Smart Cities: Improving Mobility in Berlin Through Decentralisation.

December 2019

dGen

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dGen is a not-for-profit think tank based in Berlin, Germany. We focus on how blockchain technology can contribute to a decentralized future in Europe and what this might mean for people, society, private entities, and the public sector over the coming decades.

We're working with a team of researchers exploring how decentralisation will shape our future. Our insight reports focus on specific topics and industries to drive ideas for adoption in Europe. To find out more, please visit us at dgen.org.

dGen. (2019). *Smart Cities: Improving Mobility in Berlin Through Decentralisation*.

Foreword

When we talk about how technology will change the world around us, we don't often mean this in a very literal sense. We might allude to changing habits, services, or what new devices will replace the old ones. But when discussing big topics like mobility, it's easy to imagine how these developments could shape our environment.

About a century ago when cars started to become the preferred method of private transportation, our cities developed to accommodate them. More cars meant more streets, and, in turn, more streets connecting cities and towns meant more reasons to buy a car. This vicious cycle continued to influence urban planning as more people joined the automobile revolution in post-war Europe, adding streets, lanes, highways, and parking lots to our environment. Across the continent, people were able to visit their relatives and friends, travel further for work or vacation, and depart whenever they wanted.

The unfortunate byproduct of that newly acquired freedom was twofold, and quite literally unseen: climate change and noxious gasses. As cars filled our streets, nitrogen and carbon dioxide filled our lungs and atmosphere. One solution seemed to be the introduction of 'clean diesel' cars that promised lower emission levels; a promise that wasn't just empty, but a deliberate deception that came to light during 'Dieselgate.'

Aside from the obviously nefarious impacts, we seem to have constructed a world around us where cars come first. Pay attention the next time you go outside, and you'll notice the amount of space dedicated to cars; especially when you consider that the average car is parked 96% of the time.

So how can we move to cleaner alternatives and cities that run around people, not their cars? The German government briefly considered making public transportation free, but swiftly withdrew its proposal when the public got wind of it. Others have pointed out that existing infrastructure couldn't handle a larger demand, are too expensive or inconvenient compared to cars. Technology or decentralisation is not going to solve any of these problems, but could it have the potential to make certain improvements?

One of our proposals is to operate public transport on an open source protocol as a decentralised network. This would allow any party, commercial or not, to add their service to the collective offering of public transportation. Today that could be a new e-bike startup, tomorrow it could be my self-driving electric-car picking up passengers. Some other parties might choose to contribute by improving the source code and integrate a powerful AI to offer the fastest, lowest impact or most economic option to get from A to B. Wouldn't that be truly 'public' transportation?

By considering our mobility a collective responsibility, we can collaborate to make it better. With more effective use of vehicles and better alternatives to polluting modes of transport, we have the potential to shape the world around us. Literally.

Jake Stott & Nick Dijkstra

Founding Board, dGen

Executive Summary

This report has two major purposes, the first is to identify the progress that cities are making in reducing carbon dioxide and noxious emissions, and the second is to establish how blockchain technologies can be employed to achieve this more effectively. To do this, we investigate the main objectives of the 2015 Paris Agreement as a touchpoint for global goals in regards to emission reduction. Fundamentally, these are commitments by a range of countries to reduce noxious emissions underpinned by emission level targets with specific time frames, such as zero-emissions by 2050, and reporting guidelines to hold countries accountable to their commitments. The Paris Agreement was developed with special attention paid to the scientific evidence of the negative impact of emissions.

Fundamentally, Berlin faces financial, logistical, and technical challenges to accomplishing its emission goals, and needs to set continuously monitored emission reduction targets

As cities are the largest generators of carbon dioxide and other noxious gases, special attention is paid to their progress in meeting global targets, with particular focus on public transport in Berlin. Despite not having set any defined targets before 2016, Berlin city authorities still planned and implemented strategies for reducing emissions; their achievement received relatively high ratings in a report by Deloitte. However, major challenges remain:

- air quality is still poor
- forecasts to replace diesel buses with electric vehicles by 2030 appear unachievable - half of the city has no electric tram line
- rail travel is 40% dependent on fossil fuel powered electricity
- no customer journey analytics exist
- public transportation is not widely affordable.

Fundamentally, Berlin faces financial, logistical, and technical challenges to accomplishing its emission goals, and needs to set continuously monitored emission reduction targets.

Blockchain technology demonstrates potential to facilitate solutions to many of these problems by improving data tracking and streamlining many systems.

We identify four main areas for blockchain adoption:

- Reporting
- Multimodal apps
- Cross-border contracts
- Autonomous vehicles.

Especially when combined with other technologies, blockchain has the potential to cut out intermediaries, improve communications, and provide users with better travel options and planning. For instance, blockchain's decentralised nature can aid in increasing reporting on climate initiatives as it eliminates the need for an intermediary, making this process faster and easier. Using a distributed ledger also increases transparency, and as it is immutable, has been linked to more accurate emissions reporting, especially when combined with IoT to automate reports. Blockchain can also significantly increase personal data protection through encrypted hashes, the codes that make up blockchain, and by restoring data ownership to users, making data collection via app much more secure and appealing to users. This data is essential to creating viable routes for electric buses and expanding Berlin's public transportation in general.

Open-source public blockchain also enable apps that can support a wide variety of companies and travel options. As organisations are able to build their own platforms on top of an open-source protocol, it can provide users with a much wider selection of travel options, and give them more environmentally friendly choices. These options can be combined to provide users with travel options that use various services and companies, also known as multimodal apps. Multimodal apps have been found to reduce driving and increase reliance on public transportation, effectively reducing harmful emissions.

Smart contracts, another feature of blockchain, is also important in increasing the usability of public transportation as consumers can make agreements directly with each organisation. This reduces the amount of backend work, decreasing processing time when planning a trip and purchasing tickets or services. By paying with cryptocurrency, a trip that uses multiple services in multiple countries could also be booked and paid for all on one app as an intermediary, such

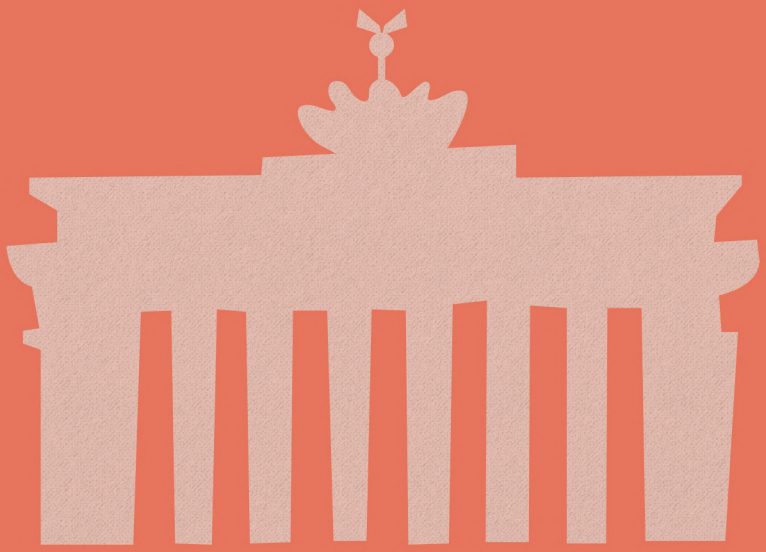
as Visa or Mastercard, would no longer be required. Overall, blockchain has the potential to reduce processing time and increase traveller options, as agreements between companies are not necessary.

Smart contracts are also useful to fully leverage the utility of autonomous vehicles. Self-driving cars are expected to have an impact on the landscape of transportation. However, the security provided by blockchain enables the cars to become even more autonomous. For instance, they could be given access to smart wallets, and with smart contracts in machine to machine (M2M) operations, can pay for charging and maintenance. Blockchain's hash system means that they wouldn't be able to be hacked into, and the wallets they are connected to as well as the vehicles themselves would remain secure. Beyond this, if they are added to a car sharing service or used in a public shuttle service, they would be able to generate their own income and increase efficiency by making more energy efficient travel available to a wider range of users and collecting and using data about transportation demand and energy use.

We recommend that cities employ experts to evaluate their current progress in emission control and oversee blockchain adoption to aid in meeting these goals

Blockchain can also be used by many cities to aid in policy creation. However, even with continual blockchain technology development, there are still barriers to blockchain adoption. Namely, many public authorities are cautious of adoption due to disruption in their current systems. This is largely due to uncertainty about the business model and general technology. However, established applications can help temper this hesitancy. Germany is already employing blockchain technology to track renewable energy. While this is already a useful step, we believe that blockchain can be expanded to serve the city and its residents further.

Therefore, based on the findings of this report, we recommend that cities employ experts to evaluate their current progress in emission control and oversee blockchain adoption to aid in meeting these goals in the most cost effective and timely manner. This technology will not eradicate dependence on fossil fuels, but can enable better and faster tracking to reach the emission goals outlined by the Paris Agreement. Implementing this technology not only has the potential to improve and expand Berlin's public transit system, but can provide necessary insights for achieving climate goals.



Introduction

The Paris Agreement

The 2015 Paris Agreement is a legally binding agreement to limit the damaging effects of climate change. The Accord was signed in Paris, France on 12 December 2015 by 196 countries,[1] members of the United Nations Framework Convention on Climate Change (UNFCCC), and referred to as the Paris Convention.[2] This pact was the latest in a long history of agreements between world powers to reduce pollution caused by a range of greenhouse and noxious gases, but focused predominantly on the emission of carbon dioxide. While noxious gases have a negative effect on human and environmental health, carbon dioxide emissions are considered to be the main cause of climate change, resulting in melting ice caps and rising sea levels.[3]

This Accord referenced a rule book for how to measure emission change, making its members much more accountable, and was considered to increase the effectiveness of climate change efforts

The European Union (EU) championed global collaboration on climate change, formally starting in 1992 at the Earth Summit held in Rio de Janeiro. The UNFCCC was agreed upon in the form of a non-binding treaty for developed countries, and emission targets were set with timelines for achievement. Notably, the United States (US) was not a party to this accord. The next step towards a climate agreement was completed in 1997. This was known as the Kyoto Protocol, a legally binding agreement on emission levels. The US did not participate in this agreement, either. China was also classified as a developing country, and therefore not legally bound to agree, weakening the effectiveness of this agreement.[4 5] A convention held in Copenhagen in 2009, attempted to garner greater commitments from the leaders of major economies with high emissions, but failed.[6]

The Paris Agreement is regarded as a greater success because it altered the structure of climate change interventions. It required member parties to instigate targets for the reduction of emissions, while asking them to suggest how these would be accomplished, as well as introducing reporting and reviewing procedures. This Accord referenced a rule book for how to measure emission change, making its members much more accountable, and was considered to increase the effectiveness of climate change efforts.

The Accord also implemented guidelines that acknowledged the needs of developing countries for economic and social growth, while still providing goals for cleaner energy.[6 4] For instance, the Accord recognizes the need of developing countries to provide increasing numbers of households with electricity.[6] To respect this need, while still pushing objectives to use less fossil fuels, the Accord arranged for financial support from developed countries to implement climate change objectives and targets in developing countries while still expanding electricity use.[6 4] Article 4 of the Accord also suggests that developed countries need to lead emission reduction globally, setting targets and aiming for reduction in emissions by 2050 at the latest.[2] However, although targets are required by the Agreement, they are not binding. Countries with very high emissions, specifically China and the US, are not party to this agreement, either, weakening its effect.

Although the target date for a reduction to zero emissions is set at 2050, a date between 2060 and 2080 is considered more likely

Overall, the Paris Agreement set the objective of limiting the global temperature increase to 2°C above pre-industrial temperatures, and to reduce this rise to 1.5°C, if possible.[1 4] One of the most notable objectives of the agreement is to achieve zero emissions, which refers to when the level of emissions produced is completely counteracted by the processes used to remove them from the atmopshere.[4] Although the target date for a reduction to zero emissions is set at 2050, a date between 2060 and 2080 is considered more likely.

