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Bao-Jie He · Deo Prasad · Gloria Pignatta ·
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Climate Change and Environmental Sustainability

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Climate Change and Environmental Sustainability

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Climate Emergency, Actions and Environmental Sustainability

Bao-Jie He, Ayyoob Sharifi, Chi Feng, Jun Yang, Deo Prasad, Joni Jupesta, and Gloria Pignatta

Abstract

The global climate is ever-changing, and climate-induced disasters are getting into a new normal. To address climate change and associated consequences, it is urgent to take actions for mitigation and adaptation. This chapter analyses the background of climate change and international frameworks for actions in terms of the Paris Agreement, UN SDGs and Carbon Neutrality. Afterwards, principles of climate change mitigation and adaptation are suggested for actual implementation, such as (i) decomposing into national, provincial and city scale for actual implementation, (ii) breaking down actions into different fields including transportation, industry, building, energy generation, agriculture, land use and forestry sectors, (iii) respecting the urbanising level of well-developed and developing cities, and (iv) well integrating and balancing the strength of mitigation and adaptation strategies. This chapter further introduces the contributions of the book titled "Climate Change and Environmental Sustainability", edited upon the 1st International Conference on Climate Change and Environmental Sustainability, to the progress of climate change mitigation and adaptation.

Keywords

Climate change • Mitigation and adaptation • Actions and principles

1 Climate Emergency

Total net anthropogenic GHG emissions have continued to rise during the period 2010–2019, as have cumulative net CO_2 emissions since 1850. Average annual GHG emissions during 2010–2019 were higher than in any previous decade, but the rate of growth between 2010 and 2019 was lower than that between 2000 and 2009 (IPCC, 2022). Scientists confirm that climate change is occurring and human activities, largely the release of polluting gases from burning fossil fuels (coal, oil and gas) into the atmosphere, are the main cause. The current global temperature has increased by 1.1 °C above the pre-industrial level (UNEP, 2020). The 1.1 °C temperature increase has increased the severity and frequency of risks and disasters such as heatwaves, droughts, flooding, hurricanes and wildfires. Climate-induced disasters are particularly aggravated in cities that are the main settlements of human beings as well as the growth engines for national economies, due to the interrelationships with other megatrends such as urbanization, population growth, population ageing and economic activities. Decision-makers of cities are under more significant challenges in balancing economy, environment and wellbeing, in addition to dealing with the existing and emerging risks and threats generated by climate change.

What is worse, the climate keeps changing in the coming decades due to the fossil-driven society and the release of carbon emissions. In line with this context, the United

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Nations Framework Convention on Climate Change (UNFCCC), in 2016, committed an agreement, namely the well-known Paris Agreement, aiming to constrain global average warming below 2.0 °C and actively control the warming below 1.5 °C above pre-industrial levels through carbon mitigation, adaption and finance. Nevertheless, the most recent scientific evidence indicates that global warming has to be controlled under 1.5 °C, whilst there will still be severe threats, as every increase in temperature beyond 1.5 °C will put lives, livelihoods and economies at more devastating risks. With only an additional 0.4 °C increase, we will touch the threshold of the 1.5 °C target, with devastating impacts on human beings.

It is required a dramatic reduction in carbon emission to prevent the warming of 1.5 °C. By 2030, global carbon emission intensity must be reduced to less than 50% of the 2019 carbon emission level, in order to prevent global warming beyond 1.5 °C. Nations have already recognized the emergency in shifting countries and economies onto a path of decarbonization (especially the lowest emission pathways) and committed to many frameworks such as the Paris Climate Change Agreement to reach the mitigation targets. However, countries' actions to fulfil the promises they have made are not yet on the right track. The current carbon emission intensity is at a high level, making it more urgent to achieve a dramatic reduction in carbon emissions. We need to make ambitious and collective efforts to achieve a far steeper rate of decarbonization. In cities, the urgency should go far beyond decarbonization to make the cities competitive, equitable, comfortable, healthy and livable settlements.

The last three years of 2020, 2021 and 2022 are under the significant challenge of the COVID-19 pandemic with the extensive impacts on health and wellbeing, social behaviour and interaction, livelihoods and economic growth across the world. Whilst the greenhouse gas (GHG) emissions saw a slight decrease, because of slowed economic and anthropogenic activities, the concentrations of the major GHGs were keeping increasing. Furthermore, emission trends have bounced back in many parts of the world after easing COVID-related mobility restrictions. The threats and risks associated with climate change are still prominent. For instance, 2020 was one of the warmest years on record, the sea-level increase was accelerating, and the capability of the ocean in regulating climate change was decreasing because of increasing ocean heat storage and acidification. In addition, the agriculture disruptions under the COVID-19 aggravated climate-induced impacts like food shortage and insecurity (WMO, 2021).

2 Global Actions on Climate Change

Under the mega challenges of climate change, fortunately, climate actions have been actively proposed and promoted internationally raising awareness of global warming. In December 2015, the Paris Agreement was reached under the UNFCCC, a turning point to bring almost all nations around the world together to combat climate change and accelerate the actions and investments for a sustainable low-carbon future. The Paris Agreement sets the long-term goals of limiting global warming below 2.0 °C and recommends more efforts to achieve the 1.5 °C target. To ensure the Paris Agreement is actionable, different work programmes have been set out, from the several key aspects including long-term temperature goal, global peaking and "climate neutrality", mitigation, sinks and reservoirs, voluntary cooperation/market- and non-market-based approaches, adaptation, loss and damage, finance, technology and capacity-building support, climate change education, training, public awareness, public participation and public access to information, transparency, implantation and compliance and global stocktake (United Nations, 2015). Moreover, the responsibility of different nations for combating climate change is developed upon equity, through the balance of sustainable development, economic growth, national capabilities, collaboration and information sharing.

The United Nations Sustainable Development Goals (UN SDGs) have been acknowledged as a comprehensive framework to address significant global challenges, including climate change, poverty, inequity, environmental degradation, peace and justice, in order to achieve the prosperity of people and the planet. Accordingly, 17 interrelated SDGs have been developed. Goal 13-Climate Action has been set out to take urgent actions to combat climate change and its impacts, which is further broken down into five targets (SDGs, 2021), including:

- Strengthen resilience and adaptive capacity to climate-related hazards and natural disasters in all countries;
- Integrate climate change measures into national policies, strategies and planning;
- Improve education, awareness-raising and human and institutional capacity on climate change mitigation, adaptation, impact reduction and early warning;
- Implement the commitment undertaken by developed-country parties to the United Nations Framework Convention on Climate Change to a goal of mobilizing jointly $100 billion annually by 2020 from all sources to address

the needs of developing countries in the context of meaningful mitigation actions and transparency on implementation and fully operationalize the Green Climate Fund through its capitalization as soon as possible;
- Promote mechanisms for raising capacity for effective climate change-related planning and management in least developed countries and small island developing states, including focusing on women, youth and local and marginalized communities.

