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THE IMPACT OF TECHNOLOGIES AND GREEN SMART INITIATIVES ON CARBON EFFICIENCY IN URBAN AREAS

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DISSERTATION: LITERATURE REVIEW

THE IMPACT OF TECHNOLOGIES AND GREEN SMART INITIATIVES ON CARBON EFFICIENCY IN URBAN AREAS

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I declare that this dissertation is my own work, and that where material is obtained from published or unpublished work, this has been fully acknowledged in the references.

Signed: Marios Fokas Tsamichas 20/01/2022

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LIST OF ABBRIEVIATIONS

CO_2	Carbon Dioxide
GDP	Gross Domestic Product
HDI	Human Development Index
ICT	Information and Communication Technologies
FE	Fixed Effects estimator
DK	Driscoll-Kray estimator
GMM	Gaussian Mixture Modelling
GTFP	Green Total Factor Productivity Index
DiD	Difference in differences statistical technique
2SLS	Two-Stage least squares regression model

1. Introduction

The fast-paced urbanization, and continuous advancement of the industrial sector in urban areas have led to the Environmental crisis becoming more prominent than ever as the COP26 conventions have highlighted earlier this year. One of the main sources of the climate change, that the global community is currently and widely acknowledging and aims to tackle, is the immense amount of CO_2 emissions being produced and accumulated in our planet's atmosphere leading to detrimental effects on the natural environment whose "well-being" is proven to be strongly correlated with both the planet and humanity's prosperity.

The scientific, governance and entrepreneurial communities have dedicated immense resources in finding solutions regarding the mitigation of human impact on the environment and more specifically the reduction of humanly produced CO_2 emissions according to SDG goals set by the UN to reach net-zero carbon emissions by 2050 (United Nations, 2020). It appears that humanity's progress and advancement have been, so far, identified and are strongly interconnected with the development of urban and industrial centers whose functional activities provide goods and services to the global community according to demand and supply.

However, this rapid urbanisation and industrialisation has been found to be the main source of humanly produced CO_2 emissions.

The past few decades there has been a collective coordinated movement by the scientific community, governance institutions and partly by businesses to tackle the above issues through innovation, technological applications, policies, and environmental initiatives. The scientific community alongside sustainability and tech related sectors are pointing in the direction of development of spatial technologies that can accurately measure the impact of human activity on the environment, replace previous fossil fuel dependent infrastructures, and to efficiently reorganise the urban ecosystem as to continue to provide us with services and products that are deemed essential or demanded, whilst mitigating carbon emissions. Some of the technologies with the above goals and characteristics that this dissertation aims to evaluate are Smart Cities and their Green, Sustainable applications.

Smart cities and smart infrastructure are relatively modern concepts that have recently attracted a lot of attention in terms of climate change mitigation, international governance policies, management of urban areas and business opportunities. As it will be discussed in the main body of this dissertation, past research and discussions are conflicted on whether the development of such ICT applications can promote the enhanced organization of urban areas as well as the mitigation of crisis and disruptions that affect them and their surrounding areas. With climate change being in the epicenter of global priorities, specific ICT technologies are being continuously developed to mitigate climate change effects and particularly the production of CO_2 emissions. Nevertheless, ICT's that are organized and directed specifically to provide solutions in urban areas such as cities, namely Smart Cities, are yet to be clearly defined and results of their impact are still inconclusive.

2. Literature Review

The aim of this dissertation is to evaluate the impact of Technology and particularly the development of Green Smart Cities and Smart Infrastructures in urban agglomeration in terms of mitigation of carbon emissions and potentially address question on how their development influences the socioeconomic and environmental development for the areas applied on. This will be achieved by firstly reviewing literature that evaluates the relationship between the urban areas and agglomerations and their carbon emissions efficiency and secondly by assessing literature on sustainable smart technologies, under the concept of Smart Cities initiatives and policie, and their potential to aid in the reduction of emissions in urban areas. This literature review will be deemed successful and fruitful in terms of proceeding to the empirical investigation of the topic by providing evidence and results from existent literature that suggest meaningful correlations and connections of the above concepts.

