions: Building a Culture of Environmental Justice

Sweden's history of environmental activism is an example of the widespread societal transformation required to achieve worldwide solidarity, collaboration, and environmental preservation. This section will analyze the work of prominent Swedish activists, scientists, and political figures throughout the decades as well as current actions by government agencies and nongovernmental organizations. Societal transformation is the basis and intersection for all other clusters described in *Bending the Curve* to foster environmental consciousness, public opinion, and action.

1940s-70s – Early Activists and Fältbiologerna

Some of the earliest environmental activists in Sweden were also some of the nation's youngest who likely did not consider themselves activists at all. *Fältbiologerna* (Field Biologists) was a branch of the Swedish Society for Nature Conservation founded in 1947 to address alienation and rekindle young people's interest in nature [12]. The organization was internally run and welcomed members between the ages of 7 and 25. *Fältbiologerna's* mantra "keep your boots muddy" encompasses the activists' mission: to always fight for what is important and never stop seeking knowledge [13]. Field Biologists pride themselves in being adventurous, knowledgeable, influential, and radical [13].

Fältbiologerna was originally apolitical, organizing hikes and other activities in the 1950s to encourage the spread of knowledge and appreciation for nature. By the mid-1960s the Field Biologists became interested in fighting for and preserving nature instead of simply experiencing it [12]. Members held public demonstrations, forums, and community service projects to draw media attention and engage their peers in the discussion of environmental action. Members openly criticized the Swedish government for watering down conservation policies and allowing economic players to dominate the discussion [12]. For example, the United Nations Conference on the Human Environment in 1972 served as a device for activists to rally against. It represented the political establishment whose "declarations and resolutions [would not] make anything better" [14]. In response, they helped organize several alternative conferences where local organizations and activists could pose their own questions and solutions.

Scientists were highly respected and regularly contributed to the organization's news journal *Fältbiologen* (The Field Biologist). One of the journal's most famous contributors was Hans Palmstierna who noted in 1968 that only "solidarity among all peoples of the world" would solve the global problem [15]. Field Biologists began to think more globally, reaching out to other groups in neighboring cities and Scandinavian countries to create a network of young activists. Since its founding, many of the Field Biologists' activities have coincided with major political decisions, global events, and publications. Many members continued to fight for the environmental cause in adulthood, such as Lars-Erik Liljelund, one of the lead editors of *Fältbiologen* during some of the Field Biologist's most radical years, who eventually became head of Sweden's Environmental Protection Agency [12].

While the organization faced moderate media scrutiny and experienced internal polarization and pushback as they adopted a more radical ideology, there is no doubt that the Field Biologists played an integral role in the early circulation of environmental knowledge and introducing the public to collective action.

1962 – Silent Spring

One of the most important books in the global history of environmentalism is Rachel Carson's *Silent Spring*. Published on September 27, 1962, in the United States and the following year in Sweden and the rest of Europe, the book is credited with provoking worldwide controversy and America's modern environmental movement by describing the harmful effects of industrial pesticide use on global health. Carson argued that because pesticides circulate throughout all levels of the ecosystem from the soil and surrounding animals to the food system, "insecticides" should instead be named "biocides" [16]. This term is an early iteration of "ecocide" mentioned later in the Swedish Prime Minister's United Nations speech, distributing the blame from industry to humanity.

While the majority of European countries refused to believe that the issues and accusations discussed in *Silent Spring* applied to them, Sweden embraced it [17]. Swedish environmental scientists were studying the link between local chemicals and the deaths of several hundred native birds that were fed seeds and grains treated with pesticides [18]. This concern provided context for *Silent Spring* to cause an even greater uproar than in the United States [17]. The book had such a large effect on Swedish society that its publication prompted a

shift in common Swedish language from the word “pesticid” to “biocid” [17].

The Swedish response to *Silent Spring* is an early example of scientists drawing connections between their local environments and overarching worldwide issues. It also served to rally scientists, conservationists, and the public behind a single issue to think critically about the role humans play in larger earth systems.

1967-72 – The Ecological Turn

The years between the late 1960s and early 1970s have come to be known as “the ecological turn” and “environmental breakthrough” [19]. This period marked the emergence of modern environmentalism and a new global attitude encompassing issues such as climate change, development, hunger, and war. Before this breakthrough there was no environmental movement aside from a few activist scientists who were vocal but did not mobilize. With the onset of the Cold War and ever-present threat of nuclear aggression, modern environmentalism emerged in the fall of 1967 when Swedish environmental scientists flooded the airwaves with threats of climate catastrophe and the collapse of global society [19].

One of the most prominent figures of the time was the Swedish chemist Hans Palmstierna, who authored the iconic book *Plundring, Svält, Förgiftning (Plundering, Starvation, Poisoning)* in October 1967. *Plundering, Starvation, Poisoning* was an eye-opening account of the role Sweden must play in shaping the future of global change [19]. In the weeks following the book’s release, Palmstierna took to television and radio to warn the country of the dangerous consequences of human actions, stressing the augmented impact on children and the condition of the world they will grow up in. He wrote articles for local newspapers explaining how humans created the global problem, citing rapid overpopulation, industrialization, and the failure to consider the consequences of their actions [19]. These features transformed the framing of the global environmental crisis and the way media presented information about the issue. Palmstierna was able to mobilize the public with urgent, relevant messages while remaining positive and hopeful.

1972 – United Nations Conference on the Human Environment

A major turning point of Swedish and global interests was in 1972 when Sweden hosted the first United Nations Conference on the Human Environment in Stockholm. The Conference was a

call to action by national governments and international organizations to establish broad guidelines and policy goals addressing the issue of human detriments to the environment. This conference was the first of its kind, bringing together countries to present shared global responsibilities and problems that must be solved in the near future.

Backed by overwhelming support from their constituents and organizations including the Environmental Protection Agency in December of 1967, members of the Swedish delegation to the United Nations proposed to host the Conference on the Human Environment [20]. Hans Palmstierna was one of the contributing authors of this proposal. There was no precedent for global conversations on the environment, as climate issues were widely viewed as isolated regional problems to be dealt with on an individual basis by science and technology [19].