These targets are important and comprehensive to not only achieve the long-term climate-neutral targets, but also focus on dealing with the current impacts of climate change on people and surroundings through investment, education, policies, strategies and planning for building and enhancing capacity. Before the development of Goal 13 of the UN SDGs, only 85 nations all over the world developed reduction strategies for national disaster risk in 2015. Fortunately, under the climate action, the number of countries that undertake actions for national adaptation plans increases rapidly, enhancing the capability of nations and then local governments to reduce climate-induced disaster risks and threats. By 2019, more than 80% of the developing countries have formulated and implemented national adaptation plans. Moreover, the investments in global climate actions also increased from $584 billion to $681 billion from 2013–2014 to 2015–2016 (SDGs, 2020).

Under climate change challenges and the continuous efforts from the international frameworks such as the Paris Agreement and UN SDGs, many countries all over the world have been presenting their ambitious targets of carbon neutrality, referring to net zero carbon dioxide emission, to curb the global warming below 1.5 °C. By December 2020, more than 110 cities have expressed their intention to achieve carbon neutrality, and many countries have already confirmed their goals such as the European Union, United Kingdoms, Japan and South Korea. Moreover, there is now more confidence to achieve carbon neutrality in the coming decades, with the involvement of major players such as China, which sets its target of carbon neutrality by 2060. Such a global coalition for carbon neutrality represents emitters of more than 65% of the global GHGs and more than 70% of the global economy. To ensure the right track to carbon neutrality, there is a need to achieve a 45% emission reduction by 2030 compared to the 2010 figures. The climate-related disaster and impact reduction are also an essential task, especially for the vulnerable countries, during the efforts for carbon neutrality.

3 Climate Change Mitigation and Adaptation

Whilst there have been many international frameworks such as the Paris Agreement, UN SDGs and Carbon Neutrality, the most urgent work is to decompose them into national, provincial and city scales for local implementation. On the one hand, the local implementation should highly respect the economic, technological, social and cultural dimensions, tailoring to the climate-induced impacts, and the local environmental and resource features. For instance, droughts, bushfires, urban flooding and extreme heat are spatially heterogenic, so climate governance is needed to properly prioritize the most critical risks and vulnerabilities a city suffers. Otherwise, this brings economic stress and technical challenges for preparation. On the other hand, there is a need to enhance policy formulation and explore innovative solutions for public participation. Whilst climate targets are getting clear, the policy system is far from sound to strengthen the enabling environment. Compulsory laws and regulations are necessary to force more enterprises to take climate actions, whilst economic support or incentive stimulation can guide and shape the priorities. Moreover, the co-benefits approach should be emphasized to enhance not only environmental, economic and social benefits but also the collaboration of different stakeholders.

Climate actions should be further broken down into different fields including transportation, industry, building, energy generation, agriculture, land use and forestry sectors. Through this, the tasks of different industries can be detailed. For instance, the achievement of carbon neutrality requires energy efficiency improvement for lower demands, electricity grid decarbonization, end-use electrification, low-carbon fuels and carbon sequestration, but it is not achievable without the actions within a specific field. In particular, the building and construction sector consumes 30–40% of global energy, and its carbon emissions account for about 40% (GABC, 2021). The consideration of operational and embodied carbon, as well as principles of circular economy, within the building and construction sector then makes the goal accountable and calculatable. More professionals such as architects, engineers, suppliers and developers can be effectively involved. Policy and regulatory landscape, the innovative sustainable materials and energy sources and the methods, systems and tools are then possible for use. Nevertheless, the collaboration of different professionals is needed to build integrative teams. The energy industry is also expected to decarbonize as fast as possible to provide renewable and clean sources for other industries.

Climate change is accompanied by the rapid upward trend of urbanization, and cities will be the key realm human being will reside. By this, climate actions within cities should be prioritized, which presents two aspects of thoughts. For well-developed cities, urban flooding and heat island effects are two fundamental phenomena of urban climate change. As a result, urban redevelopment and renewal are expected to include low-impact development and cooling strategies. This is important for urban agglomerations which are economic engines and the home to large populations, but the local climate-related impacts are more prominent. Without enough preparation and climate actions, economic productivity will significantly deteriorate and climate-related migration could be more challenging. Developing cities are expected to integrate climate resilience into urban planning and design in order to address urban climate change on the front end. Sustainable urban–rural planning and design are an important principle to achieve so, where sustainable development goals on water, energy, cities and communities, transportation, health and wellbeing, land and so on are key components.

Implementation of climate actions should integrate both mitigation and adaptation. Mitigation is to address climate change from the root by limiting GHG emissions, which is reflected by the goals of the Paris Agreement and Carbon Neutrality. Mitigation is a must and urgent task, and achieving the expected climate change goals is a gradual and long-term mission through several generations' efforts. Adaptation is to conduct adaptive approaches to protecting people from the negative impacts of climate change, including heat-related risks and threats. This is explicitly reflected in the goals of health and wellbeing and sustainable cities and communities by the UN SDGs. Adaptation is not a supplement to the mitigation actions, since the climate-induced impacts are currently severe and will be much worse in the coming decades. Adaptation should be prioritized to minimize the disproportionate impacts on vulnerable groups and low-income cities and communities. Nevertheless, compared with adaptation strategies, mitigation strategies are more effective and cost-efficient to address climate-related challenges. Overall, efforts for emission reduction and resilience improvement are two important solutions to climate change challenges (Rosenzweig & Solecki, 2018).

4 Climate Change and Environmental Sustainability

To support international and national policies and actions and enable the transformation of them into practice, the 1st International Conference on Climate Change and Environmental Sustainability (CCES) was held in Chongqing University (China) with the collaboration of Hiroshima University (Japan) and Northeastern University (China). The conference brought together researchers who are working on topics relevant to climate change and environmental sustainability to share their latest accomplishments and research findings, voices and actions towards a more resilient, livable, sustainable future. This conference served as an important resource to inform people and provide them with a comprehensive understanding of the possible opportunities for environmental sustainability to address climate change. After a blind peer-review, 22 papers were accepted and edited into the book titled "Climate Change and Environmental Sustainability".

