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Electric Vehicles, Artificial Intelligence, and Climate Policy

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ABSTRACT: This article explores the environmental implications of electrification and artificial intelligence (AI) infrastructure, emphasizing the importance of aligning technological development with climate goals. There is a lack of academic literature that explains and analyses such issues. Section 1 assesses the climate efficacy of promoting electric vehicles (EVs) and electric heating in regions where electricity is primarily coal-based. While electrification offers substantial climate benefits when powered by clean energy, lifecycle analyses reveal that EVs in coal-reliant grids may emit more greenhouse gases than internal combustion engine vehicles. Similarly, the climate performance of electric heat pumps depends on the carbon intensity of electricity sources. The section advocates for integrated policies that simultaneously promote electrification and grid decarbonization, enhancing emissions reductions and public health while mitigating the negative impacts of increased demand on polluting power plants. Section 2 uses Saudi Arabia as a case study and examines the environmental impact of AI data centers in the context of Saudi Arabia's energy and climate policies. It highlights AI infrastructure's energy and water intensity and its potential to strain environmental resources. To align AI development with national sustainability goals, the article recommends policies such as siting data centers near renewable energy sources, enforcing environmental efficiency standards, fostering R&D partnerships, mandating sustainability reporting, and expanding power purchase agreements and demand response participation. These measures aim to ensure responsible AI growth within climate-aligned frameworks. The implications of this study are that electrification and AI infrastructure can significantly reduce emissions and improve efficiency if powered by clean energy, but they also risk increasing environmental strain unless technological growth is carefully aligned with climate and sustainability goals.

Keywords: Electrification; Electric vehicles (EVs); Grid decarbonization; Climate policy; Artificial intelligence (AI); Data centers; Energy efficiency; Sustainability

1. Introduction

This article explores the environmental implications of electrification and artificial intelligence (AI) infrastructure, emphasizing the importance of aligning technological development with climate goals. There is a lack of academic literature that explains and analyses such issues. This article is divided into two sections. Section 1 evaluates whether promoting electrification, particularly electric vehicles (EVs) and electric heating, in carbon-dominated regions is advisable, given that their climate benefits depend on the cleanliness of their local electricity supply [1]. While EVs and other electrified technologies give substantial climate advantages when powered by clean electricity [2], the benefits from adopting EVs and other electrified technologies become negative in regions where electricity is primarily generated from coal. Lifecycle evaluations indicate that EVs charged by coal-intensive grids produce more greenhouse gas emissions than comparable internal combustion engine vehicles. However, as electricity grids become cleaner, the emissions advantage of EVs significantly increases.

Similarly, electric heat pumps are more efficient and climate-friendly than fossil fuel furnaces, yet their climate benefits depend on the power supply's carbon intensity. Policymakers are urged to promote electrification alongside grid decarbonization to maximize climate benefits. Electrification lowers emissions and has co-benefits, including cleaner urban air, healthier lives, and more efficient systems. However, those gains come with the cost of pollution from power plants. Section 1 recommends using coordinated policies that electrify and clean energy sources simultaneously.

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Integrating options for grid decarbonization with pushing for electrification enables policymakers to meet both long-term goals for emissions reduction and short-term issues affecting people's and the environment's health.

Artificial intelligence (AI) systems can use massive computational resources (AI compute) [3], raising concerns about their effects on energy consumption and broader environmental and climate side effects. Data centers at the center of AI infrastructure rely heavily on energy and water to operate. Section 2 aims to understand the impacts of AI data centers on Saudi Arabia's energy and climate policies and objectives. The section focuses on the direct environmental impacts of AI infrastructure in the operational stage, which includes energy consumption, water consumption, and carbon footprint.

To ensure AI development aligns with the Kingdom of Saudi Arabia's climate and environmental objectives, the section recommends several policy tools: incentivizing data centers construction in areas with excess renewable energy capacity, establishing specific standards in terms of energy efficiency, water consumption and carbon footprint, expanding research and development partnerships in water and energy efficiency between Saudi universities and leading companies in the field of data center operation, requiring the reporting and verification of all environmental and sustainability related metrics by establishing measurement standards and expanding data collection, taking advantage of cheap solar and wind energy by expanding the scope of power purchase agreements (PPA), and, finally, including data center operators in demand response programs.

The implications of this study are that electrification and AI infrastructure can significantly reduce emissions and improve efficiency if powered by clean energy, but they also risk increasing environmental strain unless technological growth is carefully aligned with climate and sustainability goals.

2. Promoting Electric Vehicles and Other Elements of Electrification in Areas with Carbon-Intensive Electricity Supply

With the world on the front foot in combating the growing threat of climate change, policymakers are shifting in a hurry to electrification, particularly switching to EVs and electrified heat to eliminate greenhouse emissions. The idea was to build these technologies to reduce greenhouse gas emissions and to clean the air in cities from dirty fossil fuels to cleaner electric ones. However, a serious environmental trade-off arises in regions where most electricity is generated by carbon-intensive sources, such as coal. In that case, the environmental benefits of electrification are diminished or even completely offset by the upstream emissions from electricity generation.

This section will explore whether policymakers should promote the use of electric vehicles and other elements of electrification in regions with carbon-intensive electricity supply. Furthermore, it will consider the lifecycle emissions of EVs, the interplay and impact on emissions reduction of electric heating, and other co-benefits on public health and air quality. Based on conceptual and empirical evidence, the analysis will establish that electrification still holds value, especially if implemented concurrently with a green transition in the power sector. The section argues that coordinated policy efforts are necessary to capture the complete benefits of electrification in dealing with climate change and improving health.

2.1. The Climate Impact of EVs under High-Carbon Grid Intensity

Electric vehicles produce no tailpipe emissions; however, their lifecycle environmental impact largely depends on the electricity generation source used to recharge them. Electric vehicles produce considerable CO_2 emissions when charging if the power comes from fossil-based fuel sources [4]. Global energy production from fossil sources remains dominant, with nearly 60% of the power generated from coal and gas [5]. Most electric cars receive their energy through carbon-heavy electricity, even if it is indirectly charged.

Lifecycle assessments show that the energy mix of the grid plays a major role in determining EVs' environmental impact. An EV battery charged on a coal-based grid can have lifecycle emissions comparable to or even greater than an equivalent gasoline vehicle. In those coal-heavy grids, EV charging increases emissions due to the CO_2 produced when generating electricity, which can outweigh the emissions avoided by not burning gasoline or diesel. It has also been found that EVs charged exclusively on coal-fired power could increase greenhouse gas emissions by 17–27% over their entire life cycle compared with a conventional internal combustion engine vehicle [1]. This challenges the widespread notion that EVs are automatically the green choice. Therefore, the environmental benefits of EVs are not guaranteed.

In contrast, EVs show substantially better emissions performance with cleaner electricity sources for charging. Research in countries such as Europe, where there is a diversified power mix including renewables, revealed that EVs have a CO_2 emissions decrease of around 20–30% over a life cycle versus a petrol car [2]. This gain happens because cleaner electricity generates fewer upstream emissions during EV operation. Furthermore, the carbon benefit jumps dramatically in power systems powered primarily by low-carbon sources.

In scenarios where electricity is generated almost entirely from renewables or nuclear energy, EVs may reach lifecycle emissions of 80–90% lower than standard gasoline or diesel vehicles [3]. This massive decline emphasizes the obligation to decarbonize the power sector, coupled with growing EVs adoption. An EV's carbon footprint is not fixed; it varies dramatically based on the local or regional electric power infrastructure. Depending on the electricity source, the same EV model type could have dramatically different environmental implications in one country than in another. This level of variation demonstrates why viewing only tailpipe emissions could be misleading when determining the full impact on climate.

Consequently, the climate benefits of EVs are closely tied to the energy sources that power the grid. In regions where renewable or nuclear power is the dominant source, EVs represent a substantial opportunity for reducing transportation-related emissions. However, the benefits can be small or negative in coal-heavy areas unless there are broader changes toward cleaner energy. To illustrate, Norway, which uses mainly hydropower, sees EVs delivering major reductions in CO_2 emissions compared to petrol vehicles [4]. On the other hand, countries or regions heavily reliant on coal gain only modestly or little unless the grid becomes less carbon-intensive. This is to say, the electrification of vehicles itself is not a silver bullet for climate change, unless it goes side by side with clean energy transitions [5]. The effectiveness of EVs as a climate solution depends on electricity production and transportation technology.

Empirical evidence from large countries supports this pattern as well. Although China's adoption of EVs has developed notably, its reliance on coal for electricity limits energy reductions. Due to the coal-dominated Chinese power mix, the EV in China abates only about 12% of CO_2 emissions relative to an internal combustion engine vehicle [6]. In some regions with more significant amounts of coal used and additional heating requirements, an EV can slightly increase the emissions of CO_2 and certain pollutant levels compared to a conventional car [7]. Regions with a mixed energy grid, such as the United States and Europe, where decarbonization is advancing, tend to see moderate to substantial greenhouse gas savings from EVs. A study shows that a medium-sized battery electric car in 2023 generated about 50% less lifecycle CO_2 than a comparable gasoline car, given the current world average power mixes [8].