Criticism

The biggest atmospheric polluters between 1850 and 1950 were the US and the EU, while China has made the fastest growing contribution

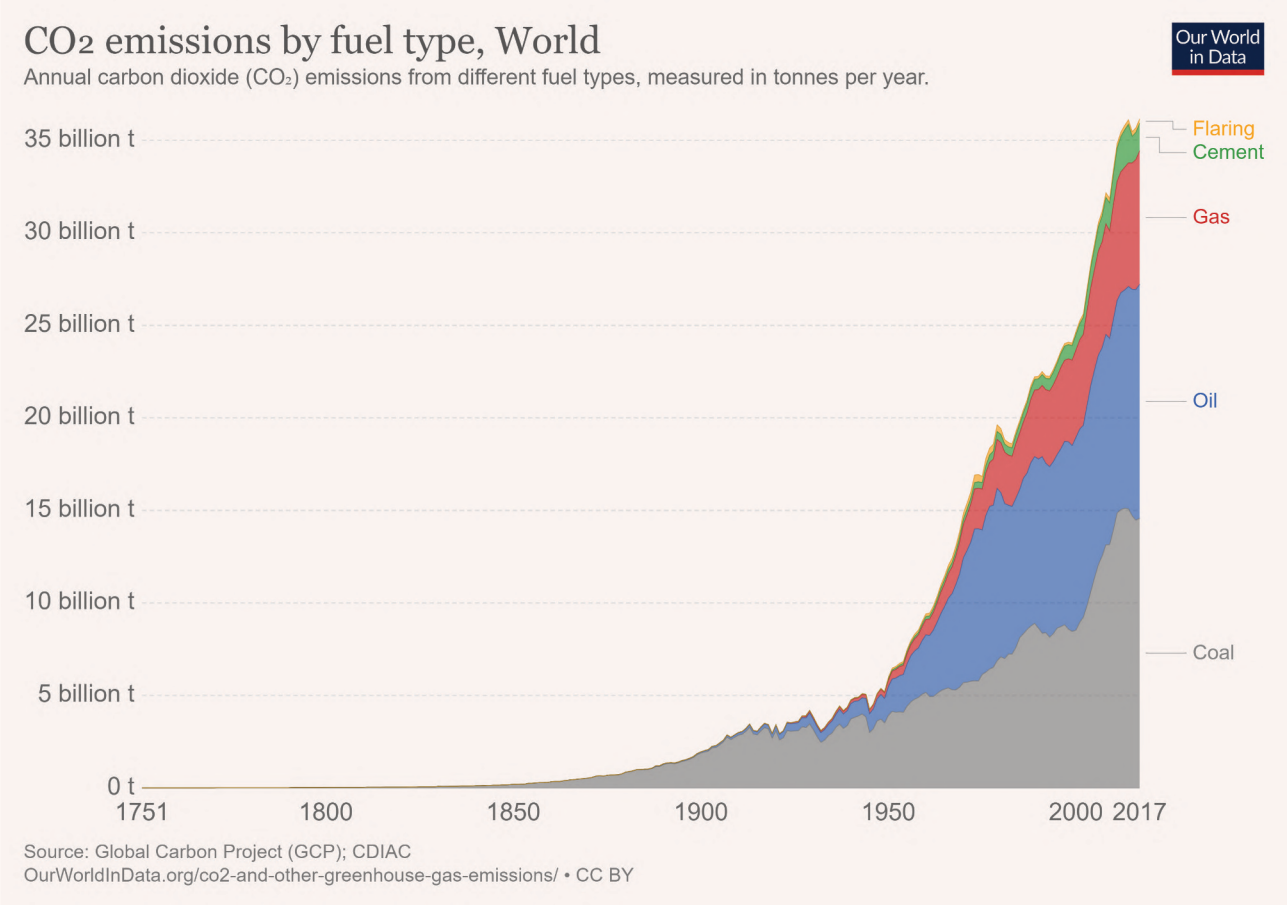
While the Paris Agreement is seen as a landmark case in terms of climate agreements, some studies, such as one by Clemecon,[4] are still highly critical of the agreement. Despite the increased acknowledgements of developing countries' need to expand access to electricity, this study claims that developing countries have been made responsible for reducing atmospheric emission levels that they had no part in generating. In other words, developed countries have effectively been partly absolved of responsibility for the critical problem they created as the pleas from developing countries to recognise their historic position was ignored. The trends in carbon dioxide emissions since the start of the industrial age are shown in figure 1, demonstrating that the biggest

The agreement created a system of funding for developing countries, but failed to set financial targets for the developed nations regarding their agreed support

atmospheric polluters between 1850 and 1950 were the US and the EU, while China has made the fastest growing contribution. China, the US, and the EU represent the three largest emitters from 1950s to 2017.[9] Developing countries have contributed significantly less.

And while the Paris Agreement created a system of funding for developing countries, it failed to set financial targets for the developed nations regarding their agreed support for developing countries' programmes.[4]

Figure1: Global Trends in Carbon Dioxide Emissions 1751-2017



Source: [9]

Scientific Evidence and Solutions

Major scientific evidence for climate change and its associated effects relies on changes measured over the past century. For instance, from 1993 to 2018, the average global sea level had risen by 81 millimetres (mm) or 3.2 inches (in), and has risen for 23 of the past 25 years; prior to 1993 the average annual rise in sea level was 1.7 mm per year. This change is predominantly attributed to melting glaciers and ice sheets and, to a much lesser degree, the additional thermal expansion of sea water that occurs when temperature rises.[3] Additional visible consequences of global warming are increased:

- flooding
- droughts
- tropical storms
- wildfires

Global warming is largely attributed to human activities and has increased the proportion of carbon dioxide from approximately 280 to 380 parts per million in the past 250 years

All of these phenomena are increasingly intense. The changes in weather patterns have been attributed to the higher level of atmospheric emissions, for instance significant variation in the quantities and timing of snow and rain.[8] Global warming is largely attributed to human activities, especially burning fossil fuels. This has increased the proportion of carbon dioxide from approximately 280 to 380 parts per million in the past 250 years.[8]

Two actions were suggested to accomplish the Paris Agreement goal of limiting temperature rise to 2°C above the 1751 level:

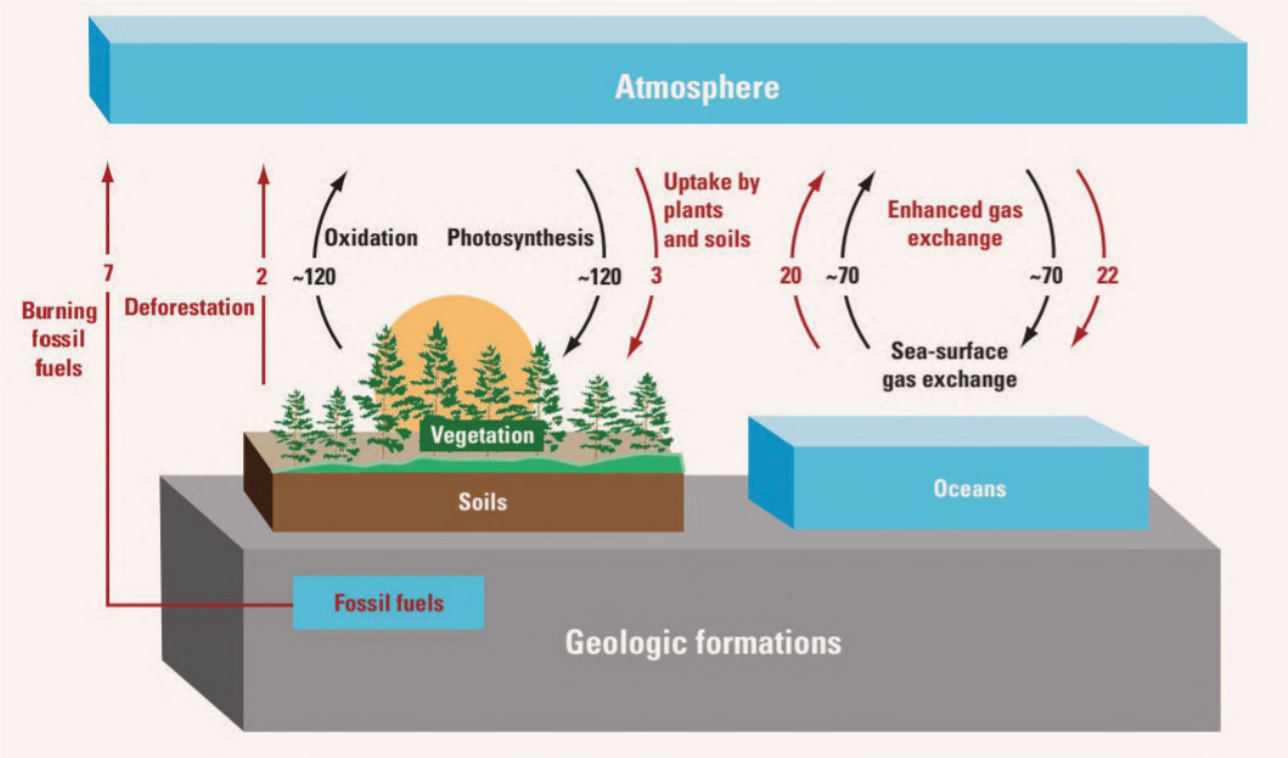
- to stop the increase in volume of greenhouse gas emissions
- to employ sequestration techniques;[1] the capturing and storage of emissions so that they are no longer in the atmosphere.[7]

Both of these methods rely heavily on integrating better and newer technologies.

Gas Sequestration

Carbon dioxide sequestration happens naturally, but in recent years, has been developed into artificial processes. Photosynthesis is the natural process of removing carbon dioxide from the atmosphere and storing it in trees, plants, and crops. This is still one of the major methods of removing carbon dioxide from the atmosphere. These plants absorb the gas and produce oxygen as a side product, figure 2.[8]

Figure 2: Sequestration of Carbon Dioxide in the Atmosphere



Source: [8]

Less trees effectively increases the impact of emissions, because trees are a major factor in removing carbon dioxide from the atmosphere

The diagram illustrates generation and absorption processes of carbon dioxide; the upward red lines represent carbon dioxide produced, and the downward red lines show absorption by means other than photosynthesis. Meanwhile, the black lines represent the exchange processes, and show relative absorption. Deforestation is noted in particular, as less trees effectively increases the impact of emissions, because trees are a major factor in removing carbon dioxide from the atmosphere. Therefore, growing new forests, grasslands, and

wetlands is promoted as a means of reducing atmospheric emissions.[8] Article 5 of the Paris Agreement mostly focuses on forests and other agricultural solutions,[1] emphasising their importance in slowing climate change.[2] Carbon dioxide can also be absorbed by tree trunks, branches, foliage, and roots, lending even more importance to land management methods, but the quantity of gases that can be absorbed is limited, meaning that climate change cannot be tacked by solely employing this method.

When carbon dioxide dissolves in water, it produces a weak acid, meaning that the acidity of seawater rises and destroys many ecosystems

Oceans and geological formations can also act as sequestration sites for carbon dioxide. The world's oceans naturally absorb environmental carbon dioxide, and in 2003 the quantity was estimated to be 2 billion metric tons. However, when carbon dioxide dissolves in water, it produces a weak acid, meaning that the acidity of seawater rises. This destroys many ecosystems, as carbonates, the basis of coral skeletons and some ocean sediments, are broken down in a chemical reaction with the acid. At present, the impact of rising acidity in the oceans on marine life might not be well understood,[8] but the extent of damage is expected to increase over time. While, sequestration in the oceans has unintended consequences, geological sequestration can be manufactured artificially, and is usually applied to remove carbon dioxide emitted from fossil fuel power plants and industrial processes. To do this, the gasses produced are captured, and using underground pipelines, injected into porous rock formations, where it is absorbed. This method has several major issues, namely that the quantity of carbon dioxide that can be captured and stored is quite small, approximately 38 billion metric tons. Additionally, most suitable rocks are associated with depleted oil and gas exploration sites, and tend to be located far away from carbon dioxide production points, making it difficult and expensive to accomplish.[8]

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Overall, these sequestration methods have limited impact. For instance, in the US, the emissions from burning fossil fuels, such as oil products, coal, and gas, were approximately 1.6 billion metric tons in 2003, but carbon capture methods absorbed only 0.5 billion metric tons. Over two thirds of the emissions generated were released into the atmosphere. This data also represents only one country's emissions; in total, the US

produced 20% of global emissions in 2003.[8] However, an alternative or complementary action to reducing atmospheric emissions is simply to minimise human activities that generate high levels of carbon dioxide, namely the burning of fossil fuels. Burning fossil fuels has greatly increased the proportion of carbon dioxide in the air; it's approximately 100 parts per million higher than pre-industrial times.[8] Therefore, preventing the creation of high levels of carbon dioxide mitigates the need for relatively ineffective carbon sequestration in the first place.