This book consists of three parts. The first part directly reflects "Climate Change Mitigation and Adaptation" with seven chapters. These chapters cover a broad range of topics on sustainable pipeline management, carbon capture, utilization and storage (CCUS), lake water temperature, urban land temperature, drought mitigation, climate adaptation and the decarbonization of the palm oil industry. Chapter 'Towards Mitigating Climate Change by Pipeline Integrity Management: Resilient Pipelines' discusses the pathway towards pipeline integrity management for a resilient energy transmission by understanding climate-induced impacts, adaptation strategies and assessment models. Chapter 'Research Progress and Hotspot Analysis of Carbon Capture, Utilization, and Storage (CCUS): A Visual Analysis Using CiteSpace' analyses the progress of CCUS advancement, where the key themes and main trends are identified. Chapter 'Using Air2water Model to Predict the Water Temperature of Fuxian Lake' indicates that under global warming, lake water temperature is also getting warmer, at a speed of 0.03–0.04 °C/a in Fuxian Lake, Yunnan, China, posing threats to the water ecological environments. The warming trend is not only limited to the land cover of water, but the regional land surface temperature is also identified in Yunnan, China (Chap. 'Analysis of Characteristics and Influencing Factors of Land Surface Temperature Change in Yunnan Province'). Urban greening (parks) is an effective solution to urban warming, whilst the cooling intensity and distance vary with park configuration and exhibit seasonal variability, as shown in the case study of parks in Chaoyang, China, in Chap. 'Impact of Urban Park Allocation on Local Geothermal Environment: Case Study of Chaoyang, China'. Drought is also aggravated by global warming, where the co-occurrence of heatwaves and drought will be a new normal. The reuse of wastewater by different industries such as green energy resources, biogas, microbial fuel cells and biodiesel can be realized through technological development (Chap. 'Mitigating the Impacts of Drought via Wastewater Conversion to Energy, Nutrients, Raw Materials, Food, and Potable Water'). Under such climate change challenges, adaptation strategies among local communities and city governments are still poorly understood, resulting in the off-track and incompatible actions. Fortunately, the world and different industries are working towards a sound technical, social, economic and policy regime. Chapter 'Is It Possible to Achieve Carbon Neutrality in Palm Oil Production?' suggests that land-use change, palm oil mill effluent utilization technology, new planting materials and nutrient management are the pathways to decarbonize the palm oil industry in Indonesia.

The second part deals with climate change mitigation and adaptation in urban planning and design, with seven chapters being focused on urban overheating, tree canopy, spatial optimization, green roof, natural wetlands, urban ventilation and residential and industrial area planning. Chapter 'Impact of Urban Overheating on Critical Infrastructure' identifies the impact of urban overheating (combined results of heatwave and urban heat islands) on transport, energy, water and healthcare services and proposes diverse suggestions for mitigation and adaptation. Chapter 'Tree Canopy Characteristics Affect Street Canyon's Microclimate Conditions and Human Thermal Comfort in Hot-Humid Climate' presents the cooling impacts of the tree canopy on the pedestrian walkways and reveals the influence of tree species and leaf area index and their implications for tree management and landscape design. Within the context of urban renewal, Chapter 'Research on Space Resilience Assessment and Space Optimization of Old Community in City' discusses space resilience assessment and optimization, by developing an indicator system in building, infrastructure and public space dimensions. The applicability of this indicator system is verified through a case study of an old community in Beijing, China. Chapter 'Trends in Incentive Policies of Green Roof: An Overview' compares the green roof policies across Germany, the United States, China, Japan, Singapore and Canada, in order to generate a learnable policy and regulatory landscape for promoting green roof adoption. Chapter Natural Wetland Evolution in China: A Review reviews the natural wetland evolution in China, finding that there is an obvious degradation trend of natural wetlands in China, whilst constructed wetland area increases with a mean of 1.80–5.95% annually. Chapter 'Urban Morphology, Urban Ventilation and Urban Heat Island Mitigation: A Methodological Framework' introduces wind-induced heat island mitigation effects and explores interrelationships among physio-morphological characteristics, external meteorological conditions, precinct ventilation performance, heat island effect and outdoor thermal comfort. Chapter 'Istanbul; the Planning of Residential and Industrial Areas in the Process of Transformation into a Sustainable city' analyses Istanbul's problem of overpopulation and examines the determination of "residential areas" and "industrial areas" in the context of sustainability.

The third part is on policies and mechanisms for heritage preservation, with the focus of seven chapters on the linkages among climate change, economic growth, carbon emissions, biodiversity, agricultural production, environmental education, green architecture, ecological balance and refugee camp environments. Chapter 'Environmental Kuznets Curve: A New Functional Form in the Case of Low-Income Countries' analysed the relationships between economic growth and carbon emission based on the extended Environmental Kuznets Curve, and the model is examined in 16 low-income countries. Furthermore, Chap. 'A Discovery of the True Relationship Between Biodiversity and Economic Growth in Light of COVID-19' presents the relationship between economic growth and biodiversity in the OECD (Organisation for Economic Co-operation and Development) countries, especially in the COVID-19 context, indicating that biodiversity could become a barrier to economic growth in the long term. Using a 100-year analysis, Chap. 'Devastating Impact of Climate Change Threatening Egyptian Outputs: An Empirical Analysis since 1900s' quantifies the impact of increasing temperature on agricultural production and activity and examines the temperature threshold determining temperature-induced production impacts. Chapter 'Preschool Children's Environmental Knowledge and the Application of Multimedia Learning for Environmental Education' investigates the environment knowledge education among pre-school children, based on a semi-structured interview in Malaysia. Chapter 'Green Architecture for Sustainability Development in Algeria: Limitations and Visions' discusses the green architecture for sustainability development in Algeria, through which the limitations are identified and future visions are given. Chapter 'The Role of Buildings Envelope Renovation to Improve the Visual Image for Existing Buildings Towards Ecological Balance' discusses the benefits of building envelope renovation strategies (e.g. vacuum insulation panels, double-skin facades system, aerogel, smart glass, titanium dioxide and photovoltaic panels) for ecological balance and demonstrates the best practices for implementing them. Chapter 'Instant Cities and Their Impact on the Environment: Al Zaatari Case Study' analyses the environmental problems (e.g. water, waste, electricity, soil, medical waste and social) of the camp in Jordan and generates experiences for future instant cities.

5 Concluding Remarks

Climate change is getting into an emergency status, which has also threatened sustainable development in various dimensions. Society must take actions for mitigation and adaptation, in which the transformation of the traditional ways of environmental modifications towards sustainability is one of the most rapid, cost-effective and efficient pathways to actually reduce GHG emissions for climate change mitigation. Fortunately, the world has well recognized, proved and projected the significant environmental, economic and social impacts of climate change, and many international frameworks for climate change and environmental sustainability have been formulated. However, uncertainties of climate actions are easily found in the slow pace and weak local implementation. There should be an updated dialogue across numerous stakeholders, professionals, governmental departments and international organizations to strengthen enabling environments for climate change mitigation and adaptation. This conference contributes to the international discussion on climate change mitigation and adaptation, sustainable urban–rural planning and design, decarbonization of the built environment and climate-related governance and challenges. This book is a valuable outcome of the CCES conference which provides people with insights on climate change and environmental sustainability.