An EV has lower net emissions than an efficient gasoline car if any fraction of the electricity comes from low-carbon sources, even with relatively pessimistic assumptions [9]. Large-scale vehicle electrification in India, which has a high share of coal power, is also projected to decrease net CO_2 if its power sector adopts moderate emissions controls and adds renewables [10]. Modelling the electrification of the entire light-duty vehicle fleet in the United States, China, and the UK through 2050 in various grid scenarios suggests that electrification can reduce lifecycle greenhouse gas (GHG) emissions by over 50% by 2050 in all three countries, if the grid is supplied by lower carbon sources consistent with announced policies [11]. This result indicates that EV mass-market penetration can be a viable decarbonization pathway in coal-heavy countries if the electricity supply is expected to improve over time.

Scientific evidence shows that supporting EVs in electricity grids with high carbon emissions will only yield climate benefits if efforts to decarbonize electricity are made simultaneously. A coal-driven EV could boast zero or a little less GHG benefit than a petrol-driven car in the short term, and may even have adverse impacts in specific cases in the United States [12]. EVs have a considerable long-term benefit, as the more the electricity supply is cleaned up, the more emissions from an EV fall exponentially. Gasoline has to produce CO_2 in the same units per mile, and it cannot become cleaner over a car's life span, whereas an EV can vary as the grid changes [13]. Consequently, electric vehicles using low-emission electricity are among the most significant single steps that can be undertaken to cut the greenhouse gas emissions stemming from transport [14].

The timing and alignment of electrification with grid decarbonization are essential for achieving considerable climate benefits from EVs. In areas where power generation depends primarily on coal, introducing EVs today may achieve only minor or no emissions savings in the near term. However, the same vehicles can yield major long-term savings as the grid moves increasingly to sustainable energy sources during their operational timespan [15]. It highlights the importance of a future-oriented policy framework emphasizing concomitant EV adoption and grid infrastructure investments. Pushing electrification until the carbon-free grid risks missing out on cumulative emissions reductions, as each year of delayed EV adoption means lost chances to replace gasoline cars [16]. For instance, even in coal-dominated regions, early EV adoption guarantees that infrastructure and consumer behavior evolve in anticipation of a cleaner grid, advancing the transition as soon as renewable power potential grows [17].

Therefore, policymakers must create plans that align EV growth with decarbonizing grids to realize the full benefits of electrification [18]. Nations such as China and India are demonstrating this dual-track approach, aggressively getting behind EV adoption, investing in renewables, and transitioning away from coal [19]. By coordinating these efforts, countries guarantee that EVs acquired today will be increasingly powered on cleaner energy as the grids evolve, amplifying the reductions in emissions over time. This strategy is unlike waiting for the fully green grid, which could push transportation electrification for decades and lock in fossil fuel dependence. Furthermore, initial EV deployment yields quick co-benefits, such as decreased urban air pollution and better public health, even in areas with low-carbon electricity grids [20]. Thus, a joint policy framework that aligns grid decarbonization timelines with EV incentives is required to gain near-term benefits and long-term climate goals.

2.2. Other Elements of Electrification: Electric Heating in Dirty vs. Clean Grids

Transport is not the only sector where electrification poses the “dirty grid” conundrum. Policymakers also promote the electrification of building heating, including switching oil or gas furnaces to electric heat pumps and other industrial processes [21]. The climate justification is similar to that for electric vehicles. Electric heat pumps, run off low-carbon electricity, can produce heating with significantly lower greenhouse gas emissions than burning fossil fuels on-site [22]. A cutting-edge electric heat pump is highly efficient, putting out between three to four units of heat for each unit of electricity. In contrast, a gas boiler delivers less than one unit of heat for each unit of gas energy [23]. Even if the electricity is from fossil fuels, heat pumps emit less carbon dioxide than a combustible heat source. However, the carbon intensity of the grid remains a critical factor.

A traditional residential electric heat pump lowers direct CO_2 emissions by roughly 55% compared to a natural gas furnace, based on the current electricity mix and average residential context of the United States [24]. Even under a relatively high-carbon grid, the heat pump achieves at least a 20% CO_2 reduction over a gas boiler. With existing technologies, an electric heat pump powered with coal-dominated electricity often includes some emission savings because of its high efficiency, although the savings are modest. If the grid is cleaner, using more renewables or gas instead of coal, switching to an electric heat pump can cut emissions by roughly 80% compared to burning fuel in a furnace [25].

Studies show that, in many areas of the United States, swapping an existing gas furnace for an electric heat pump reduces heating-related CO_2 emissions by about 40–50% on average [26]. Few coal-reliant areas see little to no immediate carbon advantage, and nowhere does it lead to a heat pump producing more CO_2 emissions than an ultra-efficient gas-fired furnace. A modern electric heat pump is therefore slightly better for the climate, even in dirty grids, and becomes much better as those grids decarbonize.

Not all emissions are limited to CO_2. When a coal-based grid powers a heat pump, it may slightly indirectly cause the emissions of air pollutants such as Sulphur dioxide (SO_2) and nitrogen oxides (NO_x) at the electricity generation step. These pollutants are bad for human health and contribute to problems such as acid rain, ground-level ozone, and respiratory disease, but they are not greenhouse gases. In contrast, a high-efficiency gas furnace emits almost no SO_2 and only relatively small amounts of NO_x at the point of use [1].

However, this presents a challenge: relying only on electric heating without addressing the electricity source might move pollution from millions of residential chimneys to a few larger power plants. Ultimately, the impact on public health depends on how clean and modern those power plants will be. While larger centralized plants often install advanced emissions control technologies, older ones or those lacking pollution control systems can expose communities to higher concentrations and deadly pollutants [2]. Therefore, net-pollution related benefits depend on the efficiency of the systems, controls at power stations, and proximity to population centers.

A study has shown that in places where coal-fired power plants are sited close to cities, a large-scale shift of households to electric heating or electric transport without additional grid decarbonization would increase local air pollution, especially SO_2 and fine particulate matter [3]. These pollutants can contribute to smog and have serious health impacts, particularly among those sensitive to air quality, such as children and older adults [4]. This example underscores that electrification, in isolation, cannot deliver cleaner air or public health benefits.

In regions reliant on coal with no emission controls or renewable energy incorporation, electrification would merely shift pollution, not eliminate it. This shows that there should be policies for improving the supply side (clean energy transition, pollution control) and the demand side (electrification). Short-term solutions should involve retrofitting existing power plants with scrubbers and filters, and in the long-term, need to prioritize coal phase-out and increasing renewable energy. Efforts to decrease global warming impacts of the power sector tend to reduce co-pollutants such as SO_2 and NOx, which further increase the benefits of electric heating and other electrified end-uses [5]. This way, practical electrification involves coupled action that includes greenhouse gases and air pollutants.

2.3. Co-Benefits of Electrification: Air Quality and Public Health Considerations

Climate impact is a major issue in the electrification conversation; however, it is not the only issue. There are substantial benefits and trade-offs for air quality, public health, and energy security when switching from fossil fuel to electric alternatives. Regardless of whether an EV or electric furnace runs from a coal-dominated grid, at least one advantage is getting rid of the exhaust on-site [6]. Moreover, reducing tailpipe emissions can improve urban areas, especially in densely populated and polluted city centers [7].

A report shows that introducing electric mobility in developing country cities offers substantial public health benefits by decreasing urban air pollution [8]. However, emissions are shifted to the power sector, which could be many kilometers away from population centers, or with the pollution controls fitted, thereby limiting population exposure to pollutants [9]. If plants are situated near communities and do not have proper controls, those communities may bear a larger pollution burden [10].

Electrification reduces vehicle emissions but may shift pollution to power stations near deprived areas. A study undertaken in California suggested that cuts in harmful emissions such as NO_x, SO_2, and fine particulate matter greatly helped affluent zones, with a slight improvement in poorer neighborhoods [11]. Similar results were seen when electrifying heavy-duty trucks: general health improvement, but privileged populations benefited the most [12]. For instance, a sample study in Chicago showed that the electrification of many trucks would reduce pollution-caused fatalities by several hundred per year. However, those benefits were primarily available only to specific urban groups [13]. Thus, if not accompanied by carefully planned policies, electrification risks exacerbating environmental injustice by moving sources of pollution closer to vulnerable communities.

Environmental justice concerns arise regarding who is exposed to pollution when vehicles become electric. Around 90% of the air pollution damages from an EV in one U.S. state can be “exported” to other areas where power plants emit. In contrast, gasoline vehicle pollution remains closer to the area of driving [14]. In coal-heavy states, the health and environmental damage from more output from power plants could outweigh the benefits from less tailpipe output, making EVs worse for overall air quality than gasoline cars in some cases. Furthermore, the local energy mix and pollution control measures heavily influence this outcome [15].