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Other Gasses

While carbon dioxide is generally viewed as the main contributor to climate change, other gases have a negative impact on society and the environment. The most notable of these nitrogen oxides (NOx) is known as nitrogen dioxide. Too many of these gasses result in poor air quality, which raises the risk of stroke, heart disease, lung cancer, and chronic and acute respiratory diseases, including asthma. According to the World Health Organisation, this causes over 3 million premature deaths annually.[52]

At the heart of this issue is the Dieselgate scandal, which sent shockwaves through Europe as US lawmakers discovered that Volkswagen, among others, manipulated sensors to show lower NOx emissions when tested.[51] These findings had definite impacts on the standards and legislation the European Union had set for air quality. The benchmarks are theoretically achievable, but still a large share of the cars on the road to date are more polluting than initially thought.

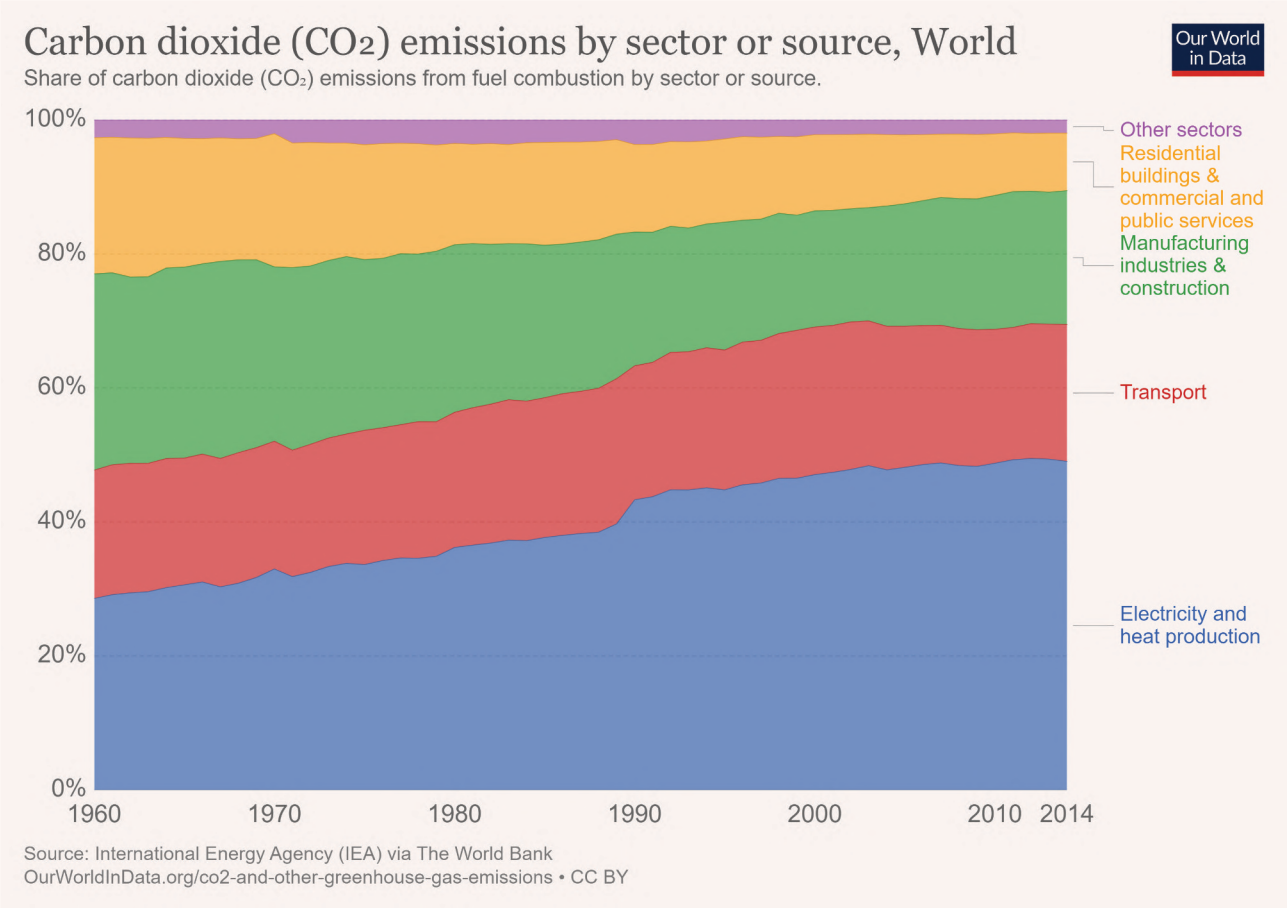
Germany briefly considered making public transportation free to avoid facing EU penalties for its poor air quality

Both Germany and Berlin have been dealing with this issue as the country still has over 8.2 million polluting diesel cars on the road.[50] So many, in fact, that Germany briefly considered making public transportation free to avoid facing EU penalties for its poor air quality.[53]

Emission Attribution

Almost 40% of carbon dioxide emissions can be attributed to electricity production, but manufacturing and construction and transportation both account for 20% each, figure 3.

Figure 3: Origins of Carbon Dioxide Emissions



Source:[9]

Almost 40% of carbon dioxide emissions can be attributed to electricity production, but manufacturing and construction and transportation both account for 20% each

While the manufacturing and construction sectors and some other groups have reduced their emissions since 1960, transport has remained relatively stable, and electricity production actually increased by 15%. The trends in other noxious gas production from 1990 to 2008 are also relevant. Industries, including transport, have contributed to the increase in methane emissions from approximately 5.6 to 6.8 billion tonnes, while nitrous oxide emissions due to transport rose by relatively little, 0.1 billion tonnes; the energy sector's generation of methane gases rose from 4.8 to 5.4 billion tonnes

and nitrous oxide doubled to 0,2 billion tonnes.[9] This data suggests that transport and energy sectors are the most important targets for elimination or reduction of these gas emissions. That being said, as the levels of greenhouse gases in the atmosphere continue to rise, it is important to focus on all of the contributors.

Economic Effects of Climate Change

During the last three years, the US has experienced climate disasters, mostly resulting from wildfires and hurricanes, with an estimated economic cost of US $415 billion

Climate change has resulted in major economic effects already, and is forecast to further have significant impact on:

- agriculture
- infrastructure
- human health and productivity
- tourism
- financial and business markets.

During the last three years, the US has experienced climate disasters, mostly resulting from wildfires and hurricanes, with an estimated economic cost of US $415 billion. Hurricane Harvey in Texas, for instance, resulted in severe flooding and cost US $125 billion.[10]

Climate change comes with a host of extremely expensive side effects, so while implementing greener technologies and practices might come with high initial costs, overall, it could prevent a lot of unnecessary spending

While natural disasters are the biggest single ticket price, there are other extremely expensive effects from climate change. In agriculture, for instance, excessive rain and flooding causes substantial crop loss, creating potential food and ethanol shortages. These shortages can also lead prices to rise. Meanwhile, heat and drought also cause low crop yield. These extreme weather conditions can also impact:

- transportation operations
- military bases
- tourism.

And, increasing warmth and rain lead to higher risk of water-borne disease and loss of working days when temperatures get too high for humans to safely endure. Drought has also led to much more severe wildfires as well, which impacts biodiversity

and has ripple effects on the health and sustainability of important ecosystems.[10] All of this is to say that climate change comes with a host of extremely expensive side effects, so while implementing greener technologies and practices might come with high initial costs, overall, it could prevent a lot of unnecessary spending.

The net economic impact is forecast at a loss of 3.9% to 8.6% of GDP from 2019 to 2100 if no steps are taken to reduce emissions. However, under stringent methods of control, it is estimated to reduce the loss to less than 1%

One report [11] estimated the global economic effects both with and without mitigation of the climate change risks; the net economic impact is forecast at a loss of 3.9% to 8.6% Gross Domestic Product (GDP) from 2019 to 2100 if no steps are taken to reduce emissions. However, under stringent methods of control, it is estimated to reduce the loss to less than 1%. Therefore, these scientists suggest that managing climate change and associated socioeconomic developments would have significant influence on how much GDP change would occur.[11]

Progress Made

World emissions increased by 2.1% in 2018, mainly due to increased coal consumption in China and India

The progress made regarding the Paris Agreement was assessed in a recent academic study.[12] According to this study most parties were not meeting their set targets in the four years following the agreement and, despite increased focus on renewable energy production, emission levels continued to rise. World emissions increased by 2.1% in 2018, mainly due to increased coal consumption in China and India. This lack of progress incited mass protests by young people in various parts of the world.[12]

City Successes

The annual tonnes per capita emissions in Germany were 11.62, compared to the US, which had an average of 23.59 in 2007; Oslo had 3.5.[13]

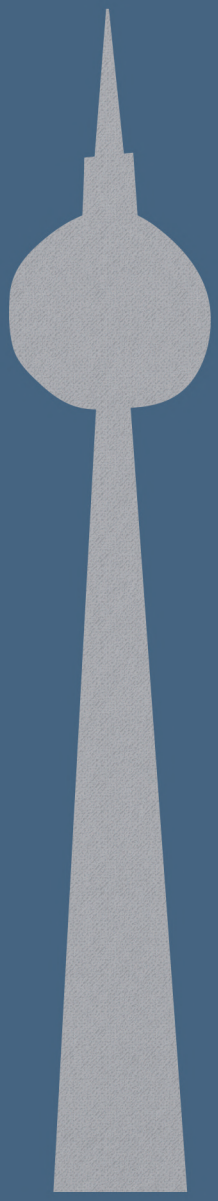
In the EU, two thirds of cities have developed a climate change policy, but most of these cities are located in northern and central Europe. The United Kingdom (UK) and France have been found to have cities with the most effective legislation.[14] In 2012, 12 EU cities which previously had high emissions, but had managed to reduce them by a minimum of 10% in the subsequent five years, were looked at to see what strategies they used. These included:

- Berlin
- Milan
- London
- Rome
- Warsaw.

City officials have devised a system to measure emissions which must be used in all parts of Oslo

Implementing green energy initiatives, reducing energy use in buildings, and providing alternatives to the use of private cars at affordable rates accounted for most of the emissions reduction. In Milan, for instance, one in seven citizens participate either in a car sharing system or use bicycles.[15] Oslo was named European Eco Capital 2019, recognizing its high performance in green initiatives, and is particularly impressive given Norway's ties to the oil industry. Oslo has set an objective of 95% reduction in emissions by 2030; to achieve this goal, city officials have devised a system to measure emissions which must be used in all parts of the city so that a council can track the city's progress. In the transport sector, almost 50% of all new cars are fully electric vehicles, owing partly to tax incentives, and its trams, electric buses, and ferries are all powered by renewable hydroelectricity. Oslo also generates domestic energy by burning waste in an incinerator plant in the coldest winter periods.