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Climate Change Mitigation and Adaptation

Towards Mitigating Climate Change by Pipeline Integrity Management: Resilient Pipelines

Guojin Qin, Yihuan Wang, and Bao-Jie He

Abstract

Energy pipelines are currently the best energy transmission infrastructure. Pipeline integrity is closely related to the sustainable development of modern industry and the well-being of people so that pipeline integrity management has been a topic of interest to regulators, practitioners, and scholars. Over the past four decades, pipeline integrity management has developed significantly. Nevertheless, climate change-induced extremes such as torrential rains, floods, and droughts have severely disrupted the safe pipeline operation and caused major failures with great consequences in public safety and energy security. Therefore, the pipeline integrity management program must cope with climate change, where developing a resilient pipeline is expected to be a solution. This work, therefore, focuses on capturing the approach from integrity management to the development of a resilient pipeline, by understanding (i) how climate change affects the safe operation of pipelines, (ii) what methods can be used to assess and manage pipeline integrity, (iii) how the pipeline adapts to climate change, and (iv) how pipeline integrity management develops into resilience management.

Keywords

Climate change • Energy infrastructure • Resilience • Natural disaster • Risk • Vulnerability

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1 Introduction

Energy pipeline is regarded as the blood vessel of the industrial system. As a channel of energy transmission, it plays an essential role in ensuring production and social stability. However, pipelines inevitably pass through geologically unstable areas due to uneven energy distribution (Wang et al., 2020). Geological disasters can cause soil movement and surface deformation, resulting in bending, compression, distortion, tension crack, local buckling, and other failure behaviors of buried pipelines (Zhang et al., 2019). Once a pipeline accident occurs, it will cause energy loss, environmental pollution, and even casualties. Risk-based integrity management can evaluate pipeline safety under geological disasters from disaster identification, the impact of disasters on pipelines, implementation effect of maintenance measures (Khan et al., 2021). Scholars have made major efforts on the impact of pipeline integrity, protection, reinforcement devices, and pipeline risk under geological disasters (Teng & Ke, 2021).

The Canada Energy Regulator (CER) statistics show that the failure frequency of Canadian pipelines due to natural and environmental forces increases by the year, and a crucial reason comes from climate change. Extensive evidence shows that climate change has a severe impact on geological disasters, and direct influencing factors are temperature rise and precipitation (Cvetković & Grbić, 2021). Temperature rise leads to atmospheric water content increase, glaciers and permafrost degradation, sea level increase, and evaporation enhancement. Changes in precipitation lead to rainfall/snow frequency, rainfall/snow cycle, and rainfall/snow intensity (Martel et al., 2021). Moreover, changes in rainfall and temperature are interactive, and these changes will directly affect the stability of rock and soil mass, leading to different types of geological disasters and affecting pipeline integrity when the soil overload carries external effects and reaches a critical state (Martel et al., 2021). In conclusion, the impact of climate change on pipeline integrity is dynamic and

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uncertain, while traditional pipeline integrity management cannot capture such uncertainties, reducing the efficiency of pipeline asset operation and maintenance management.

Therefore, this paper discusses a path from risk-based integrity management to resilience management which focuses on coping with adversity and adapting to impacts, from the effect of climate change on the pipeline, the process of risk-based pipeline integrity management, and how to adapt climate change.

2 Potential Impact of Climate Change on Pipeline Safety

Long-distance pipelines, a typical long-span lifeline project, can inevitably pass through areas with complex geological environments, making it threatened and infringed by various geological disasters (Qin et al., 2020). Geological disasters can induce severe soil movement and surface deformation around the pipeline. The different properties of rock and soil and the different action modes of rainfall can induce many geological disasters. For example, heavy rainfall can easily lead to debris flow; long-term rainfall and freezing and thawing of frozen soil can induce landslides, collapse disasters, floods, and land subsidence (Cheng, 2020).

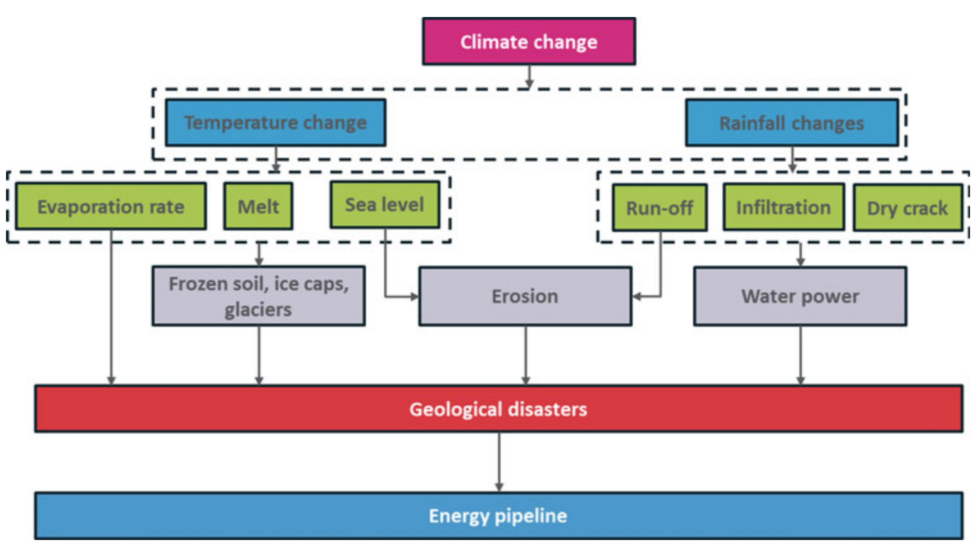
Gravity is the internal driving force of slope disaster. Surface materials (e.g., soil and rock) move downward along the slope under the action of gravity, often forming severe geological disasters. According to the composition and movement mode of sliding materials, slope disasters can be collapses, landslides, and debris flows. Geological morphology, structure, geotechnical characteristics, and groundwater are natural factors of slope instability, and precipitation is the primary inducement of slope disaster. Figure 1 shows how climate change, especially precipitation mode and temperature, affects future slope activities (Gao et al., 2017). The intensification of climate change and precipitation can induce soil loosening, mountain landform, and structural instability, lead to more severe slope disasters and make pipelines passing through the slope face more significant uncertainty.

Flood is a disaster phenomenon of the sharp rise of river water volume and water level caused by rainstorm or sudden melt ice and snow and dam collapse of the reservoir (Aerts et al., 2018). Rivers, ditches, and other water flow areas are also the place that long-distance pipelines pass through. Flow scouring may cause unstable operation conditions such as suspension, floating, and deformation of buried pipelines (Wang et al., 2020). Flooding formation depends on climate factors where seasonal characteristics of flood disasters are apparent, which occur in the rainy season or flood season. Climate change leads to frequency, cycle, and intensity changes of rainfall. Flooding will be more frequent, adding more uncertainties to the operation and protection of pipelines, along with climate change.

Land subsidence is a geological phenomenon in which surface rock and soil collapse under geological factors' action to form collapse pits, holes, and grooves. Affected by the El Nino effect, continuous heavy rainfall weather has become the primary driver to ground failure. Afterward, there could be bending deformation, suspension, or fracture of pipelines, bringing significant hidden dangers to pipeline safety. For example, in 2005, the ground collapsed due to rain in Foshan, China, which broke the pipeline and led to gas leakage. The accident analysis found that climate change affected the local groundwater level, effective soil stress, and soluble rock stratum.