Recent studies suggest that EVs’ net air quality benefits remain positive in most places in a transitioning grid. A study indicates that large-scale replacement of U.S. fleet with an EV fleet led to fewer total health impacts from air pollution across different grid scenarios [16]. Even a part-decarbonized network will lower tailpipe emissions, especially in urban centers, compared to fossil fuel use nationwide. However, health benefits are nearly doubled if electrification goes together with a clean grid [17]. The Chinese EVs had different CO_2 impacts. While some models slightly improved air quality through reduced vehicle NOx emissions, they also added some coal-fired power plant emissions of SO_2 and PM2.5 in the area, which slightly reduced the net benefit [18]. It suggests that electrification is not a complete solution to air pollution challenges as long as production in the power sector is not regulated.

Studies indicate that electrification has positive impacts on health and the economy. In the United States, converting one-quarter of the automobile vehicles is expected to prevent 437 yearly fatalities resulting from fine particulate matter and an additional 98 due to ozone, reducing associated healthcare costs by 16.8 billion dollars [19]. These savings could be significantly increased if clean electricity were combined with even more aggressive electrification. Other regional research, including that concerning electric trucks in the Chicago area, projects a significant reduction in deaths owing to air pollution. Research conducted on major cities shows that wide-scale electrification could prevent thousands of deaths annually, which in turn would save costs in healthcare and economic sectors. Altogether, these studies strongly indicate substantial public health advantages offered by combining electrification with cleaner electricity generation.

Electrification produces numerous advantages regarding energy efficiency, where technologies such as electric drivetrains and heat pumps use less energy than their fossil-fuel equivalents. For example, electric vehicles turn a large portion of the electricity cost used to charge their battery into direct kinetic energy. In contrast, internal combustion engines lose massive amounts of energy in the form of heat. In a similar way, electric heat pumps are much more efficient than any gas or oil-fired boiler because they retain heat as opposed to being generated by combustion. This efficiency also lowers total energy costs and reduces user fuel bills. Electrified solutions, such as electric steam boilers and fleet equipment in industrial applications, have lower operational and maintenance costs. This efficiency decreases energy consumption and the load of the power grid, thus making electrification an alternative option to improve energy usage in diverse industries.

Electrification is also economical in the long run as it implies lower operations and maintenance expenses. Even though the initial investment into electrified technologies appears higher, it is offset over time through long-term savings. EVs are less mechanical than internal combustion engines, with fewer components, less wear and tear, and less ongoing maintenance cost. Also, heat pumps are cost-effective because they possess multiple units of heat in one unit of electric power. In addition to direct consumer cost savings, electrification also leads to externalities associated with the health and environmental impacts of fossil fuel burning.

Research has revealed that switching to electric systems can lower healthcare expenses from health troubles caused by air pollution, including breathing problems [1]. On the other hand, numerous growth countries are getting e-mobility options, such as electric buses and two-wheels, to capitalize on those cost savings to deal with urban air pollution issues [2]. Electrification largely presents an engaging economic rationale because it saves consumers on the total expenses of ownership and society from the costs of environmental pollution and public health impacts. These benefits are key in considering electrification as a sustainable energy option.

The distribution of these health benefits depends significantly on who can access electrification technologies. Today, electric vehicle ownership and charging infrastructure are heavily skewed towards higher-income areas. At the same time, lower-income and minority communities lack opportunities for access and face greater barriers to adoption [3]. For example, research from California has shown that lower-income areas have fewer electric vehicles per capita, even though they suffer from more severe air pollution [4]. Limited availability of electrification might compel low-income groups to continue relying on polluting vehicles or home heating choices, resulting in persistent exposure to health dangers [4]. For instance, households allocating a large part of their income to energy expenditures are likelier to experience poor physical and mental health. In addition, the ongoing use of fossil fuels within homes, including gas stoves, has been found to be associated with increased childhood asthma rates [5]. Therefore, focused policies are essential to ensure that health benefits from better air quality are directed at those most exposed to pollution.

While a coal-heavy electricity generation system slows the pace of climate benefits from electrification, local air cleanliness advantages and power efficiency advancements persist. Leaders must understand that electrification leads to an important reduction in urban air pollution and public health gains from removing direct emissions from vehicles or household chimneys, putting citizens' health directly into the benefit column [6]. However, shifting pollution is only half the story if policies do not also demand cleaner energy from power generation plants. This enhances the near-term argument for electrification and offers solid rationale, such as public health and energy security, for moving to EVs and heat pumps as the grid converts towards lower-carbon energy sources.

2.4. Policy Implications: Managing Electrification and Grid Decarbonization Together

A nuanced response emerges regarding EV and electrification promotion in coal-heavy regions: yes, as long as there are coordinated policies to clean up the electricity supply. Policymakers should not characterize this as a trade-off between using the grid more efficiently and electrifying end loads; both should move forward simultaneously [7]. Moreover, achieving substantial emissions reduction requires both supply-side actions, such as decarbonizing the power supply, and demand-side policies through electrification of transport, buildings, and industry [8]. Electric vehicles and heating electrification are significant demand-side elements in most pathways that constrain global warming, but their effectiveness depends on parallel developments in the power sector.

A practical strategy is to use conditional or phased incentives. Governments can encourage EVs and heat pumps upfront through subsidies, mandates, or grid investments to accompany retiring coal plants and deploy renewables. Some jurisdictions link EV promotion to renewable electricity by incentivizing EV owners to participate in Solar charging programs or renewable energy certificates [9]. Special electricity rates for EV charging can promote energy use during surplus renewable periods and make the electrification match the clean power [10]. Smart charging and vehicle-to-grid integration also enable EVs to act as flexible loads to stabilize grids with a high share of renewables [11]. These strategies ensure that EV growth enhances, rather than hinders, the transition to clean energy.

Transitional measures can be allowed in coal-dependent regions. Promoting the sale of hybrid vehicles or more efficient ICEVs could reduce emissions in the short term if the grid is very carbon-intensive, but this is just an interim measure. Achieving zero-emission transportation ultimately requires full electrification powered by clean energy [12]. Even countries with the highest coal consumption, such as China and India, are not seeking optimal grid conditions after EV promotion. Instead, they invest heavily in EVs and renewables, believing that postponing EV deployment would sacrifice important benefits [13]. Early electrification also sets the market and infrastructure in such a way that once the grid is decarbonized, the end-use technology is already in place.

Regional differentiation is another possibility. Some argue that EV subsidies or policies might be differentiated between grid mix, with higher support in cleaner grids and less in coal-dominated areas, until their grids become cleaner [14]. However, the political obstacles and the scale of overall political EV can delay adoption under that model [15]. A more practical solution establishes national EV targets but invests in retiring old coal plants and expanding renewables in the most carbon-intensive areas [16]. This guarantees that no territory is left behind in electrification and that the electricity supply tracks demand.

Reforming the power sector is crucial. Encouraging tens of millions of EVs without altering the generation mix will perpetuate coal-based electricity for decades, which is an outcome that should be avoided [17]. Technologies such as carbon pricing, renewable portfolio standards, or strict air pollution standards on power plants prevent new EV demand from driving more coal consumption [18]. A study shows that if well managed, electrification can drive grid decarbonization by incentivizing extra renewable capacity and constructive use of those resources when well-timed EV charging is used [19].

Expanding grid infrastructure must be prioritized. The growth in EVs and electric heating increases electricity demand, requiring a more resilient, modern grid. Existing infrastructure in many nations does not manage the variability of renewables nor the load from widespread electrification [20]. Grid upgrades such as enlarging transmission lines, installing smart meters, and integrating distributed storage are necessary to make the grid reliable and flexible [21]. In the absence of these innovations, even clean energy may not deliver to demand centers efficiently, resulting in curtailment or fossil fallback. Moreover, decentralized grid models can give power to the people and enhance local energy self-reliance [22]. Investing in infrastructure is, therefore, an essential element that must be aligned with electrification policies.

Equity and access have to be central to policy development. Low-income communities may have greater obstacles to electrification, such as the upfront price of EVs or heat pumps, a lack of on-site charging, or clean energy. Electrification might exacerbate energy inequality without tailored assistance, especially in the countryside or coal-based areas. Subsidies, zero-interest loans, and utility programs can simplify it and guarantee inclusive participation [23]. Training the workforce is also necessary to transition fossil fuel workers into the clean energy industry. Community-based renewable initiatives and grassroots grid options can share benefits more equitably. Policies considering economic and geographical inequalities will promote a fair transition and maintain public support. Electrification has to be fair to be sustainable.