Sweden's Prime Minister Olof Palme gave a sweeping address to open the Conference on June 6, 1972. Two major themes in this address were unity and action. Reflecting on the history of international relations, "a careful balancing act between national independence and international interdependence," Palme stressed the urgency and fear felt around the world concerning overpopulation, food production, pollution, and energy [21]. Palme urged all countries to accept shared responsibility for the degradation of the earth and its finite resources, emphasizing a more equal distribution in the years to come [21]. "Action orientation" was a key phrase for the Conference with the release of a proposed major Action Plan for a global environmental assessment and the creation of the United Nations Environment Programme.

The intersection of international solidarity and action culminated as a final call for world peace starting with a complete elimination of nuclear, biological, and chemical weapons [21]. Palme condemned the recent displays of "ecocide," a term penned to describe lasting ecological damage and international consequences as a result of warfare, environmental neglect, and greed [21] [22].

The goal of the Conference was to establish a common language that countries could use to begin a global discussion on the human environment. Sweden was at the forefront of this effort as a leader in environmental consciousness and acting mediator between national interests and international cooperation. The major product of the Conference was the Stockholm Declaration: a document stating that all countries must accept responsibility for the future of the planet through interdisciplinary research and societal change [23]. The weight of these concerns still resonates today, almost 50 years after the landmark Conference.

Sweden's Modern Progressive Culture and Developments

Decades of public political involvement and global thought translate into modern Swedish progressivism, egalitarianism, and one of the most successful welfare states in the world. As stated in *Bending the Curve*, there are intraregional, intragenerational, and intergenerational equity issues of climate change that must be addressed to make the public receptive to further solutions [1]. Climate change recognition and environmental consciousness have close ties to other progressive values such as gender, sexuality, and racial equality, as well as separation of church and state. Sweden legalized same-sex marriage in 2011 and, as of September 2017, half of Swedish government officials are women, a goal set in 1988 [24] [25]. High taxes and low military spending allow the government to maintain a social safety net for its citizens through providing universal health care and education, unemployment benefits, and a strong social security system. The trend of taking care of others extends beyond Sweden's borders through international relief programs. Sweden recently increased its refugee quota from 1,900 in 2016 to 5,000 in 2018, making it the third largest refugee recipient in the world [26]. Additionally, Swedish culture encourages practicing hospitality, politeness, and remaining humble regarding achievements and success [27]. Because of these attitudes, the Swedish government and society, in general, are always striving to improve and innovate to make their country and the earth a better place. The population of Stockholm holds high ambitions within the area of climate, which must be matched by efforts for a socially cohesive city [28]. The efforts of environmental organizations, city planners, and activists work in conjunction to shape social norms and make sustainability a way of life.

As communication constantly evolves, it is important to consider the ways in which new forms of media and information distribution change how governments and organizations interact with the public. Stockholm-based organizations such as the Swedish Environmental Protection Agency (EPA), The Swedish Society for Nature Conservation, and The Keep Sweden Tidy Foundation have embraced social media and internet-based communication to disseminate new sustainability strategies and information. In the spring of 2017, the Swedish EPA launched the online podcast series titled "Talk About Climate" that highlights a recent environmental issue each week [29]. The Swedish Society for Nature Conservation publishes a "Green Guide" that provides updated advice on how to implement individual behavior changes, covering six different categories: travel, home, work, clothing, food, and children [30]. The Keep Sweden

Tidy Foundation promotes recycling and reducing overall waste through organized litter pick-up and coastal clean-up days [31]. These events are changing attitudes by showing people the impact of their actions first-hand. Media campaigns from similar organizations have also skyrocketed the popularity of vintage and second-hand fashion, urban community gardens and farms, and rooftop beekeeping [32]. Online resources make environmental information and eco-friendly alternatives easily accessible to the public, allowing conscious citizens to play an active role in conservation and civic service.

Stockholm's rapid growth has created new challenges in environmentally conscious urban life and transportation. Stockholm's *Environmental Programme* calls for the shift to high-capacity and environmentally friendly modes of transportation, decreasing fossil fuel dependence, and the promotion of green vehicles, trains and, bicycles. City planners are working to build a "densified Stockholm," by designing walkable urban environments that allow people to live closer to public transportation [8]. To account for increased bus and bicycle traffic, designated bus and bicycle lanes make environmentally friendly transportation alternatives safer and more accessible [8]. Automobile drivers are encouraged to carpool through parking and emission-reduction incentives. These are all examples of how Stockholm has built a responsible environmental culture that reflects the interests and societal goals of its citizens.

The most important lesson we can learn from Sweden's history of environmental action and current cultural climate is that action takes many forms and calls on multiple stakeholders to act on behalf of the earth and humanity. There is still much to do, but the progress observed in the past five decades will bring hope and inspiration to the politicians, scientists, and activists of today and for generations to come.

III. Science, Technology, and Ecosystem Solutions: Mitigation Actions and Integration

Stockholm's history has played a crucial role by setting the stage for solutions in *Bending the Curve's* Science, Technology, and Natural and Managed Ecosystem Clusters. These clusters go hand in hand because the goals of the Science Cluster are to reduce short-lived climate pollutants (SLCPs) and replace current fossil-fueled systems with clean energy, while solutions in the Technology Cluster provide the innovative tools to achieve these goals, and both contribute to the overall preservation and restoration of the ecosystem [1]. Stockholm is on the path to achieving the seventh, eighth, and tenth solutions described in *Bending the Curve:*

7. Promote immediate widespread use of mature technologies
8. Aggressively support and promote innovations to accelerate the complete electrification of energy and transportation systems and improve building efficiency
10. Regenerate damaged natural ecosystems … And implement food waste reduction programs and energy recovery systems [1]

As seen in Figure 1, 96% of Stockholm's emissions are a result of heating, transportation, and energy use; which is why the city has focused on switching to more sustainable practices in these sectors.