The increasing interaction between extreme weather and permafrost will lead to the thawing settlement of the permafrost around the pipeline, resulting in the soil subsidence

Fig. 1 The impact of climate change on geological disasters



caused by the melting of ice-rich soil in the buried depth. Geological activities can produce significant axial tensile and compressive strain, which is even as high as $\pm$ 3% (Cheng, 2020), resulting in pipe failure.

3 Risk-Based Pipeline Integrity Management

Risk-based integrity management is the mainstream pipeline pre-management process, including data collection, risk identification, risk assessment, and maintenance decision-making, as shown in Fig. 2. The risk factors affecting the pipeline (e.g., the frequency of geological disasters) can be identified through data collection; Risk assessment is carried out through corresponding assessment methods, including qualitative, semi-quantitative, and quantitative risk methods; Finally, effective risk control is realized at the lowest possible cost based on the risk assessment results. In particular, the steps are presented below.

Step 1: Risk managers collect the data of the pipeline section, such as the known types of disasters around, historical occurrence frequency of disasters, landform, rainfall sensitivity, soil type.

Step 2: Natural disasters-induced pipeline risk can be a function of vulnerability (Porter et al., 2004), i.e., Risk = Hazard $\times$ Vulnerability, where Hazard is the possibility of a disaster; Vulnerability denotes the probability of loss of capacity under particular conditions during operation, design, and implementation. The fault tree, Bayesian network, and structural reliability can be used to evaluate the vulnerability of the pipeline under the identified specific disasters.

Step 3: Risk managers seek the balance between pipeline safety and maintenance cost and decide the corresponding maintenance scheme.

Due to significant differences in the operating environment, it is necessary to capture the uncertainties to make pipelines adapt to climate change. Uncertainties are a function of the variability characteristics, amplitude, and change rate of local climate change characteristics and their sensitivity and system adaptability. Moreover, the difference of the knowledge involved in in-service environment, design, and operation will also lead to the tendency of pipeline structures to be damaged by disasters in different environments, and response and adaptability will be different. However, the traditional risk-based integrity management process does not consider the impact of climate change.

4 How Does the Pipeline Adapt to Climate Change?

The government, industries, and research institutions should play an important role in mitigating climate change impacts on pipeline safety. First, government and industry can supervise, manage, guide policies, and advocate and stimulate owners to develop innovative solutions to enhance the pipeline's adaptability to climate change (World Bank, 2013). For example, the government can promote pipeline adaptation to climate change by updating standards, codes, and recommended practices. Second, pipeline owners can cooperate with research institutions to develop novel and comprehensive methods to promote the transition from risk-based integrity management to resilience management. Climate change prediction can be incorporated into pipeline risk assessment (Vallejo & Mullan, 2017). The updated assessment procedure is expected to accurately capture the high uncertainties of the service environment under climate change and predict the sudden hazard events harmful to the pipeline (Anderies, 2014). For example, the risk and safety assessment procedure can include the evaluation index of adapting to the gradual change of climate and site conditions, which is conducive to the evaluation of the set intervention measures or the improvement of the owner's innovative thinking to enhance the pipeline resilience (Jain et al., 2018). As far as possible, research institutions should develop risk-based and resilience strategies to deal with short-term and long-term climate events. These institutions should collaborate and innovate as much as possible to promote climate change-resistant pipeline systems.

Fig. 2 Risk-based pipeline integrity management

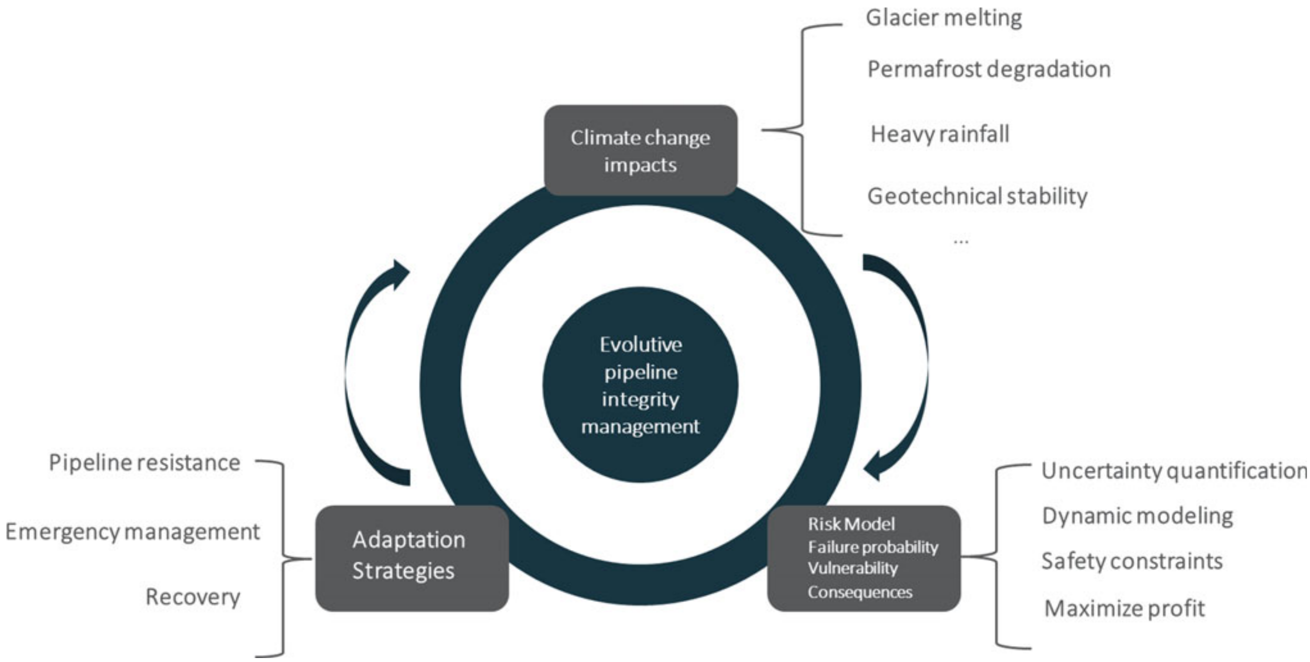


Fig. 3 Pipeline resilience management framework

Furthermore, a supporting tool for pipeline resilience management is further explored. The tool can assess the vulnerability of pipelines to climate change, i.e., additional risks brought by climate change, and further formulate adaptation strategies for new pipeline risk scenarios under climate evolution. The management framework is shown in Fig. 3. Each risk component needs to be adjusted according to climate change to update the pipeline risk model, e.g., the initiation of geological disasters and corrosion activity. It should have dynamic modeling functions and capture climate uncertainties, helping determine corresponding adaptation strategies. Mountainous areas, rivers, and other geological environment sensitive areas are significantly affected by climate change. Therefore, in addition to setting protection measures, corresponding emergency measures should be considered in management and recovery measures. Pipeline resilience management needs to incorporate new risk scenarios constantly, and the whole process needs to be recycled.