Local air quality and health co-benefits should be emphasized. Although EVs can lower CO_2 emissions worldwide, they also decrease tailpipe emissions that immediately harm human health. It includes NO_x, VOCs, and PM that worsen asthma, heart disease, and other illnesses. Even in regions of heavy coal use, EVs can get around the urban particulate pollution problem because power plants are generally located far from cities and have better emissions control than vehicle fleets. Moving emissions from urban streets to managed plants can improve local air quality. Public health agencies should emphasize these short-term health benefits of electrification in addition to climate reasons. Cleaner cities are politically attractive and deliver triable, near-term results. Connecting electrification to wellness enlarges the coalition for policy action [24].

Public communication also matters. People can ask why EVs are good when electricity is still made from coal. Policymakers must frame electrification as a long-term commitment to a cleaner future, alongside cleaning the grid. The public will remain bought in by establishing exact goals, such as determining renewable shares up to 2030 and forecasting EV emissions rates. Co-benefits, such as cleaner air in cities, upgrading the car industry, and energy independence, could swing more public opinion in favor of low-carbon options before the full climate benefits are clear [25].

3. AI Ambition and Climate Policy in Saudi Arabia

Since the launch of ChatGPT in late 2022 [26], AI has been dominating discussion topics in policy circles. This increased focus from policymakers and academics can be translated and seen in the increased investments made by governments and companies in computing capacity [27] required to train and operate cutting-edge large language models (LLMs). The computational demand for training leading models has surged dramatically; for instance, GPT-4 required a staggering 6587% increase in computation over its predecessor GPT-3 three years earlier. This computational need growth directly translates into increased demand for supporting physical infrastructure.

At the heart of AI infrastructure lie data centers—facilities housing tens of thousands of servers and the necessary support equipment [28]. These facilities are fundamental building blocks for the digital world, enabling everything from social media interactions to complex AI model training. This has led to increased global investments in data center construction, particularly since 2022. Nations like the U.S. and China are making substantial investments, recognizing data center's critical role in developing AI innovation and ensuring data sovereignty.

The Kingdom of Saudi Arabia rapidly emerges as a key player within this global race. Driven by Vision 2030 and the National Strategy for Data & AI, the Kingdom aims to become a leading hub for AI and digital infrastructure. Leveraging advantages like significant energy resources, low energy costs, strategic government investments (e.g., through PIF and companies like Alat), and a favorable regulatory environment, Saudi Arabia is experiencing explosive growth in data center capacity. Projections indicate a compound annual growth rate far exceeding the global average, positioning the Kingdom to potentially lead the Middle East market. Major international companies like Google, Microsoft, and Groq are establishing a presence alongside local players.

However, this ambitious pursuit of AI leadership presents a significant policy challenge. Data centers are inherently resource-intensive, demanding vast amounts of energy for computation and significant volumes of water for cooling. The projected increase in demand from these facilities raises critical questions about their alignment with Saudi Arabia's climate commitments and energy transition strategy. The Kingdom has set ambitious targets under initiatives such as the Saudi Green Initiative (SGI) and its Nationally Determined Contribution (NDC) under the Paris Agreement on Climate Change [29], including reducing carbon emissions substantially, generating 50% of electricity from renewables by 2030 [30], and achieving net-zero emissions by 2060 [31]. The reliance of data centers on energy and water resources could potentially strain the national grid and increase environmental pressures, particularly water scarcity, thereby conflicting with sustainability goals.

This section aims to understand and analyze the impacts of AI data center infrastructure on Saudi Arabia's energy and climate policies and objectives. It focuses specifically on the direct environmental impacts during the operational stage, primarily energy consumption, water consumption, and the associated carbon footprint. By examining the intersection of rapid technological development and national sustainability goals, this section seeks to identify potential policy challenges. It proposes a set of policy tools and recommendations designed to help the Kingdom harness the transformative potential of AI while ensuring its technological ambitions remain consistent with long-term environmental and climate commitments.

3.1. What Are Data Centers and Why Are They Important for the AI Revolution?

The amount of compute required to train the main large language models (LLMs) has increased dramatically since 2010 [32]. Figure 1 below shows the positive correlation between the amount of training compute required (FLOP [33]) and the year of publication for different models. For example, OpenAI's GPT-3 required 314 million petaflops to train. Three years later, the same company introduced GPT-4 which required a staggering 21 billion petaflops to train, that's a 6587% increase in just three years [34]. Like any digital technology, any Large Language Model (LLM) requires a physical infrastructure behind it. To engage with our loved ones on social media, our smartphones require a vast network of different infrastructures, from communication cables to cybersecurity infrastructure and servers, all working together to transmit, process, and store our data. This trend of more complex LLM's and an increased amount of compute required to both train and run the models once they are complete means more physical infrastructure is required to create the cutting-edge LLM's that many companies are promising.

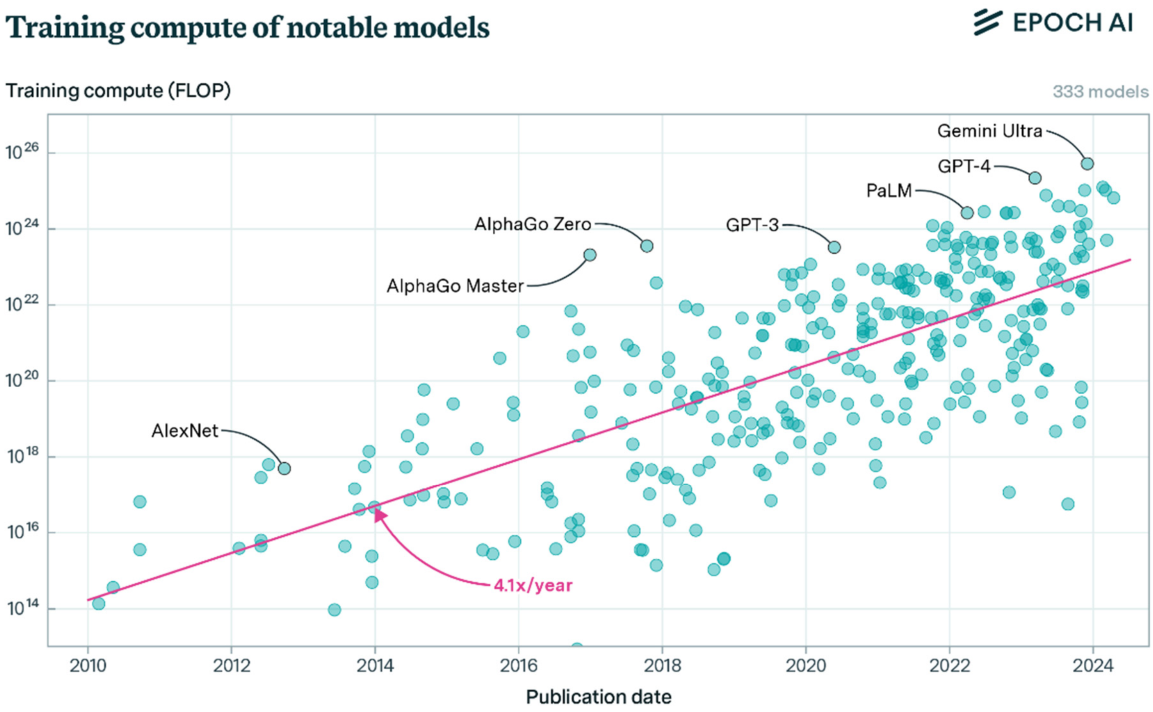

Figure 1. Amount of training compute used for different models [35].

The main building blocks of AI infrastructure are data centers, facilities that house tens of thousands of servers along with other equipment needed to operate them, like network switches, power supplies, and backup batteries for storing and managing data [36].

Investments in new data centers have surged since the launch of ChatGPT in November 2022 [37], driven by the growing interest and shifting priorities of many governments and companies. This trend is expected to continue accelerating since governments and companies around the globe are racing to invest and build computing capacity to create their own AI models, and data centers are at the forefront of such investments. The U.S is leading global investments in data centers, and as shown in Figure 2, annual investment in data center construction has doubled since 2022 [38]. Amazon plans on spending $150 billion on data centers over the next 15 years [39], Meta expects a $20 billion increase in capital expenditure in 2025, and the majority of that amount will go toward building and expanding data centers.

In China, the largest consumer of electricity globally, the Eastern Data and Western Computing (EDWC) plan was established in 2021 to incentivize data center construction by using the advantages of excess renewable energy in western China [40]. Under this project, China saw a 24% increase in data center capacity in 2024 alone [41]. Regionally, although the UAE currently has the highest capacity of 114 MW of operational data centers, Saudi Arabia is expected to become the regional leader when accounting for planned and under construction projects with an expected capacity of 529 MW [42]. The Kingdom currently accounts for 68% of the Middle East's planned data center projects in terms of MW capacity, announcing multiple projects and partnerships with key companies like NEOM [43] and Saudi Aramco [44].