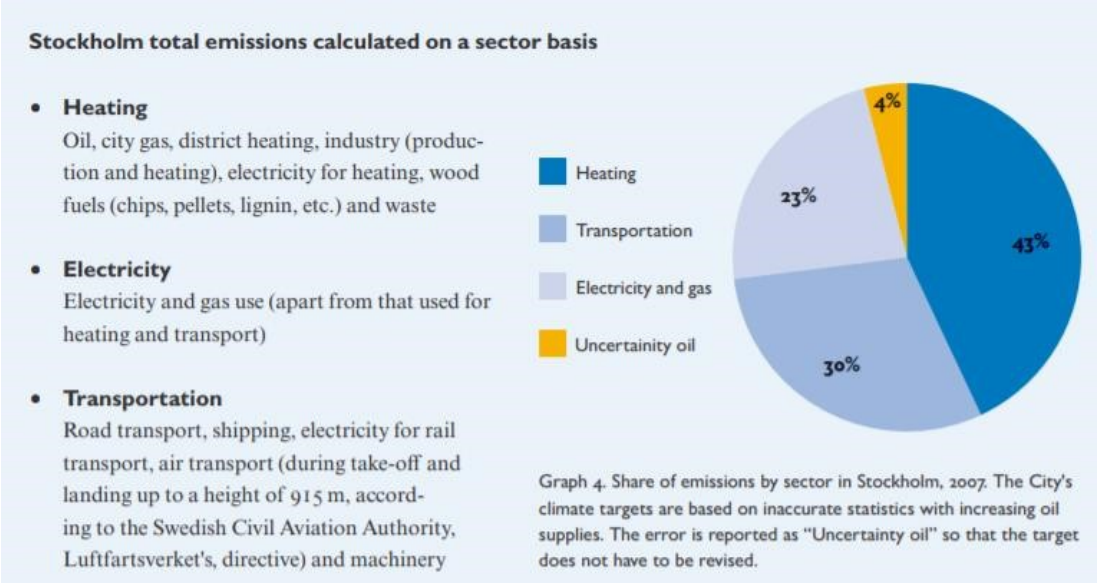

Figure 1. Stockholm's total emissions [8]

A gradual decrease in carbon equivalent emissions throughout the years is the result of transitioning to renewable energy sources, as shown in Figure 2.

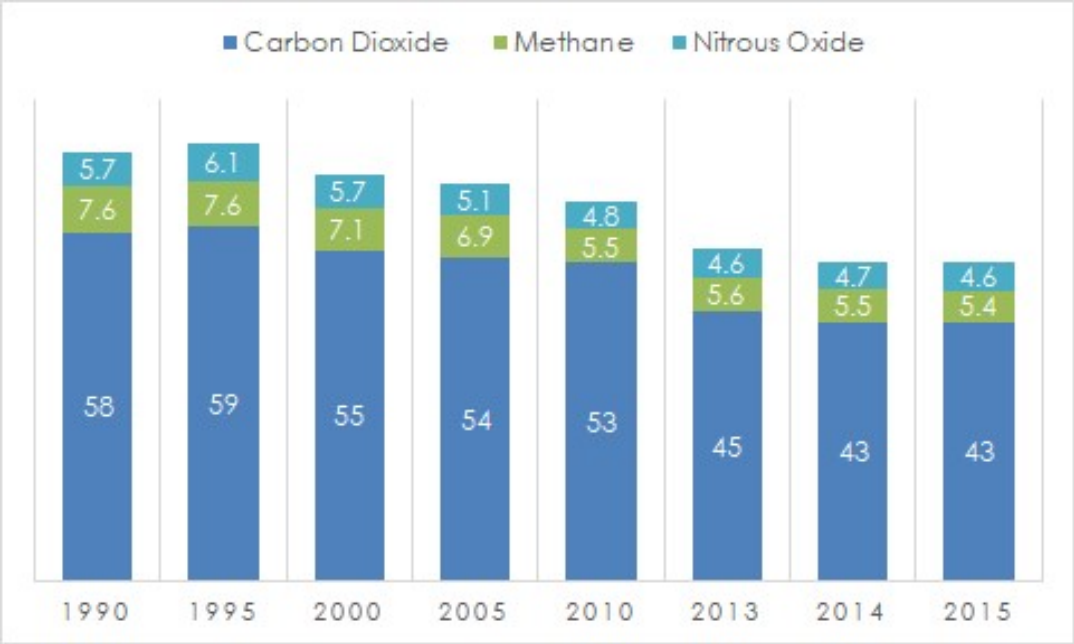

Figure 2. Swedish output in billion metric tons of carbon equivalent emissions [3]

Stockholm's *Environmental Action Programme* focuses on creating a healthy environment for its citizens, increasing resource efficiency, and reducing overall emissions. The plan addresses the need for regulations to keep the proposed implementations on track as well as public support to help navigate through transitions and achievements [4]. Stockholm also acknowledges that a plan is not enough. A constant system of checks and balances is necessary to maintain accountability and ensure Stockholm meets its goals on time. Science and technology solutions can have an even greater impact when implemented in unison with solutions from other clusters; Stockholm's acknowledgement of this is one of the reasons why it is a global leader in climate mitigation and environmental conservation.

A Non-Toxic Stockholm

In the 1960's, a major point of concern was public health and ensuring the environment was not negatively influencing the health of Stockholm's citizens. Chemicals such as dichlorodiphenyltrichloroethane (DDT), dieldrin, and toxaphene were identified as toxic to human health and banned in 1970 [6]. This led to further regulations that extended to banning other chemicals, such as polychlorinated biphenyls (PCBs) in 1978 that were harmful to the

environment as well. Stockholm continues to tackle this issue through the creation of a Chemicals Action Plan to achieve a non-toxic Stockholm by 2030. The purpose of the plan, spanning from 2014 to 2019, is to decrease concentrations of non-naturally occurring substances and their impacts on human health to as close to zero as possible [33]. This plan calls for the collaborative effort of local authorities for top-down enforcement and regulation, and citizens for bottom-up reception and mobilization.

Chemicals are separated into two categories: phase-out substances that are strictly prohibited in all sectors, and property-risk reduction substances that are used in limited concentration under supervision and suggested to be opted out for less harmful substitutes [33]. For instance, diethylhexyl phthalate (DEHP) is used in many plastic materials and listed as a phase-out substance due to its harmful effects on reproductive health; whereas, chemicals that release copper or nickel ions as byproducts are property-risk reduction substances due to their effects on the aquatic environment and the instance of allergic reactions, respectively.

Stockholm is widely known for its swift reduction in chlorofluorocarbons (CFCs) following the discovery of their harm to the stratospheric ozone layer. While a London revision of the Montreal Protocol called for a reduction of CFCs by 2000, Stockholm had already replaced nearly all CFCs by 1995 [6]. Stockholm's efforts in the reduction of harmful chemicals may not play a large role in carbon neutrality but it is significant to the well-being of the environment and sparked the conversation on what other actions the city could take to protect the environment.