However, some challenges remain. For instance, businesses protested the proposed car free city centre. Subsequently, cars are only banned from certain main streets that have been reallocated for bikes and pedestrians, with other portions of the city centre remaining open to cars. However, decentives were introduced for bringing cars into the city. For instance, road tolls for private fossil fuel cars rose by US $2 to US $5.60 from 2016 to 2019. Fully electric cars pay no toll; this action was taken because cars were found to be the major emission source. A target of 100% fully electric cars has been set for 2025.[16]



Berlin: Reducing Emissions, Strategies and Challenges

Berlin Overview

Berlin, the capital of Germany, has a population of 3.5 million.[17] Greater Berlin occupies an area of 30,370 square kilometres (km), with a population density of 3948 per km^2. Metro, bus, tram, and rail make up the public transit.[18] According to city records, private cars make up 30% of transit, bicycles 13%, walking 31%, and public transit 22%. The average congestion time is 39.8 hours per year.[18]

Several interventions implemented to reduce emissions in Berlin over ten years ago are highlighted in a 2006 study, giving a feel for the effectiveness of Berlin's past climate initiatives, and laying the groundwork for future changes.[19] Car sharing schemes were implemented fairly early on, including a cash car system, which allows individuals to lease vehicles for personal use and then share them with car-sharing groups when the lessee does not need the car. Lessees receive half of the revenue earned. This scheme reduced both street congestion in the city and emissions.[19] Deutsche Bahn, the German State railway, introduced a service named 'Call a Bike' that charges by the minute, day, or week for bike rental. A phone call provides a code in exchange for credit card information, allowing patrons to unlock the nearest bicycle, located using mobile phone GPS systems.[19]

Berlin also adopted a system that reduced the number of local goods deliveries by fostering a collaboration between neighbouring retailers

Berlin also adopted a system that reduced the number of local goods deliveries by fostering collaboration between neighbouring retailers so that they would use the same delivery vehicles, and facilitated its success by ensuring the loading and unloading areas were mandated to meet the business needs.[19] The city further attempted to reduce traffic congestion and emissions by having the concrete used in the reconstruction of Potsdamer Platz made on-site, so that most of the raw materials and waste could be delivered and removed by rail.[19] While many of these efforts are dated, they set the groundwork for modern initiatives to curb emissions.

Current Interventions

A London School of Economics report in 2015 suggests that increasing suburbanisation forced Berlin city authorities to respond to longer commuter travel distances by investing in road and rail infrastructure; rail connectivity was increased considerably, and the newly constructed main Berlin railway station expanded both east to west and north to south coverage. Subsequently in 2007, commuter flows tripled while journeys were shortened in the ten year period leading up to 2011. Decline in household car use was substantial, with 40% of those predominantly living in inner city locations not owning a car by 2013. This was possibly partially invoked by the low emission zone introduced by city authorities in 2008, in which only certified low emission vehicles are allowed. [20] The report also noted that the cycling infrastructure increased 40% from 2004, to 1000 kilometres in 2014, and was supported by the consistent increase in the number of cyclists from the 1970s; these trends explain the higher than average share of cycling for work and leisure.[20] Resident commitment to green initiatives was revealed to be a major reason for the reduction in car usage. One survey found that while 37% of residents used a car, 30% public transport, and 17% bicycle in 2015; 45% would prefer to use their car, 21% a bicycle, while less than 10% favoured public transport. Despite the rise in the popularity of cycling, it is still perceived as dangerous in Berlin. Almost 80% of those surveyed could walk to at least one form of public transport within 5 to 10 minutes, 47% in less than five minutes. [20]

In 2007, commuter flows tripled while journeys were shortened in the ten year period leading up to 2011

One survey found that 37% of residents used a car, 30% public transport, and 17% bicycle in 2015

Future Emission Reduction Plans

The 2019 to 2023 transport plan, entitled Land of Berlin, is predominantly concerned increasing accessibility and reducing harmful emissions through several initiatives; this plan focuses on bus, tram, U-Bahn, BVG ferry networks, multimodal transport investment, and integration with the regional rail and S-Bahn networks. New rail infrastructure is among future plans, and the city has implemented the Berlin Mobility Act. Berlin's Mobility Act's objectives are to remove fossil fuels from the energy used to operate its transportation system by 2030 and to ensure that any economic developments in the city and its outskirts comply with environmental standards. The extent of

Berlin's Mobility Act's objectives are to remove fossil fuels from the energy used to operate its transportation system by 2030

bicycle accommodation in rail transport is also to be increased, and any new property development applications will be scrutinised to ensure that the planned expansion of public transport is not hindered. A multi-transport option is planned for the Berlin-Brandenburg airport, which is in development stage.[21] Overall, this plan outlines a future for Berlin public transportation expansion.

Berlin's Global Ranking

An external report by McKinsey rated Berlin's mobility based on three categories:

- performance and resilience
- vision and leadership
- service and inclusion.[18]

Five ratings were given to each category:

global leader

- top performer
- contender
- aspiring
- emerging.

Berlin was rated a global leader for reliance and reliability and a top performer in three other categories: transit supply, road safety, and integrated and shared mobility

In the performance and resilience category, Berlin was rated a global leader for reliance and reliability and a top performer in three other categories, namely, transit supply, road safety, and integrated and shared mobility. However, in air supply Berlin rated much lower, in the aspiring contender class. Air quality is considerably hindered by the continued use of fossil fuels to generate electric power. When viewed together, the city was considered a high performer for the extensive and diverse transport systems, success in changing public travel preferences, and excellent safety and reliability from high investment in public transportation infrastructure.

Berlin's highest average rating was in the vision and leadership class, with vision, strategy, innovation, regulation, and

A 20% decrease in car travel and a 25% increase in bicycle usage occurred since 1998, largely due to the creation of bicycle infrastructure and low emission zones

environmental stability all being considered top performer. The data collected in the McKinsey report revealed that 70% of all journeys used public or active transport, with relatively rare traffic accidents and low congestion; a 20% decrease in car travel and a 25% increase in bicycle usage occurred since 1998, largely due to the creation of bicycle infrastructure and low emission zones.[18] Berlin's past plans were found to be effective, and the 2030 transportation strategy was also commended for its consideration for future transport and quality of life preferences of citizens as well as sustainability in mind. This plan even included provisions for developing and testing autonomous vehicles. The plan includes a pledge that all new cars manufactured will be electric by 2030, and mandates the instillation of network of charging points to accommodate this. The city already charges electric buses wirelessly, and the 2030 plan is supported by the 2020 Electromobility Action Plan.

Shortcomings

While Berlin was commended in many areas for its current and planned transportation, there were several shortcomings that McKinsey raised. For instance, while service and inclusion generally ranked highly, affordability was identified as a point of weakness within this, as prices are too high for some users. The monthly travel pass averages €81 (US $89,) earning Berlin its lowest rating. In versatility, customer satisfaction, and ease of use, the transportation system was considered to be among the global top performers for its good access, with high rail network density and widespread tram and bus routes. However, many weaknesses were evident in this category. For example, there is no smart card system or widespread app usage. There are also inadequate interlinks from major transport hubs to the city road network and significant peak hour traffic congestion, particularly near the two airports: Tegel and Schonefield.[18] So, while Berlin's mobility is generally strong, there are also some definite and identifiable points for improvement.

Berlin's overall status on the route to global leadership in mobility is illustrated in figure 4

Figure 4: Berlin's Rating as Global Mobility Leader

Figure 4: Berlin's Rating as Global Mobility Leader

Source: [18]

Overall, Berlin was found to have three major strengths:

- the city's interaction with research institutions, such as universities and private companies, in the development of new mobility solutions
- growth in transport start-ups and related events
- available data portals.

The major weaknesses the city faces are insufficient regulation of self-driving vehicles, poor tram network in the western half of the city, and relatively low air quality. Therefore, this report recommends that the city should form partnerships with private companies and experts in autonomous vehicle technologies, increase accessibility to the transportation network, and implement customer journey analytics to help reduce congestion and lack of access.[18] Although this is a concise report, it provides extremely valuable information, and is especially useful in understanding precisely where and how blockchain solutions can be applied to resolve the current challenges.

Areas for Improvement

The slow implementation of technology on the user-facing side of Berlin's public transit systems was also the focus of a recent report by Eltis,[22] which suggests that Berlin could facilitate access to mobility information by providing one mobility app called Jelbi. Jelbi would provide information on all public and private transport services operating in the city, including:

- bike
- scooter
- car sharing
- ride hailing
- taxi services
- public transport.

The service was introduced summer 2019 on iOS and Android.[22] However, this system does not solve issues for tourists or residents without smartphones.

A single decker diesel bus costs €250,000 while an electric bus costs more than €600,000

This report also researched the fuels used as energy sources for the main types of public transport. Bus transport predominantly relies on diesel fuel.[22] Although city authorities and the BVG, the main public transport organisation of Berlin, pledge to eliminate all diesel buses by 2030, currently only five of the 1400 total buses are electric; the BVG has stated that it will buy another 30. However, this is an extremely high investment, as a single decker diesel bus costs €250,000 while an electric bus costs more than €600,000. Bus drivers have also raised concerns about the legitimacy of this proposal, as the e-buses have a limited distance capability of 140km compared to the diesel bus capability of 700km; this very short distance is equivalent to only three or four hours use. Weather also impacts e-bus performance, as extreme temperatures reduce the mileage before recharge to less than four circular trips around the city. Several solutions to make the e-buses a viable option have been presented, including revamping bus routes to reduce their distance. However, total replacement of diesel buses with electric buses would require two to three times as many units to service the same daily mileage. Electric buses

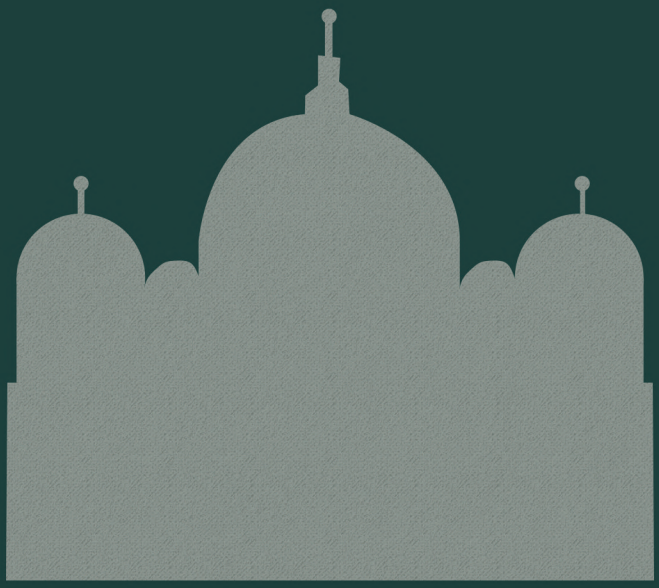
The 2030 targets on bus transport are not expected to be met

also need several hours to recharge compared with a few minutes for refuelling diesel, and are only 75% reliable, meaning that one in four buses would likely need to be serviced or repaired at any time. Overall, while the diesel buses are a prominent area for reducing Berlin's emissions, replacing them with electronic buses is still a distant reality due to the many shortfalls. Trams, on the other hand, are fully electric and require no recharging, presenting a potential solution. However, increasing tram networks would require new tracks and overhead cables; this work is both complex and expensive. In light of these issues, the 2030 targets on bus transport are not expected to be met.[23]

The railway network is also highly dependent on diesel, which makes up 40% of its power, and presents similar issues in meeting the pollution free 2030 deadline

The railway network is also highly dependent on diesel, which makes up 40% of its power, and presents similar issues in meeting the pollution free 2030 deadline. Currently diesel trains are employed for short distance urban travel, while overhead electric energy is used for longer journeys. It is difficult to obtain reliable information on how the electricity is generated for overhead electrification, though, and a report by the International Union of Railways states that generally it is still produced from oil and gas, which emit noxious fumes.[25] That being said, the average rate of railway electrification for Germany is still much lower than in other countries. For instance, 71% of Italy's railways are electric, 85% of Belgium's, and 100% of Switzerland's.[26] High investments stand in the way of making these changes.[26] That being said, in 2018, the city launched an electric hybrid train developed by Bombardier. This vehicle was promoted for being highly innovative, but initially the battery capacity was 40 km. Improvements in battery technology are expected to deliver a 100km range by 2019, though. In addition, 39 emission-free hydrogen generated trains were ordered from Alstom in 2018.[24] These trains present an exciting possibility as Berlin faces significant barriers in switching to electric power for its railway systems, and often that power is still sourced from fossil fuels.