With all of this infrastructure build-up, data centers will not only impact investments and compute capacity required for AI innovation, but they will also have a larger impact on our future energy landscape and climate goals. The expected additional power demand from large data centers will require substantial investments in electricity infrastructure, from transmission lines to new substations, as well as considering the increasing greenhouse gas (GHG) emissions if this demand is not met with clean or renewable sources of energy.

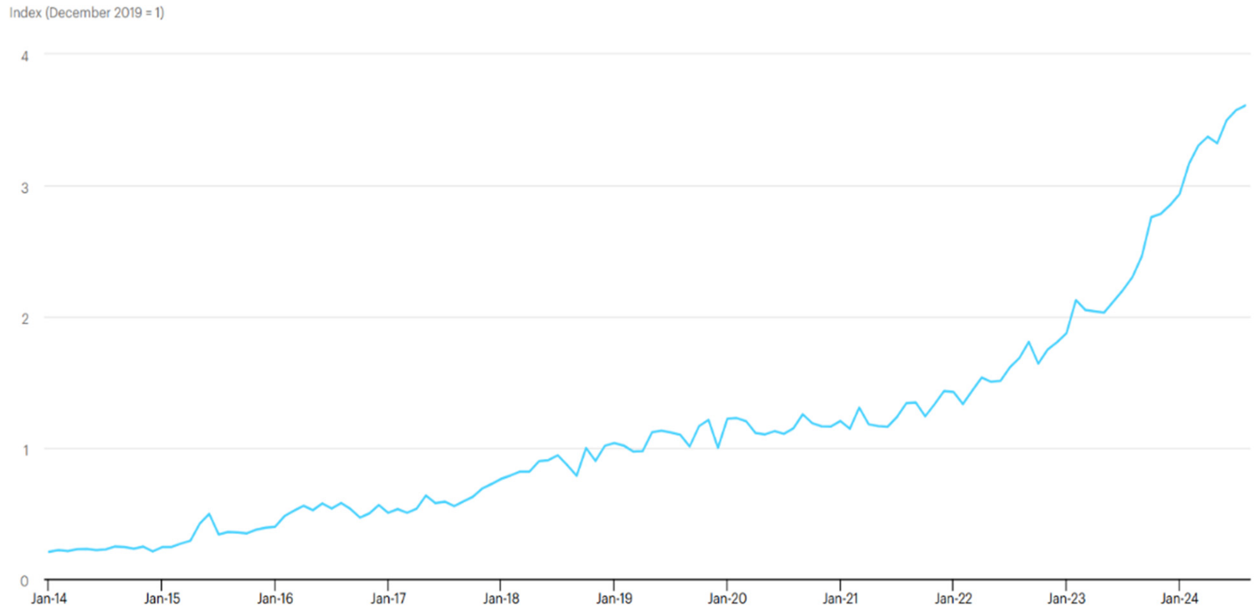

Figure 2. Investments in data centers in the U.S (Jan 2014–Jan 2024) [45].

3.2. The Rise of AI Infrastructure in Saudi Arabia

Data centers are rapidly becoming one of the most critical infrastructures of the 21st century due to their role in powering our digital world and storing critical data within national borders, which is crucial for ensuring data sovereignty and national security. With strategic policies and initiatives coupled with increased investments and transformations in the electric grid, KSA is emerging as a key player in the global digital economy. The country's vast energy resources and its commitment to investing in the AI space through the National Strategy for Data & AI, make it an ideal destination for data center investments. According to Bloomberg, the Kingdom is increasing the number of data centers by a compounding annual growth rate of 37% through 2027 [46]. As of 2023, Saudi Arabia had 123 MW [47] of data center capacity and is planning to expand capacity by 672 MW, as shown in Figure 3 [48]. Whether we look at the pace of growth in new projects capacity in global or regional terms, the growth in KSA is larger than the expected global growth of 15% [49].

A favorable regulatory environment and clear policy direction can play a big role in making Saudi Arabia a hub for AI infrastructure and data centers, but one of the most compelling advantages for data center investors and operators in the Kingdom is low energy costs and grid reliability. The electricity tariff for cloud computing is 0.48 USD per KWh [50], which is low compared to the global average, and one of the main challenges to increased data centers demand is the grid interconnection request queue [51]. As demand from data centers increases, grid operators are faced with a choice of connecting new projects after evaluating whether the existing network has the supply capacity required to meet expected demand. The interconnection queue can become a significant challenge if system operators do not invest in new grid expansion projects to handle the planned growth in demand. This is considered a challenge for utilities, especially since investing in transmission projects can be costly. Based on interconnection.fyi (accessed on 22 May 2025), a web site that tracks active grid connection requests in the US, there are currently 38,941 pending requests to connect to the grid [52]. For its part, the Kingdom has announced large investments in grid upgrades, led by the Saudi Electricity Company, which plans to invest around 500 billion SAR by 2030 in transmission networks across the country [53].

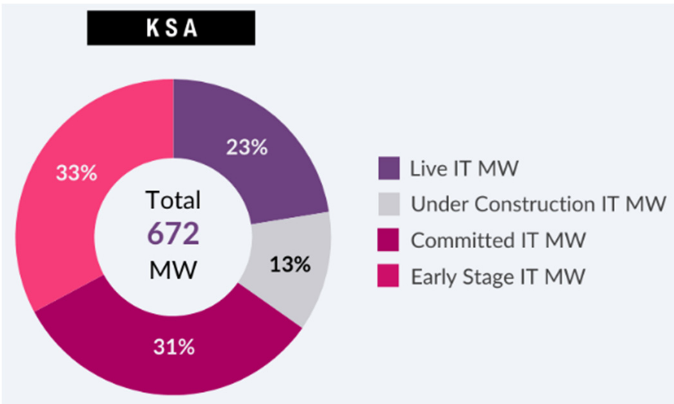

Figure 3. The growth of data centers projects in Saudi Arabia [54].

The current Saudi market is dominated by local firms like center3, a Public Investment Fund (PIF) backed company which has a total capacity of 111 MW [55]. However, global players are also taking notice of the growth and advantages the Kingdom can offer. In 2024, PIF and Google announced a partnership to establish an AI hub in Dammam [56], Microsoft also announced its data center region which is expected to be completed by 2026 [57] and at this year's LEAP conference, Groq announced a $1.5 billion project to expand the delivery of its AI inference infrastructure using its operational data center in Dammam [58]. More importantly and to ensure this growth does not collide with climate objectives and policy goals, Saudi projects are innovating in terms of sustainable solutions.

In early 2025, NEOM signed a 5 billion USD agreement with DataVolt, a Saudi operator of data centers, to construct a 1.5 GW data center located in Oxagon [59]. Based on the announcement by NEOM, the facility will operate at net zero utilizing the renewable energy capacity at NEOM and using advanced cooling technologies powered by renewable energy [60]. The project is in sync with the current government energy and climate policies, addressing the challenges of power demand and the carbon footprint posed by data centers. The project also addresses the Kingdom advantages in terms of access to large renewable energy projects, reliable grid infrastructure, and cheap electricity rates. One of PIF's major investments in AI is the establishment of Alat, which has pledged to invest a staggering 100 billion USD by 2030 across its 9 business units [61]. The electrification business unit will be focused on advancing transmission and distribution technologies [62]. The AI infrastructure unit aims to develop the entire infrastructure crucial for the development of AI solutions, including data center storage and networking equipment [63].

3.3. Saudi Arabia's Energy, Climate, and Technology Policy Landscape

The Kingdom of Saudi Arabia is embarking on a journey to transform its economy, and one of the main areas of focus is the Kingdom's latest efforts to become a hub for artificial intelligence. This push is estimated by Bloomberg to make Saudi Arabia the leading market for data center growth in the Middle East over the next three years [64]. At the same time, the Kingdom has adopted policies and initiatives such as the Saudi Green Initiative (SGI), which has set a goal to reduce carbon emissions by 278 million tons of CO_2 equivalent annually by 2030 [65], which is more than the amount of CO_2 emissions from the electricity sector in 2022 [66]. This is also an NDC announced by Saudi Arabia in

2021 [67]. By the same year, Saudi Arabia hopes to generate 50% of its electricity from renewable sources [68], paving the way to reaching net zero by 2060 [69]. So, how does this ambitious goal of becoming a hub for artificial intelligence in the Middle East intersect with the Kingdom's policies and initiatives in the climate and energy landscape?

3.3.1. Energy & Climate Policies

Blessed with rich oil and gas reserves, Saudi Arabia is a prominent player in electricity production. As of 2023, the Kingdom is ranked 11th globally in total electricity production and the largest in the Middle East [70]. With a total installed capacity of 91.1 GW in 2023 [71], and increased investments in grid technologies and transmission networks [72], Saudi Arabia is well positioned to assume a leading role in the era of artificial intelligence and big data. Since 2017, the Kingdom has started developing and implementing different policies and initiatives to address climate change challenges. Examples include the Saudi Green Initiative (SGI), the Middle East Green Initiative, the Circular Carbon Economy (CCE) framework, the National Renewable Energy Program (NREP), and the Saudi Energy Efficiency Program (SEEP).