2.1. Urban areas and CO_2 emissions

The past decades a plethora of articles, papers and research have exhibited conflicting results regarding the relationship between urban areas and their CO_2 emission efficiency. In Fragkias et al.'s (2013) paper it is mentioned that large urban areas are indeed one of the main sources of CO_2 emissions, due to their large populations and high intensity socio-economic activities that are in higher demand for energy and fuel consumption. Yet they exhibit to only be slightly more efficient than smaller ones, thus highlighting the existence of a paradox of large cities and urban areas not exhibiting economies of scale, as expected, in terms of CO_2 emission efficiency (Fragkias , Lobo, Strumsky, & Seto, 2013).

In opposition to Fragkias et al. (2013)' findings, a spatial econometric analysis of the Yangtze River Delta urban agglomeration in China by utilising the STIRPAT model found that the size of an urban area has had a substantial negative correlation to CO_2 emissions, meaning that urban agglomerations may be more emissions efficient in comparison to other areas. More specifically, this analysis shed light on some of the driving forces of CO_2 emissions such as technological advancement, mobility, connectivity, and population, that not only affect the are urban area they describe but also exhibit spatial agglomeration and spillover effects to surrounding areas. Meaning that in an urban agglomeration the CO2 emissions' driving factors and impact of a city are also co-dependent to its surrounding cities and areas (Yu, Wu, Zheng, Li, & Tan, 2020).

If we take into consideration the expected increase of 68% of the world's populations will be residing in urban areas by 2050 (Ritchie & Roser, 2018) it can be assumed that a surge of demand for urban infrastructure and energy consumption will occur, two factors that are major contributors to CO2 emissions. In their paper Zhang, Song and Yang (2021) found that all three FE, DK and GMM models, utilised in their paper, indicated a significantly positive relationship between urbanisation of resident population and CO_2 emissions across various regions in China (Zhang, Song, & Yang, 2021).

The above can also be supported and further enhanced by Hang's and Yuan-sheng's (2012) paper that found that there is a significant positive correlation between CO_2 emissions, and additional factors -besides population and urbanisation- such as economic scalability, technology, and income all of which are characteristics of an urban agglomeration with rapid urbanisation and industrial development rate. It is also critical to mention that their findings support that innovation and new technology had only initially a positive effect on carbon emissions, while at later stages through technological improvement and integration of sustainable elements the effect on CO_2 emissions was negative. (Hang & Yuan-sheng, 2011).

The above findings are of major importance as to understand what environmental technologies and policies can promote carbon emission efficiency in urban agglomeration and how can CO_2 abatement be achieved (Barido & Marshall, 2014).

2.2 Technology, Policy and CO_2 emission efficiency of urban areas

Since a relationship between urbanisation and CO_2 emissions has been thoroughly established through past literature, the growing concerns about climate change and global warming have turned the attention to the inefficient management of natural resources and energy usage in urban areas, the centres of urbanisation and industrial development. This section aims to shed light on the economic and spatial effects of environmental policies of both regulatory and technological nature on carbon emissions and finally on the economic development levels of an urban agglomeration.

2.2.1 Technology and urban areas

In terms of the influence of technology on emissions the existing literature's findings are mixed. More specifically, literature such as Samargandi's (2017) paper has found that technological innovation in Saudi Arabia's urban and industrial areas increases investment especially in the urban and industrial sectors, thus leading to more consumption of energy and consequently the production of increased carbon emissions. Moreover, this paper highlights the relationship between economic significance of industrial and energy-led sectors in Saudi Arabia in terms of GDP and their continuous growth in CO_2 emissions. Meaning that urban and industrial areas' economic and technological development has had a substantial effect on their carbon emissions (Samargandi, 2017).