Development of risk-based pipeline integrity management to resilience management enables the long-distance pipeline to adapt to the operating environment under climate change and recover quickly under an accidental shutdown, which is conducive to the sustainability of the energy supply. This brings new opportunities and challenges to pipeline practitioners in integrity, risk, and virtual training. First, mandatory documents are needed to guide the operators to standardize the safe operation of pipelines under climate change. Second, the organic combination of government and industry can promote the pipeline to adapt to climate change from the macro and technical levels. At present, the government attaches great importance to climate change mitigation and tries to promote the typical global response to climate change by strengthening intergovernmental cooperation. However, the industries have not paid enough attention since the short-term and long-term impacts of climate change on the pipeline have been well understood. Finally, addressing climate change requires not only innovative thinking but also collaboration. The impact of climate change on the pipeline has regional characteristics so that owners shall share data as much as possible to establish a sound database. However, no owner has led the establishment of a database to deal with climate change as it may involve the issue of data security. The above challenges are to promote the transition from risk-based pipeline integrity management to resilient management to deal with the obstacles of climate change, which is worthy of attention from all walks of life.

5 Conclusions

There is a need to promote pipeline owners to understand the impact of climate change and enable pipelines to achieve climate change adaptation. This paper analyzes the sudden effect of climate change on the pipeline in aspects of geological disasters caused by rainfall change and temperature change, e.g., landslide, collapse disaster, flood, land subsidence, frozen soil thawing. The path from risk-based pipeline integrity management to resilience management is given. It is critical to endow the risk assessment program to capture climate change uncertainty and dynamic modeling and increase the emergency management program. The government, industry, innovative science thinking, and collaborative cooperation of research institutions are essential for transition procedures.

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Research Progress and Hotspot Analysis of Carbon Capture, Utilization, and Storage (CCUS): A Visual Analysis Using CiteSpace

Qin Li, Yijun Liu, Wenlong Li, Yongqiang Yan, and Zhonghao Wu

Abstract

The issue of global climate change has become increasingly prominent. The reduction of fossil energy consumption and the reduction of greenhouse gas emissions have attracted more and more attention from countries. Carbon capture, utilization, and storage (CCUS) technology is considered to have the synergistic effect of achieving large-scale greenhouse gas emission reduction and low-carbon utilization of fossil energy. It is one of the important technological choices for the global response to climate change in the future. It has attracted governments and enterprises from all over the world and the high attention of the academic community. This paper screened out 1890 scientific articles related to global CCUS from the Web of Science Core Collection and used the CiteSpace to analyze the knowledge graph of the papers since 2011. The paper visually displays the most productive institutions, authors, and sources in the CCUS research. In addition, the paper explains how research subjects have changed over time and analyzes research frontiers. The results show that: (1) CCUS research has accelerated globally in the past ten years, with the United States, the United Kingdom, and China ranking the top three. (2) Research hotspots mainly focus on engineering, energy and fuels, engineering chemistry, engineering environment, science and technology, green sustainable technology, environmental science, and ecology. (3) CCUS has become a multidisciplinary research, in which all research subjects related to CCUS have been cited and correlated. In general, this research is helpful for policy guidance and follow-up research.

Keywords

Carbon capture, utilization and storage (CCUS) • Visualization • CiteSpace • Bibliometric methods

1 Introduction

With the rapid development of the global economy and the human consumption of fossil energy such as coal, oil, and natural gas, a large number of pollutants and greenhouse gases are emitted. Various environmental problems are frequently occurring all over the world, such as the greenhouse effect, haze, deterioration of water quality, and the sharp decline of biodiversity. It has caused a negative impact on the global climate and seriously threatens human health and social development (Fan, 2015). The "Kyoto Protocol" states there are six main greenhouse gases emitted by humans, of which carbon dioxide has the greatest impact on climate change. The warming effect it produces accounts for 63% of the total of all greenhouse gases, and it can last up to 200 years in the atmosphere. With the emergence of global climate issues, scientific research on climate change and how to take actions to mitigate global climate change have become hot topics discussed by the international community, governments, and even the public.

Climate issues are closely related to people's lives, and countries have made many efforts to this end. In order to reduce the greenhouse climate (especially carbon dioxide emissions), the IPCC passed difficult negotiations and finally passed the "United Nations Framework Convention on Climate Change" in 1992. It is the first international convention proposed in human history to comprehensively control carbon dioxide and other greenhouse climate emissions and slow down the adverse effects of global warming on human society. It provides a reliable basis for the international community to deal with global climate issues. On September 27, 2013, in Stockholm, the capital of Sweden, the fifth

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assessment report (AR5) of the First Working Group of the United Nations Intergovernmental Panel on Climate Change (IPCC) conducted a new assessment of the new progress in climate change research since 2007 (Shen et al., 2013; UNFCCC, 1994). It has provided new scientific support for a new round of international climate change, policies and actions, and has played an important role in promoting the adoption and implementation of the "United Nations Framework Convention on Climate Change" by governments.

The measures that we can take to mitigate climate change are very limited, for example, reducing the use of traditional energy, increasing the use of low-carbon energy, capturing carbon dioxide in the production process to achieve geological storage or utilization, biological carbon sequestration, etc. However, due to the huge global energy system and energy demand, human energy production has been deeply dependent on fossil energy, and it is difficult to change the energy consumption structure in the short term.

Therefore, considering the global environmental status, the urgency of achieving carbon emission reduction, and the limitations of emission reduction methods, carbon capture and storage (CCS) will become one of the most effective ways to global emission reduction (GCCSI, 2017).

2 Literature Review

Carbon capture, utilization, and storage (CCUS) is the process of separating CO_2 from industrial processes, energy utilization, or the atmosphere and directly using or injecting it into the formation to achieve permanent carbon dioxide emission reduction. CCUS adds "utilization" to the CCS. This concept is based on the development and deepening understanding of CCS technology, under the vigorous advocacy of China and the United States. CCUS is expected to be a critical method in achieving global warming goals (IEA, 2020; Romasheva et al., 2019; Stuardi et al., 2019). CCUS is divided into capture, transportation, utilization, and storage links according to the technical process (Fig. 1).