In 2017, the Kingdom launched the National Renewable Energy Program (NREP), which aims to ensure that 50% of the electricity capacity comes from renewable sources and the other 50% comes from natural gas by 2030 [73]. NREPs efforts are showing progress in transforming the energy mix and the electricity generation segment by increasing the role of natural gas and shifting the bulk of generation from oil. This has translated into natural gas being the dominant generation source after 2017, this trend is shown in Figure 4. Although renewable energy still holds only 1.5% of total installed capacity in 2023, the Kingdom has embarked on multiple projects that could change the domestic energy landscape, with 23.5 GW of renewable energy projects under development across the Kingdom [74]. Adding to the efforts to increase renewable energy sources in the energy mix, the Saudi government announced plans to add carbon capture technologies to all new gas-fired power plants [75]. These policy efforts are translating in the field with an announcement by the King Abdullah University of Science and Technology (KAUST) and the Saudi Electricity Company (SEC) in November 2024 for a collaboration on developing the world's first carbon capture technology capable of capturing multiple pollutants in a single system at the Rabigh power plant [76].

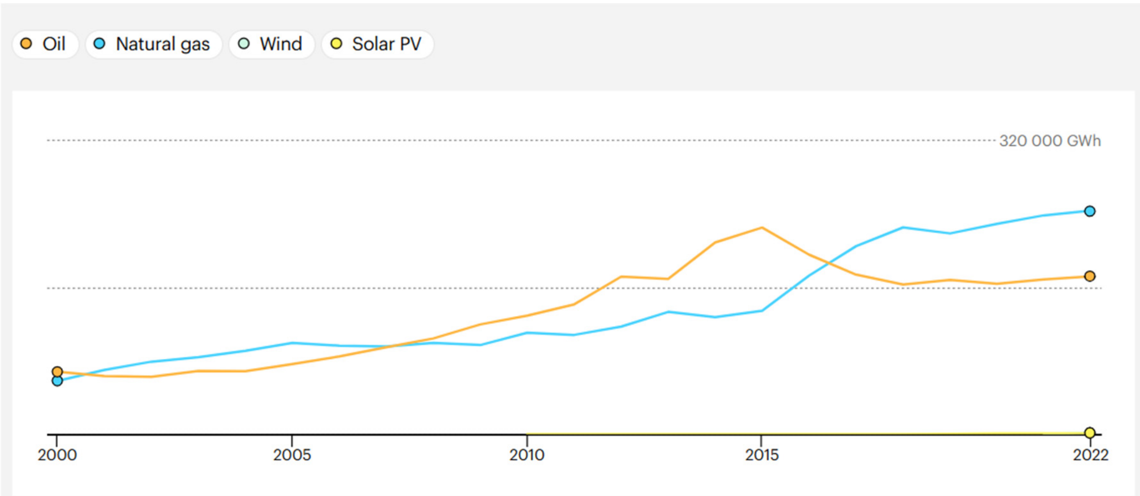

Figure 4. Saudi Arabia's electricity generation by source (2000–2022) [77].

As of 2022, the Kingdom had total GHG emissions of 532.8 million tons of CO_2 equivalent from the energy sector [78]. This puts the Kingdom as the tenth largest emitter of total and per capita CO_2 emissions globally and the second in the middle east in total emissions behind Iran [79]. As shown in Figure 5, almost 50% of total CO_2 emissions came from the electricity sector which is still heavily reliant on oil as a source of electricity generation [80]. Looking at these numbers, it makes sense for Saudi Arabia to focus its efforts on transforming the energy mix in the electricity generation segment.

In 2021, the Kingdom submitted its NDC target of reducing CO_2 emissions by 278 million tons of CO_2 equivalent annually by 2030 [81]. In the same year, Saudi Arabia launched the Saudi Green Initiative (SGI), which is an umbrella overseeing more than 85 initiatives with total investments of over 705 billion SAR [82]. SGI has three main areas of focus: emissions reduction, afforestation and land regeneration, and land and sea protection [83]. Under the emissions reduction goal, the Kingdom is targeting a reduction of 278 million tons of CO_2-equivalent annually by 2030 [84] and reaching net zero by 2060 [32]. Under this target are many initiatives ranging from increasing renewable energy capacity, enhancing energy efficiency standards across power generation, and becoming a global leader in the production of green hydrogen [85].

The role of renewable energy is crucial to ensure that negative climate side effects from increased data center demand are limited. To ensure renewable energy is better utilized in meeting the increased demand, the Kingdom of Saudi Arabia has launched one of the largest energy storage projects in the Middle East and Africa. With a capacity of 2 GWh, the Bisha Project is positioning the Kingdom to be among the top ten global markets in the field of battery energy storage [86]. By embracing grid-scale battery storage, the Kingdom now ranks third globally in announced battery storage projects with a capacity of 22 GWh, behind only China and the United States [87]. Through NREP, the planned storage capacity can reach up to 48 GWh by 2030 [88]. Grid-scale battery storage will play a pivotal role in supporting the expansion of renewable energy and transforming the energy mix, especially when global prices for grid-scale energy storage systems have declined by 73% since 2017, according to Bloomberg [89].

All of these initiatives position the Kingdom to lead the adoption of AI infrastructure in the region. The adoption of energy storage, investing in carbon capture technologies, strengthening grid infrastructure, and investing in grid solutions are essential to accommodate a significant share of intermittent renewable generation, ensuring a reliable power supply at a time of increased demand while progressing toward the announced climate policies and initiatives.

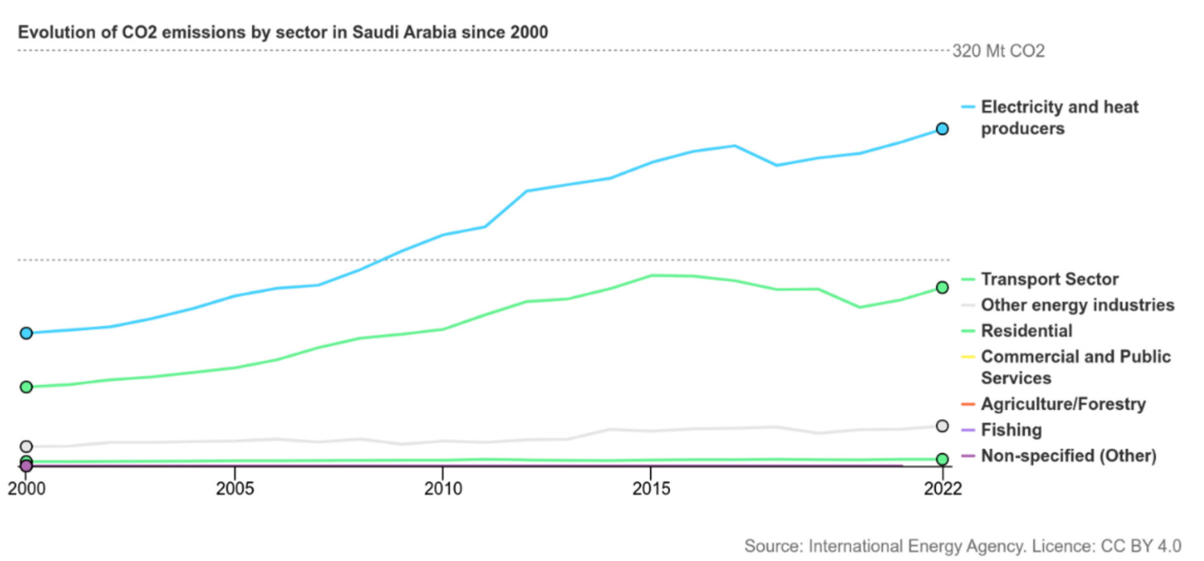

Figure 5. CO_2 emissions by sector in Saudi Arabia (2000–2022) [90].

3.3.2. Technology and AI Policy

Nations around the globe are rushing to adopt and develop frameworks and policies to take advantage of the new opportunities that AI can bring to economies and populations. To ensure its position among leading nations in the field of artificial intelligence, the Kingdom started its adoption of this technology by developing the Saudi Data & AI Authority (SDAIA), which is responsible for the organization, development, operation, research, and innovation in the field of data and artificial intelligence [91]. In October of 2020, SDAIA released the National Strategy for Data & AI with a number of ambitious goals to position the Kingdom among the top 15 countries in the field of AI and attract 75 billion SAR of investments in data & AI [92]. In September of 2024, SDAIA released the AI Adoption Framework which aims to establish guidelines for AI adoption across all sectors of the Saudi economy [93].

3.4. The Climate Footprint of AI Infrastructure

The growth witnessed and predicted in the construction of data centers is projected to increase energy consumption, water consumption, and GHG emissions. Other effects may include considerable strain on local power grids and difficulties in meeting climate targets. The role of data centers in the electricity system and the climate policy field is set to increase. Thus, policymakers and regulators must have the tools to understand this new driver of demand growth and its effects on climate targets and energy policy.