In Stern's (2018) paper it is being mentioned that Environmental Kuznets curve exhibits a trend that associates the increase of per capita income with an increase of pollution emissions until a point (figure 1), where the trend exhibits diminishing marginal effects where a high per capita income and high economic growth lead to emission decrease (Stern, 2018). If we consider Pew Research centre's (2014) study that exhibits a strongly positive relationship between high GDP per capita and technological adaptation, it can be deduced that further technological development in urban agglomeration with intense industrial activities ultimately reduces CO_2 emissions (Pew Research Center, 2014).

Complementary to this paper, Sagar's (2002) study documented that further technological enhancement of production and service processes reduce the carbon emissions by increasing energy efficiency and production of clean and renewable energy, without harming economic gains and development. Nevertheless, it does not fail to mention the need for a more systematic effort to better understand the global energy innovation system and the challenges behind developing such energy efficient technologies (Sagar & Holdren, 2002).

Dauda et al. (2019) also mention implications that arise from the place-bound context in which technological development is induced, such implication is that emissions mitigation innovations indeed reduce carbon emissions in developed countries, but this is not the case for the developing world. Additionally, economic development levels as well as spatial characteristics of an area play a significant role in the impact of technological innovation on CO_2 emission abatement (Dauda, Long, & Mensah, 2019). Thus, it can be highlighted that there is a need for systematic research of both the specific sustainable technologies that enable high levels of carbon emission efficiency, in order interpret their environmental, economic, and spatial effects more precisely as well as the geographic and socio-economic characteristics of the areas they are being applied to.

2.2.2. Smart Infrastructures, and carbon emissions in urban areas

In continuance, this section aims to present links and relations among existent literature on the basis of technological innovation such as ICT's (Information and Communications Technologies) in the form of sustainable smart infrastructures, their results in terms of carbon emission's efficiency and mitigation and their potential impact in urban areas and agglomerations.

Both the literature, institutions and industrial sector have indicated that Smart Cities and Infrastructure may be imperative for the sustainability of our planet, by measuring, optimising or even solving challenges that have arisen from decades if not centuries of inefficient resource management (Toli & Murtagh, 2020). Since the larger percentage of environmental harm and carbon emissions have been attributed mostly to urban centres and agglomerations, it can be deduced that they should be the point of interest when it come to the application and impact of such technologies.

In general, as mentioned in the paper my Angelidou (2014), "Smart Cities represent a conceptual urban development model based on the utilization of human, collective, and technological capital for the enhancement of development and prosperity in urban agglomerations" (Angelidou, 2014)**.**

In this section it is important to distinguish our focus from the plethora of different variations of smart cities and infrastructures, depending on their particular applications. This review, similar to the one by Albino, Berardi and Dangelico (2015), will be essentially focusing on their green and sustainable counterpart applications of ICT's that mitigate carbon emissions, through the means of optimisation of existent services and production processes in cities and their neighbouring areas, namely Urban Agglomerations (Albino, Berardi, & Dangelico, 2015).

Firstly, various paper from Auci & Mundula (2012), Bria (2012), Paquet & Roy (2001) agree upon the fact that technological innovation and more specifically smart city strategies can be more effective in strategically chosen urban areas due to spatial attributes and geographical locus technology has.

Kaluarachichi's (2020) study found that Smart City initiatives in the urban sectors of Transportation, Urban planning and construction have the potential to improve air quality and cities and mitigate CO_2 emissions significantly (Kaluarachchi, 2021). For example, ONS indicates that transportation is one of greatest contributors of carbon emissions in the UK, and Smart Mobility initiatives have the potential to reduce traffic and increase sustainable means of transport through electric vehicles, car sharing, cycling and others. In the field of asset management smart technologies have the capacity to provide various stakeholders with information in real-time that enable the development of carbon-free infrastructures and the efficient management of energy and resources as to mitigate air pollution and carbon emissions specifically

(Jenny, Diaz, & Ocampo-Martinez, 2019). As declared by the Department for International trade, UK leads in Green Asset management through the utilisation of green smart city technologies that aids in the identification of low-carbon and sustainable investment opportunities.