An Energy-Efficient City

The use of fossil fuels is the major concern in any city trying to reduce its carbon footprint, which is why Stockholm has made it a priority to achieve carbon neutrality by 2040. Stockholm's *Environmental Action Programme* lists several sub-targets such as reducing purchased energy by 30% and reducing greenhouse gas emissions to 2.3 metric tons per resident by the year 2020 [4].

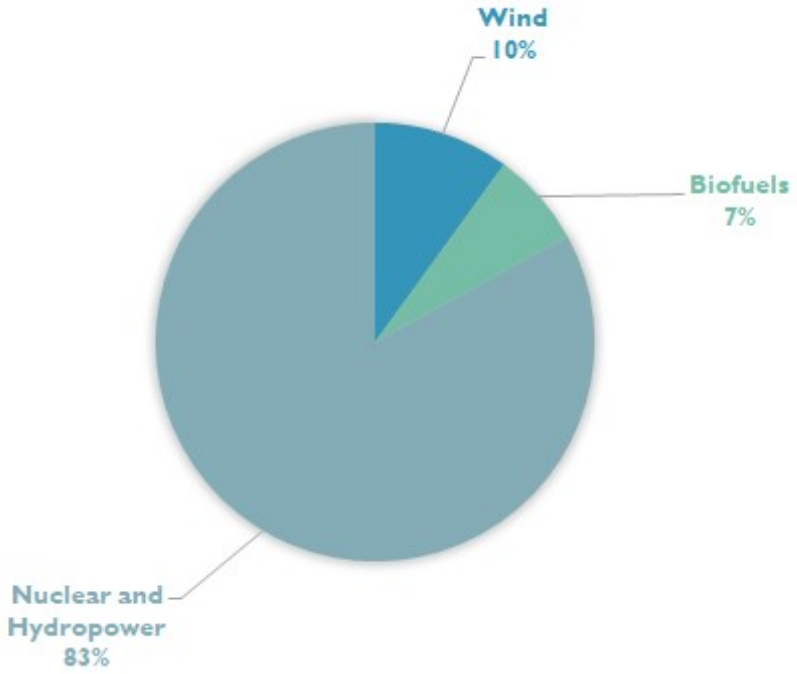

Figure 3. Distribution of Swedish electricity production [34]

As seen in Figure 3, low emissions can be attributed to Sweden's electricity output being generated by renewable sources.

Biofuels have begun to make an impact in this energy distribution and have great potential in Stockholm. In 2016, Stockholm opened a heat and power plant that relies on biofuel as its energy source. This is a great step forward in changing the way people in Stockholm generate energy [7]. However, progress will be hindered so long as Stockholm residents continue to rely on existing coal-fired heat and power plants. As mentioned earlier, the increased amount of biodegrading food waste can provide more biogas and begin to replace nonrenewable energy sources.

Given that Stockholm is surrounded by waterways, hydropower has been an appealing and cost-efficient alternative energy source. Swedish officials report that hydropower technology is under development and engineers are currently conducting studies to test the viability of hydropower on larger scales [34]. The country also has three nuclear plants in place, however nuclear energy has been a topic of political debate in Sweden. If nuclear power generation is reduced, then other forms of renewable energy must be scaled up to meet energy demands while remaining environmentally friendly.

Stockholm aims to increase solar energy use by 50% by 2019, when compared to 2015 data [4]. Stockholm currently uses solar maps to identify areas where photovoltaic panels would yield the most profit, an example is shown in Figure 4.

Figure 4. The City of Stockholm's Environmental Work with solar maps [4]

Along with introducing more options for renewable energy, Stockholm will implement regulations on new built infrastructure to limit energy use. Energy-smart buildings will reduce the amount of wasted energy as well as energy use overall. These buildings utilize integrated home control systems that control temperature, ventilation, and lighting while also tracking energy use with the use of information technology [35]. The reduction of emissions in Stockholm's heating sector will be very impactful. Stockholm has proposed several projects to achieve this, such as using heat generated from the burning of waste, as well as heat produced by data centers [36] [37]. Stockholm's plan also aims to have major renovations that will yield a 30% reduction of purchased energy overall; in feasible areas, the reduction will be closer to 50% [4]. This is important to note because it allows Stockholm to work ahead of its own proposed plan while acknowledging that some areas of the city will need more time to adjust.

Transportation

According to Stockholm's action plan for climate and energy, transportation is responsible for 31% of CO_2 emissions in the city [8]. Another set of statistics provided by Stockholm's *Environmental Programme* shows that road traffic accounts for 40% of nitrous oxide emissions and 90% of particle emissions [4]. One of the reasons Stockholm was eager to change its transportation sector was to improve air quality, as it was causing adverse effects in people with asthma. This prompted conversations about different solutions to create cleaner transportation, such as the goal to introduce fossil fuel-independent vehicle fleets by 2030 [4]. Biogas can be used to power the fleet along with having electric vehicles that run on electricity obtained by other renewable energy sources. Further research is being conducted on the feasibility of these solutions as well as the potential use of Stockholm's waterways for sustainable transportation [4]. Stockholm has also addressed traffic buildup by introducing intelligent transportation systems that provide useful information about traffic patterns and current situations that work with navigational and communication systems to ensure the least amount of time is spent sitting in traffic.

Waste Management

Stockholm's plan stresses the importance of waste management and its effects on the environment. The city's approach to improving this sector is indicative of why it has been so successful in several aspects of eco-friendly initiatives. Stockholm officials focus on three areas of improvement for the waste management system: protecting public health, protecting the environment, and attaining a circular economy [4]. Officials set short-term goals that will eventually play into long-term achievements; this makes progress easy to track and has allowed for revisions as issues arise and circumstances change.

The Waste Management Plan for Stockholm 2017-2020 describes four main objectives, identifies the responsible party for achieving these objectives, lists multiple means for achievement, and identifies ways to measure progress, such as user metrics, rear-end statistics, and waste component analysis [7]. By having a separate plan for waste management, Stockholm's Traffic Administration Office and the Environment and Health Protection Administration has made it easy for citizens to follow their waste and consumption impacts.