3.4.1. Energy Consumption and Greenhouse Gas (GHG) Emissions

The International Energy Agency (IEA) estimates the electricity demand from hyperscale data centers required for LLMs training to be 100 MW or more. This demand leads to a staggering annual electricity consumption equivalent to 350,000 to 400,000 electric vehicles [94]. As shown in Figure 6, the growth projection for data centers electricity demand is likely to account for a relatively small share of total global electricity demand growth by 2030 [95]. However, this increased demand will be more significant at the national and local levels in major data center markets. The sector will contribute to doubling the power demand in Texas by 2030 [96], and it has already surpassed 10% of electricity consumption in at least five US states [97]. In Ireland, data centers account for over 20% of all electricity consumption [98].

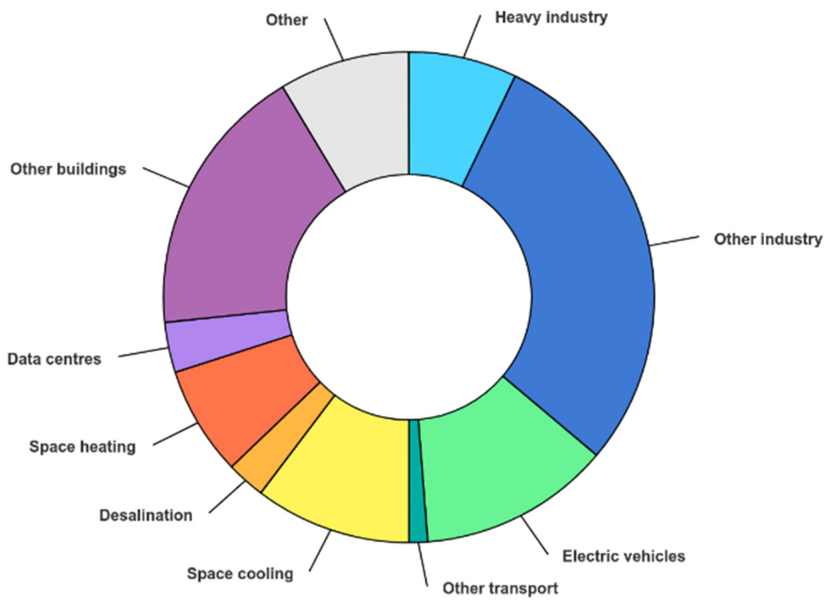

Figure 6. IEA Stated Policies Scenario projected global growth in electricity demand by use (2023–2030) [99].

2024 saw a rapid growth in global data centers installed capacity which increased by an estimated 20% (15 GW) [100], with the majority of this growth coming from the United States and China. This projected growth is most significant in advanced economies, which since 2009, have experienced relatively flat or declining electricity demand mainly due to increased efficiency gains in technology and appliances and the relocation of heavy industries to developing nations [101]. Starting from 2025, the IEA projects that advanced economies will witness electricity demand growth, thus reversing the trend of the past 15 years [102]. This growth is driven by higher consumption of different technologies, including the deployment of data centers [103].

Under the same report, the IEA projects demand from data centers to be the main driver of growth in the two largest global consumers of electricity, China and the United States [104]. A report released by the U.S department of energy (DOE) shows the significant growth of electricity consumption from data centers [105]. The report highlights that by 2023, Data centers accounted for around 4.4% of total U.S electricity consumption (around 176 TWh) [106], that's an increase from 76 TWh in 2018 (around 2% of total U.S electricity consumption) [107] and projected total data center demand in the U.S to account for 6.7% to 12.0% of total U.S. electricity consumption by 2028 [108]. Other major economies, such as the European Union, are also witnessing an increase in energy demand from data centers. In Ireland, a European hub for data center operators, data centers accounted for about 20% of total electricity consumption in 2023 [109].

When it comes to GHG emissions, today, data centers and data transmission networks are responsible for 1% of global greenhouse gas emissions [110]. Major operators are taking notice of the negative climate effects of future data center demand, and some are taking action to reduce these effects. In 2024, Microsoft announced a power purchase agreement (PPA) of 835 MW that will restart Pennsylvania's Three Mile Island nuclear facility, which was retired in 2019 [111]. Microsoft also signed an agreement with Powerex to match hourly datacenter demand in Washington state with electricity generation from hydro, solar, and wind sources on a 24-h basis [112].

3.4.2. Water Consumption

Unlike energy, water consumption is a main environmental side effect of data centers that is widely overlooked. AI data centers consume water through cooling towers to avoid server overheating due to the massive energy consumption [113]. Cooling towers rely on a process called evaporative cooling [114] which uses air and water evaporation to dissipate heat from the data center and it repeats continuously to maintain an optimal temperature [115]. This process requires a staggering amount of clean water, especially if data centers operate in humid or dry environments, which can add more strain to water-stressed areas.

It is estimated by the OECD that global AI demand will require 4.2–6.6 billion cubic meters (bcm) of water withdrawal in 2027, which is half of the United Kingdom's withdrawal [116]. Research published by Shaolei Ren at the University of California, Riverside, estimates that training GPT-3 in Microsoft's data centers consumed 700,000 L of fresh water in about two weeks [117]. This amount of water is about the same as that used in manufacturing 320 Tesla electric vehicles [99]. When multiplied by billions of its users, the total water footprint of AI becomes enormous [118]. An article by the World Economic Forum estimates that a 1 MW data center can use up to 25.5 million liters of water annually for cooling, which is the equivalent of the daily consumption of 300,000 people [119]. This water consumption can add to water stress in regions already facing shortages, like the MENA region.

3.4.3. The Impact on Saudi Climate and Environmental Policy

Like many revolutionary technologies, artificial intelligence can potentially transform and benefit humanity. AI's impact on science was highlighted in last year's Nobel Prize in Chemistry, which was awarded to Demis Hassabis and John M. Jumper for developing an AI model called AlphaFold2, which helped predict the protein structure [120]. Demis is the co-founder and CEO of Google DeepMind, the AI subsidiary of Alphabet, which was acquired by Google in 2014 [121]. This highlights AI's impact on science, medicine, and society by increasing productivity and promising new economic opportunities.

Saudi Arabia, with its long-term vision, wants to make sure it is part of this new revolution. According to PWC, the Kingdom is expected to be home to one of the largest economic gains from AI in terms of GDP growth [122]. Out of the 320 billion USD expected economic gains from AI in the Middle East, AI is expected to contribute to a staggering 135.2 billion USD in 2030 to the economy, which is equivalent to 12.4% of the Saudi GDP, behind only China, North America, and the UAE [123]. The report also highlights that one of the main reasons why Saudi Arabia and the GCC region are expected to lead the growth in AI adoption in the Middle East is access and investments in infrastructure [124].

As depicted in Figure 7, according to Mordor Intelligence, a market research firm, data center water consumption in Saudi Arabia is estimated at 20.2 billion liters in 2025 and is expected to reach 87.5 billion liters in 2030, which is a compounding annual growth rate of 34.1% [125]. It is important to note that the report does not differentiate between data centers used for AI training and other ICT data centers used for 5G. Operators in the Saudi private sector are taking notice of the water consumption challenge in data center cooling. In 2023, DataVolt partnered with AquaTech Systems, an Indian water technology company, to design, construct, and operate data centers with higher water efficiency using advanced cooling techniques and water reusage [126]. In 2024, ICS Arabia, a Saudi company specializing in the design, construction, and operation of data centers, started the construction of the Desert Dragon project with a total capacity of 187 MW. The project will be the first in the Kingdom to use the advanced immersive cooling technology for cooling the servers [127].

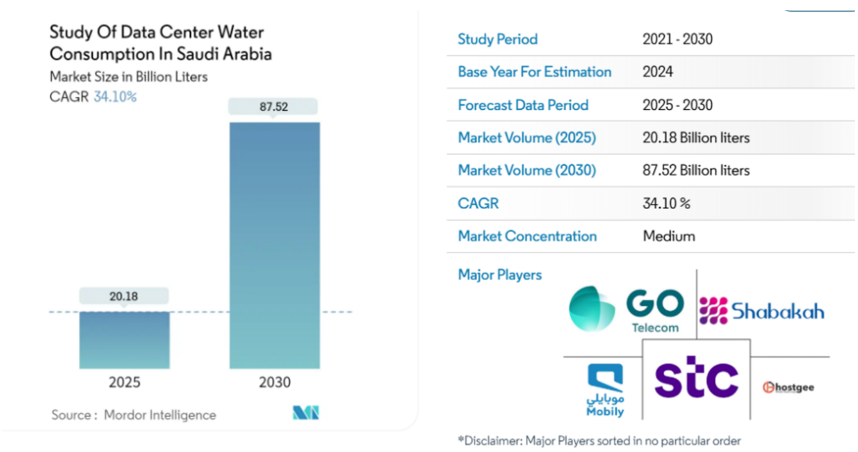

Figure 7. Data center water consumption in Saudi Arabia (2025–2030) [128].