39 emission-free hydrogen generated trains were ordered from Alstom in 2018



Blockchain Solutions

Journey re-routing is currently hindered because there is no way to measure customer journey analytics to fully determine the most effective future transport methods

Although research into Berlin's cleaner city projects demonstrate that it has made substantial progress, several major challenges remain that may hinder the city in meeting its 2030 goals. There is no evidence of formal emission reduction reporting by local regional bodies to a central authority; both Norway and the Paris Agreement both prove that reporting is extremely necessary and effective in meeting emission goals. There is also still considerable reliance on oil and gas for generating the electric power used for buses and rail on top of the widespread diesel use, which presents considerable roadblocks for quick elimination of non-renewable energy sources. The investment required to convert from diesel buses to electric vehicles by 2030 appears prohibitive, and rerouting buses and devising new timetables to enable the shorter journeys these electric buses need presents additional challenges. Journey re-routing is currently hindered because there is no way to measure customer journey analytics to fully determine the most effective future transport methods. Huge investments are also required to increase suitable public tram transportation to the western part of the city. In general these efforts are stunted by the lack of inclusion of broad swaths of the population due to affordability and low analytics due to limited data collection. Therefore, a variety of solutions are necessary, based on both effective financial investments and technological developments.

Blockchain for Reporting

This system is ideal for record keeping, and can be implemented as an immutable and secure means of reporting and tracking city and country progress towards meeting emission goals

Blockchain may be able to assist in resolving or reducing the impact of many of these challenges. Blockchain offers a secure system that allows transactions directly between parties, which can cut out expensive mediators. The information stored in the database could theoretically be accessed by any individual with a smart device, such as a smartphone or computer, and completely does away with the need for central coordination. This can lower record keeping costs while maintaining data security, because copies are present on several devices, and maintenance fees do not need to be paid to a third party.[27] The decentralised system enables central and local city authorities to exchange information without fear of hacking and/or

corruption of data by any other individual, as they would have to change every copy of the ledger simultaneously.[27] This system is ideal for record keeping, and can be implemented as an immutable and secure means of reporting and tracking city and country progress towards meeting emission goals.[28]

This ledger system can be leveraged to be even stronger when combined with other technologies which use the securely stored data to create real time analytics. The Internet of Things (IoT) is one such technology, and refers to a network of objects that communicate with each other via the internet using embedded sensors. This enables data from these devices to monitor and record data automatically, allowing for far more extensive data to be collected. Adding automatically collected data to the network, increases reporting accuracy and allows for real time financial and risk modelling. The application of artificial intelligence enables the huge amounts of data provided by IoT to be processed, reducing administration and financial analyst costs.[28] This potentially allows for accurate revenue and cost forecasting and the exchange of data can be used to make decisions.[29] This has obvious benefits for Berlin's transportation networks, which are sorely in need of greater data points to efficiently restructure and allocate funds.

However, initial criticism of blockchain in the context of climate change has come out, pointing to the high energy consumption, and direct contribution to high emissions of processing blockchain. The strong computer processors necessary for blockchain are used in cryptocurrency mining processes, such as Bitcoin, in which individuals compete to conduct the validation process. This isn't pertinent in regard to these proposed city climate change applications, which would most likely run on a private blockchain or new alternative network, rather than Bitcoin's Proof of Work validation method.[28 30] Though private or permissioned systems have the drawback that they are not as decentralised and democratic as public blockchains, this system adds a measure of security, and allows the blockchain to add to an already established level of trust. This would mean that city officials would not have to compete to produce the next block with the same intensity and therefore, the computing power needed would be negligible and have minimal environmental impact.[30]

Data Collection

Deloitte identified the lack of analytics on customer journeys as a major weakness, pointing to the fact that the lack of this data effectively hinders the planning of both new and shorter routes

In Berlin, Deloitte identified the lack of analytics on customer journeys as a major weakness, pointing to the fact that the lack of this data effectively hinders the planning of both new and shorter routes. This restructuring is needed to incorporate electric buses, with their limited distance capacity, and address the lack of trams and the comparatively poor coverage of west Berlin by public transport. Smart cards or apps that collect data are the most applicable solutions. However, neither are currently used at scale to gain analytics in Berlin. Transport for London (TfL) is one example of a system that relies on mobile apps, and has harnessed this technology to collect data from customers' mobile phones and improve the information provided to them. TfL gathers information on how users movement in the network to alert them to delays or congestion and suggest additional routes. Potential personal privacy issues are removed by ensuring no identification is recorded.[40] TfL states that it uses data gathered precisely for the purpose of: journey planning, area coverage, and to create customer value by transforming their expectations of public transport travel,[40] which subsequently encourages less individual car travel and supports emission reduction. These analytics would greatly improve the services that Berlin's public transportation could provide.

Berlin needs a similar system of tracking public transit use in order to effectively update the system, and as with any data collection system, needs to adequately protect and encrypt data

Berlin needs a similar system of tracking public transit use in order to effectively update the public transit system, and as with any data collection system, needs to adequately protect and encrypt data. Smart cards provide a potential alternative to tracking phones, as they can be issued anonymously, and therefore do not include the same level of personal data that tracking an app would. Smart cards can be used as a ticket for public transportation, and swiped or tapped at the beginning and end of journeys. This data would then be sent from a sensor in the swipe mechanism to a DLT. Based on the analytics about journey type, frequency, use, and time, the data necessary to plan necessary new routes or expand existing routes would be available.

Data Tracking and Privacy

Using blockchain is another way to mitigate any concerns about personal data, as it is secure and personal details can be encrypted. The Keyless Signature Infrastructure (KSI), created by the Estonian public sector, provides a prime example of this, as it protects all of the personal data collected by allocating hash values to the data, which are then stored on blockchain and can be distributed via the distributed ledger network. While the hash values can identify specific records, they do not reveal the personal information.[40]

The blockchain system of permissions greatly increases personal agency in data acquisition, and means that individuals are still the owners of their own data

Smart cards, then, are a solution, but as more and more infrastructure runs on data processed by smartphones, blockchain can also be leveraged to encrypt personal data acquired from apps. While TfL has a disclaimer for users, blockchain enables a system that actually requires authorization from individuals to record data.[31] The blockchain system of permissions greatly increases personal agency in data acquisition, and means that individuals are still the owners of their own data, not large companies. Individuals who still own their data, then, can revoke connections, track all transactions involving their information, and define what information the any given device is willing to share.[31] Obviously, this is a much more secure method for sharing personal data, and means that individuals retain not only ownership of their own data, but also the rights to revoke or trace use of that data. Therefore, by using blockchain, cities such as Berlin would be able to acquire the necessary data to effectively plan changes to public transportation, and continue making effective emission reduction steps without violating personal privacy.

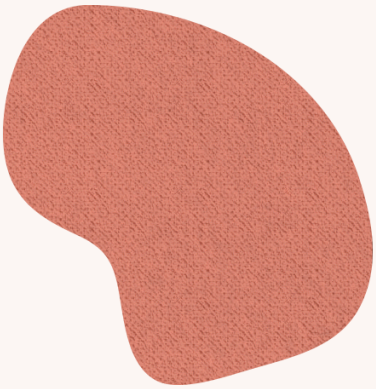
Multimodal Apps

Apps have the ability to further incentivise public transportation by making information more accessible and payments faster and easier. Berlin's public transport already consists of trains, trams, buses, bike shares, e-scooter shares, car shares, shuttles, and cabs. While much of this is already linked through ownership by the BVG, Berlin's new

38% of respondents reported driving less as a result of using multimodal apps, with 56% noting increased bus use, and 43% increased rail use

transportation app, Jelbi, which premiered in the summer of 2019, brings together even more options.[22] Jelbi includes all of the BVG's travel services (bus, train, tram, and hailable shuttle), but also gives access to one of the many kick scooters, e-scooter, bike, and car sharing companies that operate in Berlin. This is an important development in moving towards lower emission goals as one study found that multimodal apps, such as Jelbi, led to travel that was less energy intensive and increased the likelihood of using public transit.[32] Overall, 38% of respondents reported driving less as a result of using multimodal apps, with 56% noting increased bus use, and 43% increased rail use. Using these apps though, did not lead users to decrease walking or cycling. Therefore, providing residents with apps that account for multimodal transportation is imperative in increasing reliance on public transportation and reducing emission.

While Jelbi collects multiple modes of travel into results for one search, it has yet to integrate those modes.[32] For instance, it won't provide a route that combines trains with a bike share. At present, although the app brings together many different companies, it has not yet been able to integrate those modes to give a route that combines several different companies. Citymapper and Google Maps have both integrated these models to provide users with the fastest, cheapest, and most convenient routes based on multiple companies resources. Jelbi needs to improve to provide users with integrated multimodal trip information, and the most effective way to do this is to open-source the code of the app, so that organisations can easily integrate with it, and enable the platform to host a growing number of transportation options.



Open Source Code

Jelbi has provided the means for increased knowledge and access to travel operations, as payment can even be streamlined across these modes of travel. However, there are still issues beyond the lack of integration between transportation types. For instance, this app only brings together one company operating each mode of travel. If it operated on open source code, though, different companies would be able to add their services, giving users even more options through only one app. Open source coding simply

means that the code is available for others to see and modify freely.[33] Therefore, by operating on a decentralised open protocol, Jelbi would provide other companies and individuals access to the code so that they could add their own services or improvements to the code. This would likely even further increase reliance on public transportation and bike, car, or scooter shares, as users would be able to compare prices and find the closest and fastest methods of travel. Tokyo had great success with opening up much of the data behind their metro system in a competition for better and more accessible updates before the 2020 Summer Olympics. This returned such great results, that the city has opted to leave the data available.[41]

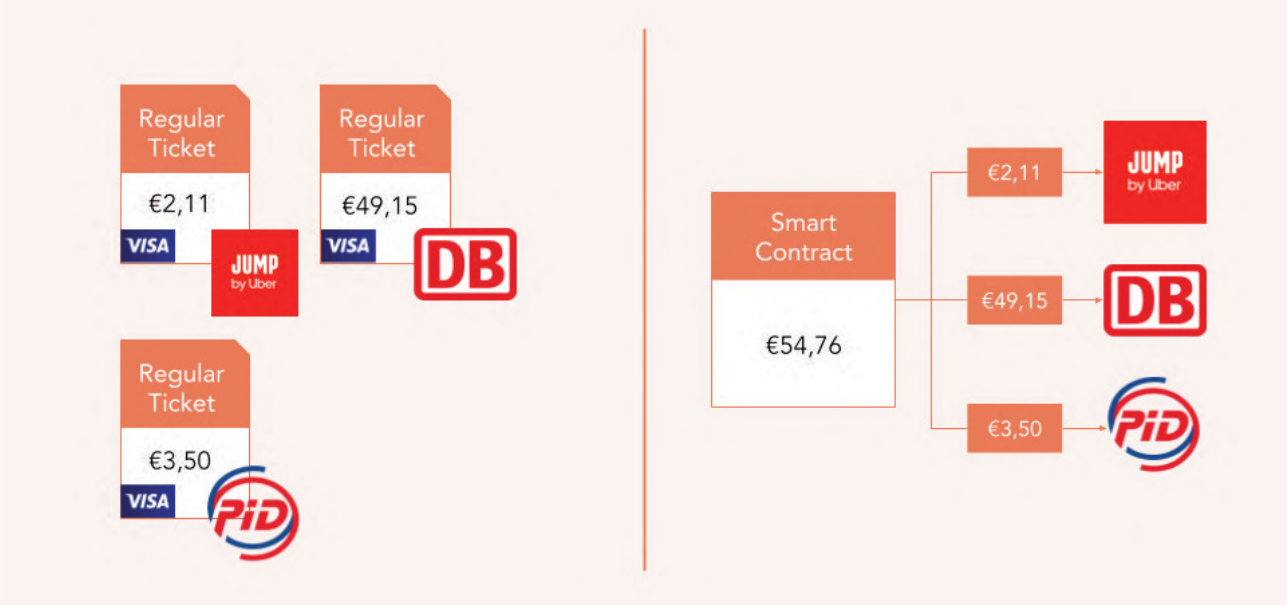
Cross Border Contracts

Smart contracts and cryptocurrencies allow users to pay companies directly, rather than having to go through a third-party operator, such as Visa or Mastercard, and would allow users to bundle multiple products in one transaction