The *Environmental Action Programme* describes Stockholm's ambitions to reduce the amount of generated waste, use mechanical systems to separate waste, and biologically process food waste for energy and agricultural purposes. It follows the European Union waste hierarchy: prevention, preparation for reuse, recycling, and disposal as a last resort. By properly processing waste, Stockholm makes the most efficient use of its resources and reduces methane production, which is a byproduct of waste decay. The city continues to lay the groundwork for further progress in the waste management sector and hopes to achieve many of their goals by 2020. Typical waste processing contributes up to 8% of greenhouse emissions in other developed countries [38]. Therefore, Stockholm stresses the need for proper separation and the repurposing of other waste materials. However, the methods used to repurpose waste must be critically analyzed to assess their viability and overall environmental impact.

Sweden's government website reports that the country recycles 99% of all household waste [37]. This information is misleading because, despite Stockholm's efforts to reduce waste and improve recycling, half of all waste in Sweden is burned to produce energy at waste-to-energy (WTE) incineration plants [37]. In the United States, recycling is defined as "using waste as material to manufacture a new product" while burning is a form of transformation, "incineration, pyrolysis, distillation, or biological conversion other than composting" [39]. Sweden also states that since toxic emissions such as dioxins and furan have been reduced by advances in flue-gas cleaning, the only product of waste incineration besides ash is "99.9% non-toxic carbon dioxide" and water [37]. While CO_2 is technically not toxic in normal atmospheric concentrations, the amount produced from WTE incineration suggests otherwise. One third of CO_2 released from WTE comes from burning fossil fuels to ignite the waste. The other two thirds come from the waste itself and is considered carbon-neutral biomass that would have been released as a part of the natural carbon cycle [40]. Many scientists in the United States dispute this claim because WTE plants release large quantities of carbon at once, whereas the natural carbon cycle releases carbon over several decades [41]. Nevertheless, waste incineration is a major contributing factor preventing 99% of waste from going to landfills and provides energy for heating. Sweden acknowledges that WTE is not the most ideal solution to household waste, which is why alternatives must be found to address the growing population's waste production and compensate for energy previously provided by WTE.

With the focus of reducing the amount of waste generated, Stockholm hopes to use communication strategies to educate businesses and individuals about the content of their waste so they can play an active role in reducing their output [33]. This includes using less packaging and construction material waste as well as proper disposal [4]. By educating the public, Stockholm faces less resistance to change since it is framed as a public health issue that affects the overall well-being of the environment and its inhabitants. Table 2 shows the progress these initiatives have made and forecasts for the future.

	2006	2008	2010	2012	2014	2015	2020	2026
Residual waste	235,205	234,112	234,074	234,518	230,569	229,348	188,774	200,597
Food waste	2,925	3,192	6,409	9,953	14,495	16,019	66,677	67,503
Bulky waste	134,096	149,589	141,219	130,938	145,827	137,036	143,391	151,406
Packaging material	74,981	75,357	71,188	65,147	60,776	58,154	60,851	64,252
Total amount	447,207	462,250	452,890	440,556	451,667	440,557	459,692	483,759
Inhabitants	782,885	810,120	847,043	881,235	911,989	923,516	1,016,142	1,139,637
kg/inhabitant	571	571	535	500	495	477	452	424

Table 2. Breakdown of collected waste material in metric tons per year [7]

The data gathered shows a shift to proper waste management since 2006. Not only has there been more extraction of food waste along with others, there has also been a reduction in overall kilograms per inhabitant despite projected growth in population.

Stockholm's environmental program discusses plans to create a web-based tool that will facilitate the repurposing of materials such as furniture and air conditioning units. Models such as the Swedish ORWARE (ORganic WAste REsearch) have been developed to provide a comprehensive review of the environmental effects in varying simulations of waste management and existing recycling systems [42]. Stockholm's innovations have enabled the city to stay on track and inch closer to becoming a zero-waste city through recycling and recovering 100% of natural resources [43].

Food Systems

Sweden has adopted a national Food Strategy to address the sustainability and long-term impacts of food production and supply chains. Introduced in 2016, the Food Strategy was accompanied by the allocation of 5 million SEK (4.9 million EUR) over five years for research projects

exploring food, nutrition, and sustainable growing practices [44]. The Food Strategy works in tandem with Stockholm's *Environmental Action Programme* by setting goals for 2030 that encourage responsible agriculture and generate growth in employment and revenue, while also achieving national environmental objectives. It requires the food production sector to improve resource-efficiency to meet the nutritional demands of the growing population while minimizing detrimental effects on the fragile ecosystem [45]. Collaboration between scientists, government regulatory bodies, and the agriculture, forestry, and fishing industries is necessary to preserve the agricultural landscape as well as plant and wildlife biodiversity.

Urban gardening projects in Stockholm aim to revolutionize the modern food system by integrating agriculture, technology, and architecture. The Stockholm-based company Plantagon hopes to launch crowdfunded campaigns to design and build multi-level indoor urban farms that have their own self-sustaining food, water, and electrical systems [46]. The company utilizes agricultural technologies such as hydroponics, which does not require soil, and aeroponics, which utilizes hanging planters to minimize space. A more democratized and government-backed arm of urban gardening is the Swedish Association of Allotment Gardens, which provides residents with resources to cultivate small plots of land in urban spaces that are shared with neighbors and used to grow fresh fruits and vegetables. The organization is over 100 years old with 25,000 members and a 260-member network of urban farming organizations and gardening collectives [32]. These projects rely on public support and participation, emphasizing the importance of solutions from the Societal Transformation Cluster.

Most of the science and technology solutions Stockholm employs are replicable and have been adopted by other leading green cities. However, the extent of support and progress displayed is in part due to solutions in other sectors.

IV. Governance Solutions: Organization and the Role of Effective Leadership

Stockholm's success in implementing its environmental policies can be largely attributed to its government leaders, who have made it their priority to ensure Stockholm promotes and practices environmental sustainability. Internationally, Stockholm has strengthened its commitment to climate mitigation by making pacts with other large cities and sub-national jurisdictions across the globe, holding itself and others accountable to established goals and regulations. While Stockholm is still far from 100% sustainability, the city has been extremely successful in its efforts to test and implement forward-thinking climate solutions. This is a result of the dedication of city leaders and the efficiency of the city's governance practices. By adhering to the fine-tuned and efficient governance practices Stockholm has instituted to reduce its environmental imprint over the past several decades, other jurisdictions can help to preserve the future of the planet by incorporating these practices in their governing bodies as well.