3.5. Policy Tools and Recommendations

The potential for Saudi Arabia to digitize its economy and become a hub for artificial intelligence will make the Kingdom a leading market for data center growth in the Middle East. The Kingdom has multiple advantages from leadership ambition, a clear policy and regulatory environment, government-led investments in supporting infrastructure, and a favorable cost advantage in power prices. For KSA to capitalize on this opportunity and reap the benefits that this new technology will bring to its economy and citizens while ensuring it does not come at the cost of the climate, the environment, climate commitments, and energy strategy, some policy tools can be developed.

Incentivizing the private sector to build data centers in areas where access to renewable energy can have tremendous positive effects on meeting the increased demand. This policy can be similar to China's Eastern Data and Western Computing (EDWC) plan, which incentivizes meeting the computing demand with data center construction in areas with excess renewable energy [129]. This policy can enhance resource allocation by addressing the imbalance where some regions like Riyadh, Mekkah and the eastern region have high demand for computing power due to large populations and economic activity but face constraints on land crucial to developing renewable energy projects like solar energy, while regions like NEOM have abundant renewable energy resources and cheaper land. This policy can also promote development and economic growth across the country while ensuring that data center demand across the Kingdom is met sustainably and cost-effectively. This can also create data center hubs across the country and incentivize different regions to specialize in this specific industry.

The design of data centers is evolving, especially in terms of energy efficiency and water consumption. This is crucial, especially for countries with hot and dry climates. Data center projects in Saudi Arabia, such as the NEOM project, ref. [130] must be encouraged to adopt renewable energy sources and the most efficient technologies in power usage, water usage, and carbon emissions. A policy that ensures data centers built in the Kingdom are within specific standards in terms of average Power Usage Effectiveness (PUE) [128], average Water Usage Effectiveness (WUE) [131] and average Carbon Usage Effectiveness (CUE) [132] can ensure that policies do not just focus on growth in terms of MW capacity but also ensures the most efficient and sustainable growth while meeting compute demand.

One key issue relating to water usage in data centers is the major data center operators' lack of tracking of water consumption. A 2024 report published by the Uptime Institute found that only 43% of data centers track water use due to low priority in terms of cost and environmental considerations [133]. Requiring mandatory tracking methods by data centers operators can be a first step in addressing water usage by policy makers. For example, the EU Energy Efficiency Directive will require data center operators to report their water footprint [82], which is a major step in addressing this challenge and applying higher standards on data center water consumption.

There is a global gap in collection and reporting of data center sustainability metrics [134]. Although operators are inclined to report on total power consumption and PUE, these metrics do not show the complete picture of the environmental effects of data centers and are not adequate to track climate and sustainability effects. Energy-related metrics are mostly tracked due to their direct impact on the operational costs of data centers and business performance. That is why it's crucial to introduce a policy that mandates the reporting and verification of all environmental and sustainability-related metrics. These metrics can be water usage, the percentage of renewable energy used, the reliability of on-site generation, recycling of equipment waste, and carbon emissions. Reporting these metrics will encourage local and international investors to construct data centers using the most efficient technologies while allowing policymakers to better assess and track data centers on climate policies.

Encouraging the use of new existing technologies that can lower the energy and water demand, like direct chip liquid cooling [131], full immersion cooling, using wastewater for cooling [135], and water recycling [136] through collaborations and partnerships, will minimize water consumption, especially in the Saudi hot climate. This can be done through research and development (R&D) partnerships with main companies and universities [137]. A policy encouraging R&D with Saudi universities in the field of data centers water and energy efficiency can make sure that new technologies are developed with a focus on the future ambitions in the field of AI while tackling the climate and environmental challenges of the Kingdom.

Breaking global records in the lowest prices for solar [138] and wind [139] energy, the Kingdom is well-positioned to meet any demand growth from clean energy. A policy that encourages data center operators to use renewable energy or clean energy to meet their growing demand is important to ensure that the Kingdom can reach its NDC and other climate goals. Although the Saudi energy policy has succeeded in increasing private sector participation in developing renewable energy projects through power purchase agreements (PPA) [140], expanding the scope of this policy and allowing PPAs to be signed directly between private sector participants can further encourage the development of renewable projects to meet the growing demand for data centers. One example is Microsoft's agreement to restart the Three Mile Island nuclear reactors after years of shutting down [141].

This 20-year PPA, which is intended to provide energy to Microsoft's data centers, is expected to add 835 MW to the grid [142]. When secured via a PPA, renewable energy projects can provide long-term energy cost stability for data centers and add more renewable energy to the market. The Kingdom also focuses on developing its hydrogen production through Saudi Aramco [143] and NEOM, which is developing the largest green hydrogen project in the world [144]. Hydrogen is already being used to power data centers in California and operators in Saudi Arabia can benefit from the country's push to be a global producer of Hydrogen and develop the local market.

Lastly, introducing a demand response program [145] for data centers can help in meeting the demand growth, while ensuring minimal effects on the Saudi grid. It can help the grid operator in planning future generation capacity. Demand response programs can be a critical tool in helping reduce the need for investment in new generation sources and improve grid operations by incentivizing data center operators to reduce their energy usage during periods of peak demand [146]. Data centers can adjust their operations to low-demand hours without impacting their performance, especially in the summer months [147]. By participating in demand response, AI data centers can lower the pressure on the grid, especially during high-demand periods, like summer afternoons or during the Hajj season. This can balance supply and demand, prevent power outages, ensure grid reliability, and avoid the challenges of increased interconnection queues observed in other countries [148].

4. Conclusions

Policymakers should promote EVs and other electrification in areas of high carbon intensity of the power sector, but not in isolation. EVs and electric heat offer the biggest environmental advantages when the power sector decarbonizes, but they still deliver efficiency and better air quality locally in the short term. It is a dual strategy that deeply cleanses the electricity generation and boosts the electrification to meet the climate goals [149]. It guarantees that early electrification is not paid at the price of negative impacts. Waiting for a completely green grid before introducing EVs could retard sizeable benefits and hinder the reformation of vehicle and appliance markets [150]. On the other hand, electrification can be a strong enabler of renewable investments and grid upgrades, meeting increasing electricity needs with a clean energy supply.

Primary emission reductions from EVs or heat pumps in coal-heavy grids are likely to be small at first. However, these technologies pave the way for much larger future savings as the grid decarbonizes. Regions benefit immediately from reduced urban particulate air pollution and oil usage when shifting to electric end uses, reinforcing the action case. It is not a matter of selecting between EV and Grid Decarbonization, but how it can be harmonized. Stacking EV incentives on top of renewables requirements and shutting down coal plant emission caps shows synergy.

Electrification is a core element of any major deep decarbonization pathway [151]. Regional holders of a power system with a high carbon content have no reason to be afraid of EVs or electric devices, but rather an incentive to transform their power generation system simultaneously. That way, EVs and electrification are treated as a genuine climate solution, not just an emissions substitute. Those regions can profit from fast electrification as coal is retired and clean energy takes the lead. They reap the entire climate benefit of EVs and swift benefits from new air quality and energy security. In short, promoting electric vehicles and other electrification, supported by a large effort to decarbonize the grid, is sensible and needed for a sustainable future, especially in places with a very carbon-intensive grid.

The definitions of the abbreviations in this paper are shown in the Table 1 below.

Table 1. Definitions of the abbreviations.

Abbreviation	Definition
AI	Artificial intelligence (AI) is a set of technologies that enable computers to perform a variety of advanced functions, including reasoning, decision making, data analysis, make recommendations, and more [152].
PPA	A Power Purchase Agreement (PPA) is the contract made between a public sector purchaser "offtaker" and a privately-owned power producer. It usually provides the primary revenue stream which underwrites public-private partnership projects in the power sector [153].
NDC	Nationally Determined Contributions (NDCs), are countries' self-defined national climate pledges under the Paris Agreement [154].
GPU	A Graphics Processing Unit (GPU) is a specialized electronic circuit designed to perform vast numbers of calculations rapidly handling data-intensive and computationally demanding tasks. GPUs are key to the wide adoption and evolution of artificial intelligence systems [155].
EV	Electric Vehicles (EV) are vehicles powered by a battery and an electric motor [156].

Author Contributions

Conceptualization, R.L.-A.; Methodology, R.L.-A.; Formal Analysis, M.A. and N.A.; Resources, M.A. and N.A.; Data Curation, M.A. and N.A.; Writing—Original Draft Preparation, M.A. and N.A.; Writing—Review & Editing, R.L.-A.; Supervision, R.L.-A.; Project Administration, R.L.-A.

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Not applicable.

Informed Consent Statement

Informed consent was obtained from all subjects involved in the study.

Data Availability Statement

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The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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