Even though literature on the performance of smart cities on decarbonisation is limited due to fact that their emergence is recent and large-scale applications are still under development, there are cases of cities of Masdar, Morocco, Hong Kong, Taipei, Copenhagen, and Barcelona that have achieved low-carbon emissions by utilising smart city and ICT applications. In Sankaran and Chropra's (2020) case study of Masdar city in Abu Dhabi, it has achieved 0% of carbon emissions by investing in its Smart city future and developing a smart transportation and urban planning system as well as an energy grid that utilises clean and renewable energy sources to cover the energy demands of the city and its 40.000 citizens (Sankaran & Chopra, 2020). Positive results, in regards to city decarbonisation, have been exhibited by Amsterdam Smart City and multiple of its initiatives such as Climate Street that have achieved a reduction of 8* of Carbon emissions through energy savings and another 10% by switching to green energy, while its objective is to reach at further 14% of energy consumption and CO2 emissions reduction (Mora & Bolici, 2015).

In Chu et al. (2021) it is mentioned that Smart City development increase the potential of an urban area to reduce its carbon emissions (Chu, Cheng, & Yu, 2021). Specific examples are presented in Curiale's (2018) paper such as Smart Grid initiatives that include the empowerment of Smart Mobility through Electric Vehicles that can drastically reduce and even halve carbon emissions that are attributed to fossil fuel in urban areas. An additional application is the integration of LED smart lightning in the overall ecosystem of a smart city that has the potential to reduce a city's budget on energy needs up to 40% that can be translated into reduction of demand for energy consumption and fossil fuel, thus consequently leading into mitigation of CO_2 emissions especially from carbon intense resources (Curiale, 2014).

On the contrary, Ipsen et al.'s (2019) paper found that in Copenhagen the overall Smart City solutions have limited positive impact on the environmental sustainability performance as the polluting burdening factors are shifted from directly observable impacts to embedded ones that are often out of sight and hard to monitor (Ipsen, Zimmerman, & Nielsen, 2019). Nevertheless, it is indicated in Hoang et al.'s (2021) study that applications of Smart Cities such as Smart Grids that integrate renewable energy systems are the ones to be the most impactful in terms of decarbonisation and potential for enhanced economic growth in urban areas (Hoang, Pham, & Nguyen, 2021). This is achieved through the ability of the above technologies to either shift more efficiently to renewable energy sources or reduce the energy consumption levels of urban areas (Mardoyan & Braun , 2015). Specific examples of applications and their results of the abovementioned technologies are depicted in figure 1 in the Appendix (Hoang, Pham, & Nguyen, 2021).

The study and research conducted by Hoang et al (2021) has essentially determined that reliability, energy efficiency, and integration of low carbon energy technologies that regulate supply and demand of energy are among the main attributes of green and sustainable smart cities. The interconnection of multiple energy sub-sectors, such energy that supports urban utility needs (e.g., Electricity, Gas, heat etc.) has been enabled by the synergetic and viable symbiosis of these sub- systems through the infrastructure of smart sustainable ecosystem, the Smart City. Consequently, it can be deduced that there are immense opportunities that occur by integrating Smart Grid, Smart Mobility, Green Urban Planning and Renewable Energy into Smart Cities (Hoang, Pham, & Nguyen, 2021).

Regardless though of potential impact and economic related gains, Ruggieri et al. (2018) point out that transitioning to a Smart City environment in terms of infrastructure and technological applications in urban areas require multi-year development, management and financial and cultural investments that are empowered and enabled through effective environmental and sustainable policies on a local and national level (Ruggeri, Ruggeri, & Vinci, 2020).

2.2.3. Policy

Based on the above findings, Smart Cities and ICT applications in urban areas also incorporate the guidance and practices of local and international institutions, authorities and governance entities that facilitate the development of such infrastructures and technologies. Meaning that targeted and coordinated environmental and green policy is an essential aspect of the development of Smart Cities.