Sweden's System of Government

The Swedish government's main desire is to be a global leader in development, equality, and climate change adaptation, with an emphasis on the equal worth of all people and the ability to change the future [47]. Sweden has a parliamentary democracy system in which the people elect representatives to the Riksdag, Sweden's parliament, who make decisions according to their constituents and implement laws, proposals, and amendments. There are three levels of government in Sweden: local, regional, and national as well as the continental level which is influenced by Sweden's involvement with the European Union.

The Swedish government has put great effort into establishing a strong relationship of trust from the public. Two of the most important principles in the governing system are the Freedom of Press Act and the Fundamental Law on Freedom of Expression. The Freedom of the Press Act was adopted in 1949 and establishes the right to disseminate information in print form with accountability before the law and the right of public access to official government documents [48]. The Fundamental Law on Freedom of Expression was adopted in 1991 and extends the Freedom of Press Act to include new forms of media such as radio, film, television,

and online content [48]. These laws form the basis of Sweden's effective government and the relationship between officials and the public.

Stockholm's Comprehensive Climate Action Plan – The *Environmental Action Programme*

For over forty years, the *Environmental Action Programme* has been an integral part of Stockholm's successful campaign to reduce its carbon impact and make the city as environmentally friendly as possible. Stockholm is on its ninth iteration of the *Environmental Action Programme*, which was instituted in 2016 and will be in effect until 2019 [4].

The *Environmental Action Programme* is revised every few years by Stockholm's city government and, with help from scientists and members of the public, sets new goals and sub-targets for the city. The most uniquely effective characteristic of Stockholm's *Environmental Action Programme* is that it tasks committees of local businesses and members of the public with finding the most cost-effective and efficient ways to reach these sub-targets [4]. Once these committees find the best way to meet sub-targets and actions have been implemented, they continue tracking the progress of the climate solutions to make future improvements. Integrating the *Environmental Action Programme* into the city's governance system ensures compliance, accountability, and a system for feedback.

Stockholm has found consistent success under this unique system. Since 1990, Stockholm has cut its carbon emissions by 25% per resident [5]. Under the *Environmental Action Programme*, Stockholm has offered tax reliefs for industries that work to become less emissions-intensive and has instituted a carbon tax that has increased over time, which have been some of the most cost-effective ways Stockholm has reduced emissions [2]. Furthermore, Stockholm has shifted towards renewable energy and has utilized the newest technologies to curb its emissions through the creation of centralized, more efficient neighborhoods and heating systems [5]. These innovative climate solutions, among many others that have reduced Stockholm's emissions and environmental impact, are the result of the city's process for implementing the sub-targets of the ambitious *Environmental Action Programme*. This has allowed Stockholm's leaders to employ effective governance practices, leading to a great deal of success for the city of Stockholm in its mission to bend the curve.

Stockholm As a Model for International Climate Cooperation

Greenhouse gases and pollutants circulate through the atmosphere and reach the other side of the world in a matter of weeks, making emissions a global issue that requires international cooperation to resolve [1]. While one jurisdiction may reduce its emissions, it will not make a noticeable impact on a global scale if other jurisdictions do not do the same. Through international coalitions, Stockholm and other sub-national jurisdictions have advanced the success of international agreements such as the Paris Agreement. Stockholm is one of the few cities that has shown it can successfully work with other sub-national jurisdictions from all parts of the world to devise and implement climate solutions on an international level, validating why Stockholm is a model for international climate cooperation.

The C40 Alliance of Cities is a coalition of over ninety large cities across the globe with a combined population of over 650 million people [49]. It has strengthened international cooperation for more than a decade and created a network in which the most advanced climate solutions can be shared. With such a large network, there is potential to influence climate change mitigation at every corner of the globe, and the cities currently in the network connect with one another to share their most advanced climate solutions with each other and the rest of the world.

Stockholm's Leadership

Stockholm has become a leader in practicing and promoting climate change solutions. At the center of these practices has been a network of strong government leaders who set a positive example for the citizens they represent. The fourth solution of *Bending the Curve* emphasizes the importance of leadership in climate mitigation efforts. One of the fourth solution's sub-focuses states that "national and subnational leaders must promote international action and cooperation for unilateral climate policies to succeed and to minimize potential detrimental effects [of global warming]" [1]. Since the 1970's, Stockholm's leaders have acted diligently to reduce the city's environmental impact through promoting national and international cooperation and utilizing both small-scale and large-scale solutions to help combat global warming.

While there are many examples of leaders steering climate policy over the course of Stockholm's history, the current mayor of Stockholm, Karin Wanngård, has been a pioneer and champion of modern-day climate policy and sustainability both domestically and internationally. She has led the city's actions towards being 100% fossil-free by 2040, and she has reinforced her

support of this goal by committing to shut down the city's last coal power plant by 2022 [50]. Wanngård has been a facilitator in the advancement of the city's district heating system, however, other options must be explored besides the current proposed plans for biogas and waste-to-energy models [50].

In addition to these smaller-scale projects in Stockholm, Mayor Wanngård has worked with city leaders across the globe to push the boundaries of technology and test new ways to bend the warming curve. Mayor Wanngård published an article in *Climate Central* in 2017 stating that "leadership is really important when you want to make things happen…You need to take the bold decisions and accept the debate and then later it will cool down" [50]. This risk-taking mentality has made Stockholm one of the world's leaders in climate solutions. Committed leaders have propelled Stockholm to the forefront of the campaign to bend the curve. The *Environmental Action Programme* and the C40 Alliance have had full support from the city's highest leadership throughout the years.

The Replicability and Scalability of Stockholm's Governance Solutions

Stockholm has been extremely successful in implementing its governance solutions. By means of its *Environmental Action Programme*, the C40 Climate Alliance, and strong leadership, Stockholm has become a living laboratory and model for climate change solutions.

Stockholm's process for implementing the sub-targets their *Environmental Action Programme* is now engrained in the city's governance practices, and every few years when a new *Environmental Action Programme* is devised, more ambitious goals are set and they are met more efficiently. Stockholm's combination of climate change mitigation strategies emphasizing energy efficiency, public transportation, waste management, and community involvement is unique, but is certainly a valuable resource for other jurisdictions to model their own climate actions after.