CO_2 capture refers to the process of separating CO_2 from industrial production, energy utilization, or the atmosphere (Fig. 2). CO_2 transportation refers to the process of transporting the captured CO_2 to an available or storage site. According to different modes of transportation, it is divided into tanker transportation, ship transportation, and pipeline transportation. CO_2 utilization refers to the process of recycling the captured CO_2 through engineering and technical means. According to different engineering techniques, it can be divided into CO_2 geological utilization, CO_2 chemical utilization, and CO_2 biological utilization. Among them, CO_2 geological utilization is the process of injecting CO_2 into the ground to achieve enhanced energy production and promote resource extraction, such as improving oil and natural gas recovery, mining geothermal, deep salt water, uranium, and other types of resources. Biomass carbon capture and storage (BECCS) and direct air carbon capture and storage (DACCS) are highly valued as negative carbon technologies. BECCS refers to the process of capturing, utilizing, or storing the CO_2 produced in the process of biomass combustion or conversion. DACCS is a process of directly capturing CO_2 from the atmosphere and using or storing it. Compared with CCS technology, CCUS can recycle carbon dioxide and bring obvious economy benefit (IPCC, 2005). CCUS can contribute nearly one-fifth of the emission reduction required by the entire industrial sector. It is estimated that CCUS technology could account for 32% of the global reduction in carbon dioxide emissions by 2050 (Regufe et al., 2021).

3 Materials and Methods

3.1 Data Sources and Screening

The bibliographic data collected in this study came from the Web of Science Core Collection (WOSCC). WOSCC's bibliographic sources (SCIE and SSCI) are very comprehensive, and its data sources are representative and accessible (Id et al., 2016). The time span of this study is from January 1, 2011 to July 10, 2021. Set the search subjects to the followings: TS = "carbon capture, utilization and storage" OR "carbon capture and storage" OR "carbon capture and utilization." Through the category refinement function of the Web of Science, the document type is refined into "ARTICLE." We went over the titles of all publications and removed those that were not relevant to the study. We ended up with 1890 records and downloaded these bibliographic records (involving titles, authors, keywords, abstracts, periodicals, and other publication information, see Supplementary File S1). Then, we use CiteSpace to perform a scientometric analysis of the data records.

3.2 Analytical Methods

There are many commonly used visual analysis software, including HistCite (Garfield et al., 2002), VOSviewer (Zhu et al., 2021), RefViz (Simboli et al., 2004), SATI (Liu et al., 2012), and CiteSpace (Chen, 2017). By comparing the characteristics of the above programs, we chose to use CiteSpace 5.6R3 as the main tool for literature analysis.

CiteSpace is a software developed by Professor Chen in 2004 (Meerow & Stults, 2016), and it is an important analysis and visualization tool in the field of scientific metrology (Chen, 2010). CiteSpace can professionally analyze the basic knowledge in the literature and achieve

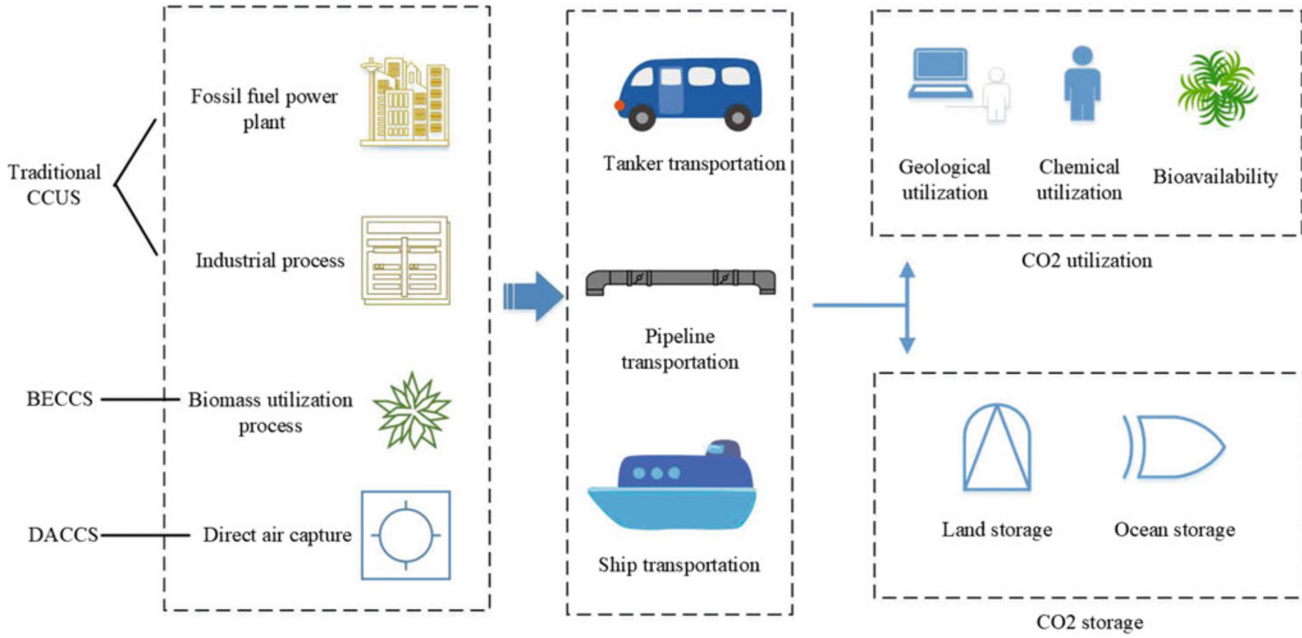


Fig. 1 CCUS technical route diagram (from China agenda 21 management center)