Running travel apps on an open source public blockchain platform with smart contracts has the potential to enable far more streamlined travel, and even crossborder travel. Smart contracts and cryptocurrencies allow users to pay companies directly, rather than having to go through a third-party operator, such as Visa or Mastercard, and would allow users to bundle multiple products in one transaction. By giving users the ability to use one app to directly pay multiple companies, this reduces the need for partnerships and management on the backend, and streamlines the process for bringing multiple companies together. If expanded, this could even be pushed beyond borders, so that the same app can be used to secure tickets for a trip that uses an e-bike in Berlin, Deutsche Bahn, and a tram in Prague. Cryptocurrencies and smart contracts make these interactions fast and secure, and mean that the companies do not need to have contracts with each other, as they can all interact with the individual traveller directly.[42] This can be a solution for travellers in new cities whose credit cards may not work, may encounter high fees for currency exchange, or when the payment gateways do not accept non-German bank card types (like Maestro or American Express). It would also eliminate the need to sign up for multiple services; the price set for the full journey will automatically be divided by all parties that participate. Figure 5 shows how one payment can be made directly to each service.

These interactions are fast and secure, and mean that the companies do not need to have contracts with each other, as they can all interact with the individual traveller directly

Figure 5: One way trip Berlin - Prague, door-to-door

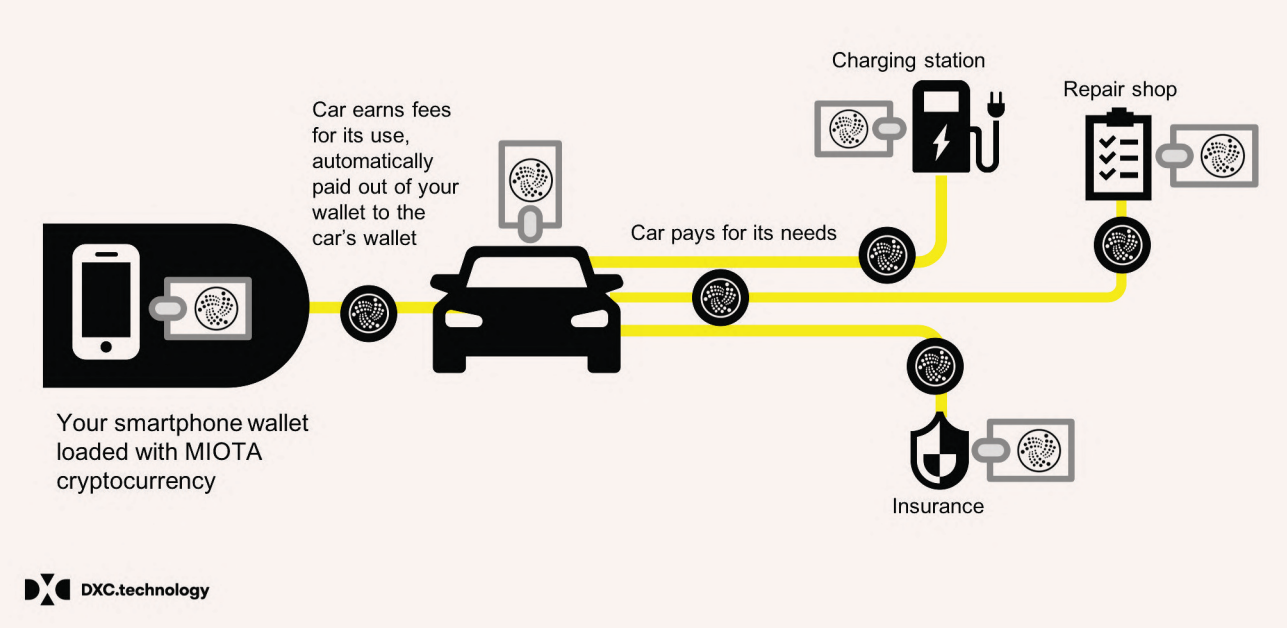


Autonomous Vehicles

If these vehicles are given access to smart wallets, they would essentially be able to manage their own charging and maintenance payments using smart contracts to make agreements with service providers and creating a completely traceable ledger

Berlin is already investing in switching to electric vehicles, both for its bus fleet and by only allowing vehicles with low emissions in certain zones of the city.[43] However, autonomous vehicles, which are overwhelmingly electric, are changing the scene of transportation, and could even further improve the extent and efficiency of Berlin's public transportation services and Berlin's overall emission rates. Beyond ridding the streets of high emission producers, autonomous vehicles have the potential for much greater smart management. When operating on blockchain systems with smart contracts and access to smart wallets, these vehicles are able to do much more than steer themselves. For instance, if these vehicles are given access to smart wallets, they would essentially be able to manage their own charging and maintenance payments using smart contracts to make agreements with service providers and creating a completely traceable ledger[47], figure 6

Figure 6: Autonomous Vehicle Systems



Source: [47]

If these vehicles are given access to smart wallets, they would essentially be able to manage their own charging and maintenance payments using smart contracts to make agreements with service providers and creating a completely traceable ledger

This model shows how when a car is linked to a wallet, it is able to pay for charging, repairs, and insurance. By running this system on blockchain, it is secure, so that while the vehicle is operating autonomously, it is not open to external corruption that would allow another person to access the vehicles revenue or funds. Its transactions are secure, and could potentially entirely account for the vehicles maintenance and charging.

Autonomous Vehicle Revenue Flows

This could even be extended to allow these vehicles to create their own revenue flows by enabling a system of leasing them out. This would also provide access to green transportation options to more people. Car sharing apps connect available cars to individuals, all of which can be coordinated through smart contracts.[44] Then, payment could either be funneled to the owner or used directly to cover the cost of charging and maintenance. These vehicles would essentially operate seamlessly on their own as they are self-driving and would be able to create revenue to cover the cost of charging, maintenance, and potentially even parking. This system could also streamline operations for city bus fleets or shuttle systems as well.

These self-driving vehicles would essentially operate seamlessly on their own and would be able to create revenue to cover the cost of charging, maintenance, and parking

Looking towards a future with a more interactive electric grid, autonomous vehicles could also be harnessed to economise energy use. Processing the data these vehicles produce can enable smarter energy choices, and even allow for the vehicles themselves to be added to the grid as energy generators.[45] For instance, many electric vehicles leverage technologies to capture energy generated in use, such as regenerative braking. Some vehicles also have other energy generation means, such as solar panels, installed. By enabling secure machine to machine (M2M) transactions through smart contracts, the vehicle would be able to assess when it contains excess energy and sell that power back to the grid during peak hours.[46] Most of these transactions might be considered micro payments, which become economically viable due to the efficiency of blockchain technology, allowing for instant verification without the need for a trusted third party.

By enabling secure machine to machine (M2M) transactions through smart contracts, the vehicle would be able to assess when it contains excess energy and sell that power back to the grid during peak hours

Therefore, when autonomous vehicles are run on a blockchain system, they can be enabled to manage their own maintenance and payments, and even enable the sale of unused energy back to the grid system or be added to a car sharing network in a manner that is both secure and seamless thanks to the records, smart contracts, and security enabled by blockchain.

Autonomous Vehicles for the City

BerlKönig, Berlin's on-call shuttle service, allows users to pay very low prices for what is essentially a bus-taxi hybrid. While this model is already greatly improving mobility options, it is a prime use case for updating to autonomous technology. At present, an app is used to hail the driver to one of many potential stops and direct them to another in the area they operate, picking up other passengers along the way. However, if this system is updated to allow for autonomous driving, vehicles would be able to add themselves to the system, pick up passengers, and then stop to recharge when there is lower demand. One report on replacing all taxis with electric autonomous vehicles estimates that they will decrease greenhouse gas emissions by up to 94% per mile.[48] The BerlKönig system, as a shuttle service, can reduce emissions even further using electric autonomous vehicles, as vehicles are shared by passengers going on similar routes.

Replacing all taxis with electric autonomous vehicles is estimated to decrease greenhouse gas emissions by up to 94% per mile

This model would greatly decentralise transportation options, as individual cars are incorporated into major transportation services, and do not require users to go through only one company or follow specific lines. Both individual car owners and larger organisations, such as the BVG, could add vehicles to this service, and one app or open source code would connect those services so that users only need to download one app and log their payment information only once. While these systems can be implemented on some level without blockchain, using blockchain provides secure, efficient, and autonomous transactions.[47]

Technical Considerations

Blockchain can also offer solutions in policy making. It can offer potential solutions in cases where cities are experiencing difficulty with:

- devising new emissions policies by traditional methods
- where emission reduction attempts have been met with low levels of success
- where cost reductions would lead to better outcomes.

Blockchain can provide a system for tracking data and lower cost for data storage to mitigate many of these issues.[34] There are several conditions under which blockchain is likely to be effective. These are:

- the elimination of trusted third parties to reduce cost and/or time efficiency
- when third parties are not easily identifiable or using them reduces the effectiveness or timeliness of the policy
- legal reporting compliance can be continuous rather than periodic.[34]

In relation to relatively autonomous city authorities, these conditions should all be viable. A survey of blockchain platform effectiveness in the context of policy making on climate change was conducted based on five criteria:

- ease of programming
- operating cost
- security
- usability
- trustworthiness.[34]

The analysis looked at four major blockchain platforms to compare the suitability of a blockchain implementation. Choice in relation to relevant tools on the platform and its software development capability were assessed, as were the associated overall maintenance and operating costs. In relation to security, a risk assessment was conducted to evaluate the ease of system manipulation and whether the coding languages were suitable to devise smart contracts (programming rules). Usability is assessed based on the nature of documentation, support, and distribution, while trustworthiness concerns the method for network governance. The last feature was not included in the evaluation and would be vital to public sector authorities.[34] An analysis starting with these five criteria can be an effective way to determine the suitability of the many blockchain platforms and solutions on the market. This report looks at only four options, but there are many other, potentially more suitable, blockchain platforms for specific use cases.

Figure 7: Comparison of Four Established Blockchain Platforms

Each category is rated on a scale of 1-5 (with 20 total possible points), in which 1 (red) is poor and 5 (dark green) is ideal.

	BITCOIN CC	EHTEREUM	HYPERLEDGER	EOS
Programmability				
Operating Costs				
Security				
Usability				
Trustability	n/a	n/a	n/a	n/a
SCORE	12	18	16	13

Source: [34]

Barriers to Blockchain Adoption

Uncertainty about the business model and the associated technology are underlying concerns, especially as understanding of the potential of blockchain use is limited

Despite a variety of applications of blockchain to emission reduction and general climate change issues, a number of barriers exist to its common use by governments and public authorities. Both tend to be cautious of adoption of new ideas and processes, making blockchain adoption even more difficult. Uncertainty about the business model and the associated technology are underlying concerns, especially as understanding of potential of blockchain use is limited and there is a shortage of skilled blockchain developers. Additionally, understanding how to combine IoT and artificial intelligence with blockchain is limited. Local laws and regulations may actually inhibit its use, and it is generally met with traditional mindsets that prevent evaluation in an entrepreneurial spirit.[36] Therefore, in many cases, lawmakers should adopt a more entrepreneurial approach towards blockchain in order to employ it in optimising their emission reductions.