Yigitcanlar & Kamruzzaman's (2018) investigation of 15 UK cities that exhibit various levels of sustainable "Smartness" resulted in inconclusive and ambiguous results regarding their ability to abate carbon emissions. However, their investigation and analysis highlighted lack of availability of data and insufficient or one-sided policy making. More specifically, it is mentioned that efficient Smart City development should incorporate policies that take into consideration the economic, socio-cultural, spatial, and institutional development of the urban areas it is intended to be applied upon (Yigitcanlar & Kamruzzaman, 2018).

The above suggestions can be deemed valid especially if the "youth" of Smart Cities and lack of empirical investigation are being taken under consideration. More specifically, Barido & Marshall's (2014) Journal found through regression models that estimate carbon emissions as a function of agricultural land, energy consumption, income, and urbanisation, that in areas that practice stronger environmental policies, urbanisation has a significant positive effect on carbon emission reduction and vice versa (Barido & Marshall, 2014). Thus, exhibiting that environmental policy's results, such as those of Smart City initiatives, vary depending on both policy intensity levels and spatial characteristics of the specified areas such as size, population, and urbanisation rate. Additionally, Barido & Marshall's (2014) findings shift the focus from developed to developing countries that exhibit fast paced urbanisation but lack sustainable policies that regulate their carbon emissions. The above partly justify the fact that a handful of Smart City applications in the developing world are not deemed to be "fruitful" in mitigating CO2, something that many studies support. Finally, Xin & Qu's (2019) findings from Quasi-Natural experiment in China show that the size of the urban areas that Smart City policies are integrated to play a significant role, on the one hand Large cities are enabled to vigorously develop such technologies and facilitate high-intensity urban functions that can sustain carbon emission reduction while smaller sized cities are able to fully utilise targeted and specialised smart applications according to their needs, specific inefficiencies and ultimately maximise carbon emission efficiency. Additionally, their findings highlight that overall sustainability and environmental functions of Smart City Policies can significantly improve urban

GTFP, without however exceeding the appropriate investment scale as unwanted and harder to observe spatio-temporal effects may occur (Xin & Qu, 2019).

3. Research Question

Smart Cities and ICT applications have been the central subject of discussion among academic literature, governance institutions and industrial sectors as to the potential benefits they are claimed to be able to provide. Such are efficient urban planning of cities, and the optimisation of many of their processes that are needed to offer quality of life and a sustainable environment to their citizens. As it can be observed from the above review, the existent literature and its findings have been so far inconsistent if not contradictory in terms of how Smart Cities aid in the abatement of carbon emissions in urban areas. It can be deduced that asymmetric information and lack of integrated models that include multidisciplinary data, variables and instruments are some of the main implications that stand in the way of accurately assessing the impact of Smart Cities on the carbon emissions efficiency of urban areas. The determination of carbon emissions in an urban area is much more complicated to be attributed only to a single factor, thus assessing the impact of a complex technological, environmental, spatial, societal and governance structure such as a Smart City is much more sophisticated. Thus, it is logical to propose the formulation of a spatial-econometric model that will integrate as many of the facets a Smart City is consisted of as possible by using multidisciplinary data sources (Papastamatiou, Marinakis, Doukas, & Psarras, 2017). The added value of the proposed methodology lies on the combination of spatial characteristics of an urban area (e.g., size, proximity to nearby cities), demographic characteristics (e.g., population, density, urbanisation rate), socio-economic characteristics (e.g., GDP per capita, HDI), environmental characteristics (e.g., CO_2 emissions, energy consumption, source of energy) efficiency and governance and political characteristics (e.g., Environmental Policy Stringency Index) (Johnstone, Haščič, Poirier, Hemar, & Michel, 2012).

Assuming the availability of the above data, it is proposed to conduct an empirical investigation on the carbon emissions levels of urban areas before and after the development of Smart City and Smart Policies, through a DiD model and the utilisation of regression models such as 2SLS. The second proposed methodology is the investigation of possible correlations between urban areas, that exhibit a negative correlation of carbon emissions and smart city technologies and policies, and their surrounding areas as to determine the effect of Smart cities on urban agglomerations. The final proposition regards the highlighting of a potential linkage between the correlations found in the previous methodologies and economic development levels of both urban areas and their surroundings.