V. Market-Based Solutions: Economic Strategies and Incentives for Green Growth

Market-based solutions are identified in the *Bending the Curve* report as incentives that will encourage industries and individuals to reduce their carbon emissions [1]. These are closely related to the Governance cluster, as they both focus on regulation and initiating change. Sweden has seen economic growth, emerging green technology industries, and high employment rates as a result of strong taxes on emissions and other pilot programs that incentivize sustainability.

Sweden's Carbon Tax and International Trade Considerations

Sweden implemented a tax on carbon emissions in 1991. This policy provides incentives to reduce greenhouse gas consumption, improve efficiency, and increase the use of renewable energy sources. When first introduced, the tax rate was 250 SEK (26 EUR) per metric ton of CO_2 emitted, and has gradually increased to the current rate of 1,150 SEK (120 EUR) [51]. Incrementally raising the price of carbon gave households and businesses time to adapt and replace appliances and equipment. Sweden's greenhouse gas emissions have decreased by 26% since implementing the tax in 1991 to 2016 [9].

An energy consumption revenue system was already in place prior to 1991, making the introduction of the carbon tax policy a smooth transition to include CO_2 emissions. Sweden had been taxing energy since 1924 starting with a tax on petrol and eventually adding diesel, oil, coal, and natural gas to the list [52]. This was solidified as one single energy tax in the 1970s following a national oil crisis [52]. The 1991 carbon tax was an updated complement to the general energy tax. Additionally, the tax is levied on all fossil fuels based on their carbon content because CO_2 emissions released during combustion are proportional to the carbon content of the fuel [51]. This makes it very easy to calculate how much an individual or business should be taxed without measuring the actual emissions. Revenue collected from specific taxes is compiled into the national general budget [51]. Budget funds are allocated to public works projects and invested into new technology innovation.

Additionally, in 2006 Stockholm implemented a traffic tax on drivers entering traffic-heavy areas. License plates of cars entering the area are scanned and drivers are appropriately charged a fee depending on how much pollution their car emits. Four years of this policy resulted

in immediate benefits such as the reduction of traffic by 25% over four years, and long-term benefits such as a decrease in pollution by nearly 10% and a decrease in asthma-related children's visits to hospitals by more than 45% [53]. Drivers avoid being taxed or spending more money on gas by taking alternative routes, carpooling, and utilizing more sustainable forms of transportation such as public transit or biking.

Other countries have since implemented their own carbon taxes. In 2016, Canadian Prime Minister Justin Trudeau passed a policy that would require all Canadian provinces to set a carbon tax by 2018. The initial minimum price is 10 CAD (6.10 EUR) per metric ton of CO_2 and will increase annually by 10 CAD (6.49 EUR) to reach 50 CAD (38.55 EUR) by 2022 [54]. This national tax plan was modeled after a policy introduced in British Columbia, Canada's third largest province, in 2008. British Columbia's initial tax rate was 10 CAD (6.10 EUR) per metric ton of CO_2, increased by 5 CAD (3.24 EUR) every year until 2012, and has since remained at 30 CAD (19.47 EUR) [54]. The province's greenhouse gas emissions have decreased by 12% per capita from 2008 to 2013 [54]. This excludes emissions from electricity production because most of British Columbia's energy comes from hydropower and accounts for only 2% of total emissions, compared to the national average of 20% [54]. Despite this overall decrease, British Columbia's emissions increased slightly in 2012 and 2013 after the rate stabilized. This suggests the need to continue increasing the price of carbon.

California takes a more hands-off approach to regulating carbon. Instead of a carbon tax, California's cap-and-trade system, introduced in 2012 by Governor Jerry Brown, issues permits for emission allowances that industrial firms and corporations can exchange or sell at quarterly auctions. Revenue collected at these auctions is invested back into green government programs. Thus the "trade" portion of this system incentivizes companies to keep emissions below the "cap" so they can trade or sell later on the carbon market. The theory behind cap-and-trade is that establishing a firm limit on emissions with no other guidelines provides industries the flexibility to decide their own course of action in order to stay below that limit [55]. Some environmentalists and economists fear that the success of this exchange program will cause companies to buy and hoard allowances for future use, as permits do not expire.

Consumption-Based Imported Emissions

While Stockholm and Sweden have dramatically decreased domestic emissions through innovations in green technology and implementing green policies and economic incentives, it is important to note the impact of increased consumption and the emissions from producing and importing goods. Outsourced emissions are embodied in products consumed within developed countries but produced abroad. Under the Kyoto Protocol, emissions from production are assigned to the country where production takes place instead of where the final products are consumed [56]. This allows developed countries to claim more success in reducing emissions while also significantly underestimating their contribution to climate change.

According to a 2011 study conducted by the National Academy of Sciences that analyzed territorial and imported emissions of 113 countries between 1990 and 2008, Sweden's domestic emissions decreased from 51 million metric tons of CO_2 to 48 million metric tons during this time, while imported consumption-based emissions have fluctuated from 92 million metric tons in 1990, to 76 million metric tons in 2000, and rising again to 80 million metric tons in 2008 [57]. Thus, in 2008 Sweden's total domestic and imported emissions were 128 million metric tons, with trade accounting for 62.5%. In comparison, the same study reported that Canada's total emissions in 2008 were 1,163 million metric tons with 51.6% from trade, and the United States produced 11,827 million metric tons with trade accounting for 52% [57]. Sweden's absence of large-scale manufacturing accounts for the large amount of imports in comparison to Canada and the United States. A report published in 2013 by the Swedish Environmental Protection Agency estimated that imports increased by 40% from 2000 to 2008 [11]. This global perspective sheds light on the need for more accurate and transparent measurements of national emissions and carbon footprints that incorporates both territorial and imported carbon. In addition to reducing territorial emissions, Sweden and all industrialized countries must work to reduce the amount of imported embodied carbon by promoting local and sustainable consumption practices.