Blockchain in Action

For Berlin, it could be used to determine and continually track emission levels and identify the range of emission reduction or escalation in different parts of the city

This hesitancy could be tempered by a number of specific, relatively established blockchain applications used in emissions reduction. One example is Swytch, a blockchain project designed to support the reduction of carbon dioxide emissions. The project aims to measure emissions in real time to offer both security and transparency. The system works by connecting blockchain to other measuring devices, such as instruments with embedded sensors, smart meters, and IoT devices.[37.] It can produce data on carbon dioxide emission levels and the extent of sustainability efforts, as well as the influence of these efforts on emissions.

For Berlin, it could be used not only to determine and continually track emission levels, but also to identify the range of emission reduction or escalation in different parts of the city. The data provided is specific enough to discover the reasons for influxes or reductions in emissions. This allows learning to be applied to help low performing parts of the city to improve, test out new initiatives, and measure the impact of changes in detected behaviour. Additionally, Swytch cuts out the need for an administration or central body to process data before passing it on to those who can read it and make decisions based off the numbers, overall increasing efficiency. To do this, Swytch has designed Open Oracle, a system that expands Swytch's services by incorporating artificial intelligence and machine learning to provide even more analysis and ensure the system stays up to date and continues to improve.[37] These combined technologies provide the ideal means for understanding and incorporating data for the most efficient system.

The Swytch system is already operating in the German energy sector, incentivising those who reduce their energy use and noxious emission with Swytch tokens, a form of cryptocurrency. It has reduced fraudulent reports from local councils and lowered administration costs for all reporting bodies.[38] But, the system can be applied much more broadly. Swytch, for instance, could be used by all citizens with appropriate adaptation. Under this broad adoption, incentives can be expanded, and by choosing greener transportation options, users could also receive tokens. Additionally, electric vehicle

While some of these solutions are easier to implement, others will take time, investments, and further advancements in technology

users could be added to the system, and by being part of a larger city-wide system, could be further incentivised to participate in initiatives. For instance, they could be alerted to when their neighborhood needs more electricity, and could be incentivised to cycle rather than drive to reduce their neighborhood's reliance on fossil fuel produced energy.[38] This can help introduce cleaner energy into Berlin's electric power sources, and mitigate the use of fossil fuels as criticised in the McKinsey report.[18]

Overall, blockchain presents a wide range of solutions to Berlin, and many other cities' issues in reaching their climate goals. While some of these solutions are easier to implement, others will take time, investments, and further advancements in technology. However, all of these are improvements to be worked towards, especially as the issue of climate change becomes ever more pressing.

Conclusion

This report strove to identify the successes and challenges of European cities in meeting national and global benchmarks for reducing noxious atmospheric emissions, particularly those of carbon dioxide, methane, and nitrous oxides. In light of the current state of these efforts, potential solutions using blockchain technology to diminish the practical challenges and support faster accomplishment of targets are presented.

Global Emission Goals

Cities are particularly important in reducing harmful emissions because they are responsible for approximately 80% of the total volume

The Paris Agreement provides an understanding of the global goals of many nations on climate change. The specific numbers and timelines are considerably more stringent than the previous internationally agreed protocols, largely due to the establishment of a rulebook for reporting emission targets in relation to associated achievement dates. However, the Paris Agreement is still lacking in that the world's largest polluting nations, China and the USA, did not sign the Accord. Additionally, developing nations who have not historically contributed to the current climate crisis at the level of developed nations, are bound to take action despite a lack of resources for these initiatives, and the fact that they can hinder further socio-economic development. The Accord did attempt to account for this with an agreement for developed countries to assist emerging countries, but progress is slow and many of the developed nations are failing to meet their own targets, much less provide support for other nations. This can be seen in the continuing unacceptably high levels of carbon dioxide generated by Denver and Sydney, among others. Cities are particularly important in reducing harmful emissions because they are responsible for approximately 80% of the total volume. While many cities continue to be characterised by high emission levels, some that have previously been listed as the highest polluters, such as Milan, have successfully considerably reduced their emissions, largely by encouraging the population to alter its behaviour. This data provides a framework for the most effective steps to take in emission reduction, and points to a need to collect more data on the behaviors of the population to do so.

Areas of Focus

A high proportion of transportation relies on fossil fuels and/or electricity produced from them

Transport and electricity generation sectors are some of the highest industrial polluters, and therefore need to be the focus of specific projects to reduce emissions. A high proportion of transportation relies on fossil fuels and/or electricity produced from them, naming these systems as particularly necessary to focus on. Oslo was awarded the global status of Eco City for its low levels of carbon dioxide emissions. Oslo has instigated a variety of measures, including mandatory emission reports from all local councils within the city and the urban boundaries, giving the city data to track and plan reductions over target periods. Incentives for citizens to buy electric vehicles has also been a major factor in lowering city emissions, and has resulted in 50% of all cars being fully electric. This measure was complemented by tolls for non-electric vehicles entering the city. Oslo's hydroelectric power generation also enabled the city buses, trams, and ferries to be run entirely by renewable energy sources, which is supplemented with power from waste incineration. While many of these initiatives should act as the blueprints for other cities to reduce emissions, some are non-transferrable. For instance, Berlin does not have the means of producing hydroelectric power. But, Berlin's high reliance on diesel fuel for buses and fossil fuel generated power for rail transport is a major concern, and sourcing energy from cleaner technologies should be a prime objective for Berlin.

Berlin is especially well-known for the reliability and diversity of its public transportation system, which combines trains, trams, buses, cycles, walking, and cars

That being said, Berlin is still commended for being a global leader in some aspects of emission reduction strategy and implementation. Berlin is especially well-known for the reliability and diversity of its public transportation system, which combines trains, trams, buses, cycles, walking, and cars. Berlin's bicycle policy has been largely successful, allowing the city to create huge emission free zones by discouraging citizens from using cars to travel into the city by introducing high road tolls. The vision and leadership of city officials is commended for the foresight into a future system to benefit health and quality of life of citizens. However, Berlin still faces several serious limitations. Particularly highlighted are the financial and logistic issues associated with replacing the predominantly diesel bus transport with electric buses; the electric buses cost

The city is lacking the necessary data and funding to replace diesel buses, especially in west Berlin

more than double what a diesel bus costs, and have also been met with driver resistance due to their relatively low mileage capacity and the increased maintenance and battery charging time. While revising and shortening bus routes across the city has been proposed to enable the use of electric buses, this is still a daunting task as there are no customer analytics to support re-routing with customer preferences in mind. This information is not available as there is no comprehensive data collection method in Berlin. Additionally, tram coverage is poor in the western part of the city and, although electric, has a high installation cost. Therefore, the city is lacking in the necessary data and funding to replace diesel buses, especially in west Berlin. Railway transport is also only available for short journeys and 40% remain fossil fuel dependent. And, while Berlin's public transit system is recognized for its efficiency and coverage, the cost is a limitation, as it may not be affordable to the poorer residents. Overall, the main challenges for Berlin to reduce emissions in transportation can be summarised as financial, logistical, and technical.

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Potential Solutions

This research demonstrates that blockchain technology has the potential to resolve many of these issues. A shortage of data is a primary area for improving the system in general. Blockchain's decentralised nature has the potential to improve city reporting systems, so that cities and countries can more efficiently and accurately track their climate initiatives. Using blockchain cuts out intermediaries, making reporting instantaneous, continuous, and immutable. This is especially effective when paired with IoT devices, as they automate the process. However, when paired with apps, blockchain also presents solutions to personal privacy concerns. Blockchain encrypts user data into a hash, the encoded numbers that make up blocks, meaning that personal data is not recorded. Users can also retain ownership of their data, instead of being forced to trade their personal information in order to use a service, as is often the case now. Rather, when users retain ownership of the data they are granted the ability to track and deny use of said information.

By using open-source, organisations would be able to add their own services to the app, giving users an even wider range to choose from

Travel apps, then, appear to be the solution for data collection, especially multimodal apps, which streamline trip planning services and have been shown to greatly improve public transportation use. Berlin launched its transportation app, Jelbi, in the summer of 2019, but this app still will not plan a trip that utilizes multiple transportation systems (i.e. a bike share as well as a bus). Though this app is a good start to integrating cleaner transportation options, by using an open-source blockchain, organisations would be able to add their own services to the app, giving users an even wider range to choose from. This could promote lower emission transportation even further.

The decentralised nature of blockchain and smart contracts allow users to deal with providers directly

Additionally, smart contracts enabled by blockchain allows users to not only plan a trip using multiple providers, but even enables them to pay multiple providers from only one app. The decentralised nature of blockchain and smart contracts allow users to deal with providers directly. This reduces backend contracts between operators and reduces processing time, giving users even more travel options. And, by using cryptocurrencies, payments can be made in any country, regardless of currency. Traveler can pay each company directly, streamlining the process and decreasing processing time.

However, smart contracts can be used for more than travellers, and provide a potential solution for integrating electric vehicles, including those that operate as a hailable bus service, a major issue in Berlin's current transportation plan. For instance, autonomous vehicles given access to smart wallets, would be able to make secure transactions via smart contracts to pay for their own charging and maintenance. These vehicles must be run on blockchain to ensure that they cannot be hacked. Blockchain also presents the ability to add them to ride sharing services so they could lease themselves out, creating their own revenue, or on a city level, be hailed as a bus service. This varies from Berlin's current plan to simply replace diesel buses with electric buses, but has the added benefit of door-to-door travel for users and adjusting more readily to daily influxes in demand.

Blockchain can also be useful in creating public policy. The increased timeliness can greatly increase the effectiveness of policies, and makes reporting of legal compliance faster. In

general, blockchain can help cut out many of the bureaucratic inefficiencies, making policies more relevant and implementation smoother. While many government officials might hesitate to implement the new technology, it is already being used in Germany to report on renewable energies. Hopefully, on seeing the utility of this system, officials will be convinced to expand blockchain reporting and tracking beyond its current uses to provide even more tracking and management solutions.

Overall, we recommend blockchain for its ability to improve data security, both for cities and private users, enable cross organisation and cross border partnerships, facilitate smarter autonomous vehicles, and influence public policy creation. Blockchain has the potential to aid many of these systems. Although the possibilities of blockchain suggested in this report are not exhaustive and the technology is still developing, the research demonstrates the power of blockchain technology to support the accomplishment of climate change emission goals.

About dGen

After Gen X, characterised by big societal shifts, Gen Y, better known as millennials, and the digital native Gen Z, the ***decentralised generation*** will grow up in a future shaped by different dynamics and technological developments. AI, blockchain technology, and IoT will individually bring disruption to many industries, but it's at the crossroads where we expect our whole socio-economic fabric to change.

dGen is a not-for-profit think tank based in Berlin, Germany. We focus on how blockchain technology can contribute to a decentralized future in Europe and what this might mean for people, society, private entities, and the public sector over the coming decades.

Emerging technology focused on decentralising society will shape the next part of the twenty-first century; The dGen will grow up with opportunities for borders to fade and traditional networks to dissipate. Meanwhile, most blockchain developments are still in the early stages; focusing on building solid products and exploring regulatory requirements to create a fertile yet safe environment for companies and investors. The industry is focused on solving the big topics right now, while we encounter a lot of great ideas in the blockchain community about adoption. It's time for those ideas to find a purpose and for the real decision-makers in the world to learn what decentralisation will mean for them.

We’re working with a team of researchers exploring how decentralisation will shape our future. Our insight reports focus on specific topics and industries to drive ideas for adoption in Europe. If you’re researching how decentralisation is shaping our future, and would like to get involved, please get in touch at dgen.org.

dGen

Contributors

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One of the founders of dGen and with a rich background in tech, Nick knows how to build organisations from scratch and can transform ideas to great tech products. As a former Product Manager at LiveIntent and Director of Customer Success at Avari he shipped software to a user base over 15% of the US population and has organised 200+ events in Berlin. As the COO at hype partners, he is currently helping top-tier blockchain firms strategise their market approach.