4. Conclusion

Overall, by putting forth, linking, and comparing the abovementioned, the lack of empirical evidence, the modernity and the conservatism have highlighted the need for holistic and multidisciplinary approach of the topic (Aslam , Salman, Irfan, & Jabeen, 2018). Through the obtaining of newly acquired data from various sources, integrated models can be formulated that even though may lack accuracy they will shed light further on the potential impact of Smart Cities on urban areas and their surroundings' carbon emission efficiency and sustainability related economic development. Criticism on these technological and governance structures cannot be disregarded, however by having Ahvenniemi et al.'s (2017, p.242) saying below as compass for the further development and enhancement of these smart green initiatives this review stands optimistic on their future potential and impact on urban areas and their emission performance.

"The role of technologies in smart cities should be in enabling sustainable development of cities, not in the new technology as an end in itself. Ultimately, a city that is not sustainable is not really smart" (Ahvenniemi, Huovila, Pinto-Seppa, & Airaksinen, 2016).

5. Appendix

Country	Design objectives	As-used models	Goals	Year	Ref
Hong Kong	Cost	TRNSYS	Nearly-zero-energy building	2015	Sun (2015)
Switzerland	Environment, energy consumption, grid interaction	Energy hub	Integration of decentralized energy systems	2015	Orehounig et al. (2015)
China	Environment, cost, energy consumption	Fuzzy algorithm	CCHP system	2016	Li et al. (2016)
Finland	Energy consumption, cost	Energy hub	District energy system	2016	Sepponen and Heimonen (2016)
Spain	Energy consumption	TRNSYS	Centralized poly-generation System	2016	Soutullo et al. (2016)
Hong Kong	Life cycle cost	TRNSYS, GA	HVAC system for commercial buildings	2016	Cui et al. (2017)
Italy, Denmark	Energy consumption	EnergyPLAN	Cross-border system and cross-sector system	2017	Thellufsen and Lund (2017)

Country	Design objectives	As-used models	Goals	Year	Ref
Italy	Environment, cost, energy consumption	EnergyPlus, MATLAB, GA	Building energy system	2017	Ascione et al. (2017)
Iran	Total net-cost	Energy hub, mixed-integer nonlinear programming, GA	Multi-energy micro-grid system	2017	Amir et al. (2017)
United Kingdom	Energy consumption	TRNSYS	HVAC system	2017	Diallo et al. (2017)
France	Cost, energy consumption	TRNSYS	Home energy system	2018	Ferrara et al. (2018)
China	Environment, cost, energy consumption	Mixed-integer nonlinear Programming	CCHP system	2018	Zheng et al. (2018)
Indonesia	Environment, cost, technical Performance	SuperPro Designer /UniSim Design	Municipal Solid Waste to Electricity	2018	Octavianthy and Purwanto (2018)
Germany	Energy consumption	MPC/RBC	Power-to-gas	2018	Fischer et al. (2018)
Croatia	Environment, cost, energy consumption	EnergyPLAN	SES with 100% RE	2018	Bačeković and Østergaard (2018)
India	Cost, energy consumption	TOPSIS MADM	Hierarchical architecture of an SES	2019	Ahuja and Khosla (2019)

Country	**Design objectives**	**As-used models**	**Goals**	**Year**	**Ref**
India	Cost, energy consumption	ANN	Efficient lighting	2019	Mohandas et al. (2019)
Ghana	Barriers, cost	Two-step fuzzy DEMATEL	Smart energy city	2019	Addae et al. (2019)
United Kingdom	Smart energy management	Computational Intelligence/Machine Learning	SES	2019	O'Dwyer et al. (2019)
Korea	Economic and energy efficiency	MRESES	100% Electrified and hydrogen cities	2020	You and Kim (2020)
Denmark	Techno-economic analysis	TRNSYS	PVT-based smart energy	2020	Behzadi et al. (2020)

Figure 1 - (Hoang, Pham, & Nguyen, 2021)

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