Economic Incentives for Green Growth

There has been a measurable rise in the gross domestic product (GDP) of Stockholm due to its shift to clean technology and adoption of sustainable policies. As Stockholm's emissions began to decrease, its GDP increased by approximately 30%. For comparison California's GDP has

increased by 25% from 2000 to 2014 [5]. This correlation suggests that adopting sustainable practices will not harm a city's economy, but may in fact improve revenue and economic growth. Stockholm's increase in GDP and environmental impact follow the Environmental Kuznets curve. This curve predicts that as a city's GDP increases, environmental degradation also increases until the curve plateaus and environmental degradation begins to decrease as GDP continues to increase. Stockholm has shown a downward trajectory while most major cities are attempting to level off [58]. It is safe to say that an increase in a country's revenue is a universal incentive that is attractive to almost all countries, regardless of political or societal issues.

The Organization for Economic Co-operation and Development (OECD) conducted a study to analyze the ties between sustainable policies and technologies to the economic success of Stockholm. The vision to make Stockholm "the green capital of the world" comes with "extensive opportunities for work and education, a thriving business environment, regional growth… vocational programmes and entrepreneurship" [59]. Stockholm is chosen as a living laboratory case for its notable environment innovations and policies. This unique feature of the city attracts global attention, increasing tourism and making Stockholm a popular study-abroad destination for foreign students. This increase in tourism correlates with an increase in revenue generated from recreational activities, such as restaurant visits and museum admissions. Additionally, this has opened doors for global businesses and new working relations, especially for Stockholm's green technology companies.

It is a common fear that the shift to renewable energy will leave many workers in the coal industry unemployed, but Stockholm has proven otherwise by creating thousands of jobs at renewable energy plants and green technology companies. Stockholm's climate activities have produced an economic boom with Stockholm County reporting a 17% increase in overall employment since 1998 and a 14% increase in employment in the green sector since 2003 [59]. Stockholm's first eco-district, Hammarby Sjostad, provided opportunities for nearly forty urban developers and many more for green technology companies. The success of green technology in this eco-district allowed the companies to branch out and sell their commodities outside of Sweden [60]. Developers and other companies benefit from Stockholm's brand as a green leader, setting an international example of the intersection between green technology innovation and economic growth [59]. Although the cost of construction for this eco-district is high, the money saved from energy efficiency and the price redeemable through leasing and selling of the homes

result in a hefty pay-off for construction companies and the government. One eco-district in Stockholm received 85% of its funding from a private sector while funding for the district's green research projects were equally matched by public and private institution investments [59].

Stockholm's employment and revenue trends suggest that cities considering more sustainable practices should not view these changes as detriments to their economies. Although more evidence is needed to conclude that there is a direct correlation, Stockholm's increasing GDP and employment show promise for the future of environmentally friendly cities.

VI. Conclusion and The Stockholm Model

Looking to the Future of Stockholm's Path to Carbon Neutrality

Cities around the world can learn a great deal from both the successes and failures of Stockholm's environmental initiatives. The city's leaders stress the importance of celebrating their achievements but acknowledge that there is room for improvement. Further research is required to discover new ways of facilitating change and replacing unsustainable practices such as waste-to-energy incineration and inflated consumption.

Sweden imports twice as much carbon equivalent emissions as it produces [11]. Consumption-based emissions must be incorporated into Sweden's future goals with more accurate national measurements and greater transparency in reporting. Stockholm must work to reduce the amount of imported embodied carbon by adopting more sustainable and local consumption practices.

Stockholm has addressed 9 of the 10 scalable solutions proposed in *Bending the Curve*. The final solution calls for the immediate reduction of black carbon and methane using available technologies [5]. Reducing short-lived climate pollutants (SLCPs) is of equal or even greater concern compared to other greenhouse gases because they are the most potent. Efforts to reduce SLCPs have been a byproduct of other initiatives such as the reduction of methane due to proper waste disposal. To bend the curve immediately, Stockholm must make a targeted effort to utilize existing technology to cut black carbon by 90%, methane by 50%, and HFCs completely, further solidifying Stockholm's status as a green city [1].

Replication of Solutions

Stockholm has applied a wide variety of solutions to foster its largely successful climate mitigation campaign. Other cities can look to Stockholm for inspiration to implement and tailor their own actions to lower emissions and promote sustainability. The world can also learn from Stockholm's shortcomings and weaknesses to build upon a universal model of climate mitigation and carbon neutrality: The Stockholm Model.

First and foremost, countries must undergo a paradigm shift that fosters a new culture of climate literacy and concern for global health. Society must be willing to accept responsibility and act on individual, interpersonal, community, and governmental levels. This requires the

collective efforts of scientists, activists, and politicians to engage the public through education, media campaigns, and pilot programs that change the habits and social norms of the population.

Further research and technological innovations are necessary to reduce fossil fuel dependency and integrate new sustainable technologies into city development and everyday living. Green alternatives must also be affordable and accessible to developing nations in order to avoid the historically fossil fuel-heavy transition stage of industrialization [61]. While many of Stockholm's urban development projects in waste management, energy, and transportation are region-specific, other cities can learn from Stockholm's success utilizing existing infrastructure and creating new systems that are adaptable to the built environment.

The next solution is to elect officials with public and environmental interests to develop and implement effective legislation and regulations. An informed and educated public must be vigilant to hold government officials accountable and push for more progressive action in national and international affairs. Stockholm's system of setting targets, constantly reviewing progress, and updating its goals and activities accordingly is a great example of a government that listens to its constituents and encourages civic engagement. Governments must also strengthen, and in some cases, rebuild, trust from the public through systematic reform and actions that prove the government's commitment to serving its people.

Finally, economic incentives and regulations must be available to encourage industries and other financial stakeholders to reduce their carbon emissions and invest in green technology. Stockholm has proven that introducing energy taxes and transitioning to sustainable practices are not detriments to the city's economy. In fact, Stockholm's economic growth and high employment rates are the result of its unprecedented green activity. Although Stockholm and the country of Sweden have relatively small populations, the trends observed in Stockholm provide encouragement for larger cities and countries to follow suit.

Stockholm will continue to be an environmental leader in the years to come. The city's progress and status as an environmental leader can be attributed to its utilization of a variety of disciplines across all levels of society, technology, and government. There is no single solution to this global problem. Stockholm acknowledges this limitation and embraces the potential of a multidimensional approach that is greater than the sum of its parts. Stockholm's record of environmental innovation and the diversity of its effective strategies make the city a perfect living laboratory.

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