Jake Stott

Before founding dGen, Jake was originally a partner at Signal Ventures, investing in blockchain tech. In late 2017 he founded hype partners to help build and nurture ecosystems for blockchain projects and has worked with many top 100 projects. With these combined experiences he is able to distinguish legitimacy, necessity, and nonsense in this space.

Maggie Clarendon

Maggie is a writer, researcher, and editor. Trained in literature, critical theory, and gender studies, they are now exploring the ways that technology is changing the landscape of human interaction.

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Francisco has a degree in Business and Law, and is currently working for dGen to communicate its vision for blockchain adoption to an audience of thought leaders in tech companies, corporates, and the public sector as a researcher and marketer.

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REFERENCES

1. Climate Focus. (2015). The Paris Agreement Summary. Amsterdam: Climate Focus

2. United Nations. (2015). Paris Agreement. New York, NY: United Nations.

3. Lindsey, R. (2019, September 19). Climate Change: Global Sea Level. Retrieved from https://www.climate.gov/news-features/understanding-climate/climate-change-global-sea-level

4. Clemencon, R. (2016). The Two Sides of the Paris Climate Agreement: Dismal Failure or Historic Breakthrough. Journal of Environment & Development, 25(1), 3-24.

5. Britannica. (2019). Paris Agreement. Retrieved from https://www.britannica.com/topic/Paris-Agreement-2015

6. Stern, T. (2018). The Paris Agreement And Its Future. Washington: The Brookings Institute.

7. USGS. (2019). What is carbon sequestration? Retrieved from: https://www.usgs.gov/faqs/what-carbon-sequestration?qt-news_science_products=0#qt-news_science_products

8. USGS. (2008). Carbon Sequestration To Mitigate Climate Change. U.S. Geological Survey.

9. Ritchie, H., & Roser, M. (2018). CO_2 and Greenhouse Gas Emissions. Retrieved from: https://ourworldindata.org/co2-and-other-greenhouse-gas-emissions

10. Cho, R. (2019, June 10). How Climate Change Impacts the Economy. Retrieved from: https://blogs.ei.columbia.edu/2019/06/20/climate-change-economy-impacts/

11. Takakura, J., Fujimori, S., Hanasaki, N., Hasegawa, Y., Hirabayashi, Y., Honda, Y., Lizumi, T., Kumano, N., Parch, C., Shen, Z., Takahashi, K., Tamura, M., Tanoue, M., Tsuchida, K., Yokoki, H., Zhou, Q., Oki, T., & Hijioka, Y. (2019). Dependence of economic impacts of climate change on anthropogenically

directed pathways. Nature Climate Change, 9, 737–774

12. Tollefson, J., & Monastersky, R. (2019). The Hard Truths of Climate Change, Nature, 573, 324-325.

13. United Nations. (2010). Cities and Climate Change: An Urgent Agenda. Washington: United Nations.

14. Wentworth, A. (2018, May 17). 66% of EU cities have plans in place to combat climate change. Retrieved from: http://www.climateaction.org/news/66-of-eu-cities-have-plans-in-place-to-combat-climate-change/

15. McGrath, M. (2018, September 14). Cities lead the way on curbing carbon emissions. Retrieved from: https://www.bbc.com/news/science-environment-45515216

16. Bevanger, L. (2019, January 2). Oslo starts 2019 as Europe's eco capital. Retrieved from: https://www.dw.com/en/oslo-starts-2019-as-europes-eco-capital/a-46786866

17. UrbiStat. (2019). Berlin. Retrieved from: https://ugeo.urbistat.com/AdminStat/en/de/classifiche/dati-sintesi/province/berlin/11/2

18. Deloitte Insights. (2019). Deloitte City Mobility Index: Berlin. London: Deloitte MCS.

19. Goldman, T., & Gorham, R. (2006). Sustainable urban transport: Four innovative directions. Technology in Society, 28, 261–273.

20. Rode, P., & & Hoffman, C. (2015). Towards New Urban Mobility; The Case of London and Berlin. London: LSE Cities.

21. Railway Gazette. (2019, 1 March). Accessibility and sustainability at the heart of Berlin transport plan. Retrieved from: https://www.railwaygazette.com/vehicles/accessibility-and-sustainability-at-the-heart-of-berlin-transport-plan/48134.article

22. Kollinger, C. (2019, March 18). Berlin will soon have one app to integrate mobility services. Retrieved from: https://www.eltis.org/discover/news/berlin-will-soon-have-one-app-integrate-mobility-services

23. Marcus, I. (2019, June 24). Berlin's New Electric Buses: Pride and Curse of the City. Retrieved from: https://berlinspectator.com/2019/06/11/berlins-new-electric-buses-pride-and-curse-of-the-city/

24. Parkin, B. (2108, September 17). Bombardier debuts battery train in Berlin in challenge to diesel. Retrieved from: ttps://montrealgazette.com/business/local-business/bombardier-debuts-battery-train-in-berlin-in-challenge-to-diesel

25. International Union of Railways. (2016). Technologies And Potential Developments For Energy Efficiency and CO_2 Reductions In Rail Systems. Paris: International Union of Railways. (2016).

26. Alliance Pro Schiene. (2019). Electrification: overhead lines for freight trains, not HGVs. Retrieved from: https://www.allianz-pro-schiene.de/en/press-releases/electrification-overhead-lines-for-freight-trains-not-hgvs/

27. Connolly, L., Drazen, E., Eickhoff, G., Graham, P., Thoumi, G., & Wardell, D. (2018)

The Missing Link: How A Distributed Ledger System Can Support Global Climate Action. Jakarta, Singapore: Lestari Capital

28. Deloitte. (2019). Blockchain Technologies as a Digital Enabler for Sustainable Infrastructure. Paris: OECD.

29. Keskin, T., & Kennedy, D. (2015). Strategies in Smart Service Systems Enabled Multi-Sided Markets: Business Models for the Internet of Things. In: 2015 48th Hawaii International Conference on System Sciences. Hawaii, 5-8 January 2015.

30. Matthews, K. (2019, April 18). 4 ways to counter blockchain's energy consumption pitfall. Retrieved November 2019, from https://www.greenbiz.com/article/4-ways-counter-blockchains-energy-consumption-pitfall.

31.López, D., & Farooq, B. (2018). A blockchain framework for smart mobility. IEEE International Smart Cities Conference. Retrieved from https://arxiv.org/pdf/1809.05785.pdf

32. Shaheen, S., Martin, E., Cohen, A., Musunuri, A., & Bhattacharyya, A. (2016). Mobile Apps and Transportation: A Review of Smartphone Apps and a Study of User Response to Multimodal Traveler Information. California Department of Transportation. Retrieved from http://innovativemobility.org/wp-content/uploads/MobileApps_UCCONNECT.pdf

33. Salter, J. (2018, March 8). What is open source programming? Retrieved November 2019, from https://opensource.com/article/18/3/what-open-source-programming.

34. Semarnat. (2019). Blockchain Potentials and Limitations for Selected Climate Policy Instruments. Bonn; Semarnat.

35. Dob, D. (2018, July 17). Permissioned vs Permissionless Blockchains: Understanding the Differences. Retrieved from: https://blockonomi.com/permissioned-vs-permissionless-blockchains/

36. Born, R. (2018). Distributed Ledger Technology For Climate Change Action Assessment. Zurich: EIT Climate-Kic.

37. Hillemann, D. (2019, July 11). Blockchain - climate-killer or climate-saver? Retrieved from: https://medium.com/@DHillemann/blockchain-climate-killer-or-climate-saver-b00f45852c6d

38 Smart Energy International. (2019, June 14). Swytch to pilot first blockchain platform with German consumers. Retrieved from: https://www.smart-energy.com/news/swytch-blockchain-e2m/

39. Schenker, J. (2019, September 1). Is It Time For A Swytch? Retrieved from: https://innovator.news/is-it-time-for-a-swytch-aec4433300bc

40. Smart Cities World. (2019, July 14). Transport for London collects anonymous data via Wi-Fi to improve Tube journeys. Retrieved from: https://www.smartcitiesworld.net/news/news/transport-for-london-collects-anonymous-data-to-improve-tube-journeys-4358

41. Kurosawa, K. (2016). Tokyo Metro Efforts in Open Data. Japan Railway & Transport Review, 67. Retrieved from http://www.ejrcf.or.jp/jrtr/jrtr67/pdf/16-21.pdf

42. Lei, A. P., Cruickshank, H. P., Cao, Y. P., Asuquo, P. P., Anyigor Ogah, C. P., Sun, Z., & IEEE, M. (2017). Blockchain-Based Dynamic Key Management for Heterogeneous Intelligent Transportation Systems. IEEE Internet of Things Journal, 4(6). Retrieved from http://epubs.surrey.ac.uk/841948/1/AoLei IEEE IoT Journal Final Version. Blockchain-Based Dynamic Key Management for Heterogeneous Intelligent Transportation Systems.pdf

43. Low-emission Zone. (n.d.). Retrieved November 2019, from https://www.berlin.de/senuvk/umwelt/luftqualitaet/umweltzone/en/fahrzeug_plakette.shtml#fp7.

44. Rajbhandari, R. (2018). Exploring Blockchain - Technology behind Bitcoin and Implications for Transforming Transportation. Transportation Policy Research Center. Retrieved from https://static.tti.tamu.edu/tti.tamu.edu/documents/PRC-17-13-F.pdf

45. Mwasilu, F., Justo, J. J., Kim, E.-K., Do, T. D., & Jung, J.-W. (2014). Electric vehicles and smart grid interaction: A review on vehicle to grid and renewable energy sources integration. Renewable and Sustainable Energy Reviews, 34, 501–516. Retrieved from file:///C:/Users/m/Downloads/ElectricVehiclesGrid.pdf

46. Cohn, A., West, T., & Parker, C. (2017). Smart After All: Blockchain, Smart Contracts, Parametric Insurance, and Smart Energy Grids. Georgetown Law Technology Review, 1(2). Retrieved from https://georgetownlawtechreview.org/wp-content/uploads/2017/04/Cohn-West-Parker-1-GEO.-L.-TECH.-REV.-273.pdf

47. Bhavani, V. K., & Rajaram, G. (2019, January 29). Machines that pay each other using digital wallets. Retrieved November 2019, from https://blogs.dxc.technology/2019/01/29/machines-that-pay-each-other-using-digital-wallets/.

48. Bischoff, J., & Maciejewski, M. (2016). Simulation of City-wide Replacement of Private Cars with Autonomous Taxis in Berlin. Procedia Computer Science, 83. Retrieved from https://www.sciencedirect.com/science/article/pii/S1877050916301442

49. Y. McKinsey. (2017). Using blockchain to improve data management in the public sector. Retrieved from: https://www.mckinsey.com/business-functions/mckinsey-digital/our-insights/using-blockchain-to-improve-data-management-in-the-public-sector

50. Bannon, E. (2018, September 18). Dieselgate, three years on: 43 million dirty diesels on our roads - and still growing. Retrieved December 2019, from https://www.transportenvironment.org/press/dieselgate-three-years-43-million-dirty-diesels-our-roads-–-and-still-growing.

51. Chappell, B. (2015, October 8). 'It Was Installed For This Purpose,' VW's U.S. CEO Tells Congress About Defeat Device. Retrieved December 2019, from https://www.npr.org/sections/thetwo-way/2015/10/08/446861855/volkswagen-u-s-ceo-faces-questions-on-capitol-hill?t=1575480676593&t=1575545648876.

52. Janjevic, D. (2016, May 12). WHO: Air pollution kills millions every year. Retrieved December 2019, from https://www.dw.com/en/who-air-pollution-kills-millions-every-year/a-19251189.

53. Staudenmaier, R. (2018, February 12). Germany considering free public transportation to take on air pollution. Retrieved December 2019, from https://www.dw.com/en/germany-considering-free-public-transportation-to-take-on-air-pollution/a-42574053.