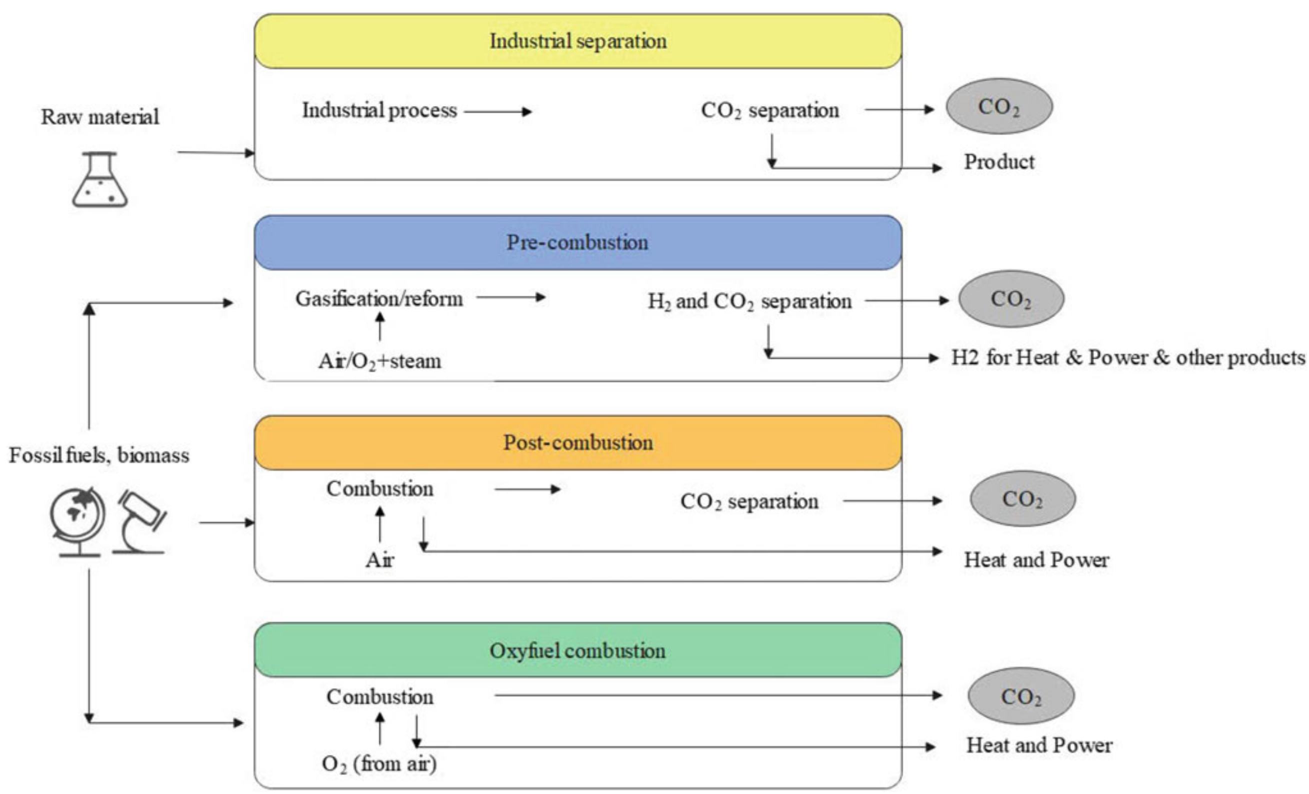


Fig. 2 Carbon capture technology roadmap

multi-dimensional, dynamic, and time-division analysis. In addition, CiteSpace also provides scholars with a bibliographic co-occurrence analysis system such as countries, institutions, and authors, which can conduct cooperative analysis from the perspective of cooperative networks (Muller, 2007).

Compared with other visualization software, the main advantages of CiteSpace are as follows: (1) review and study the theoretical roots of rapid changes and complex regions; (2) improve the clarity and interpretability of visualization; and (3) through the time segmentation visualization in the evolutionary network, detect and explain the tipping point, transformation mode, and emerging research directions for researchers who are not experts in the field (Milman & Short, 2008; Ooi et al., 2013). The overall flow chart of this research is shown in Fig. 3.

4 Results and Discussions

4.1 Characteristics of Publications

Since the amount of annual publications can reflect researchers' attention to a knowledge field, the time trend of data records is shown in Fig. 4. In the past ten years, the number of papers published by CCUS has shown an overall upward trend. In 2011, there were 73 publication records on CCUS. However, the number of publications has suddenly increased since 2012. By 2014, the number of publications on CCUS was twice that of 2011. From 2015 to 2018, although the number of publications fluctuated, it basically showed a steady upward trend, with the number of publications exceeding 150 each year. Since 2019, the number of publications each year has exceeded 200. Especially in 2020, CCUS has attracted the attention of global scholars, which may be related to national policies. More and more governments are incorporating carbon neutrality goals into their national strategies.

For example, the European Union's "Climate Neutral Law" submitted in March 2020 aims to ensure that Europe will become the first "climate neutral" continent by 2050 from a legal perspective. California and China have set targets for "carbon neutrality" in 2045 and 2060, respectively. Due to different stages of development, developed countries have generally experienced "carbon peaks." In order to achieve "carbon neutrality" by 2050, to a greater extent, it is just a continuation of the previous slope of emission reduction. China's total carbon emissions are still increasing, and it needs to experience "carbon peak" before 2030 and then move toward "carbon neutrality" before 2060.

4.2 Cooperation Networks Analysis

4.2.1 Network of Countries and Institutions

Our analysis of cooperation networks focuses on the importance and relevance of countries, institutions, and authors to the field. It reveals the distribution of research power, cooperation intensity, and distribution among different nodes in the global research network. A collaborative relationship network has been formed between the state and the institution. In the collaborative relationship network, nodes refer to different countries and institutions, and links describe their collaborative relationships in CCUS. Figure 5 shows the cooperation relationship between countries and institutions in CCUS.

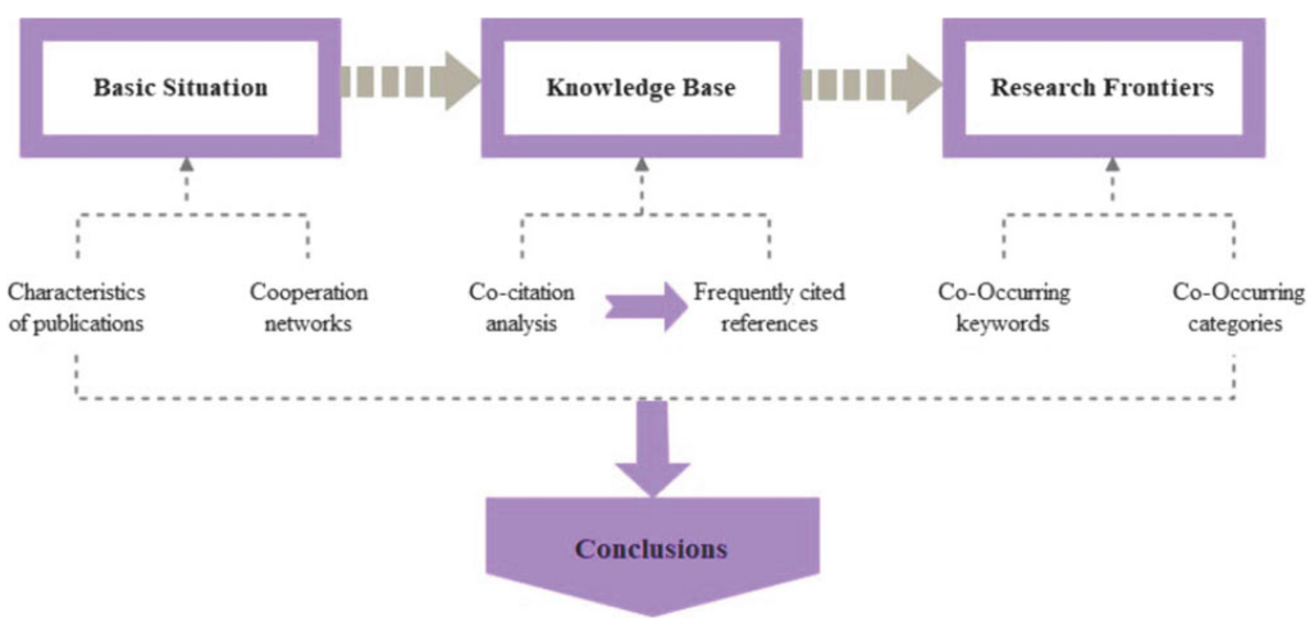


Fig. 3 The overall flow chart of the research

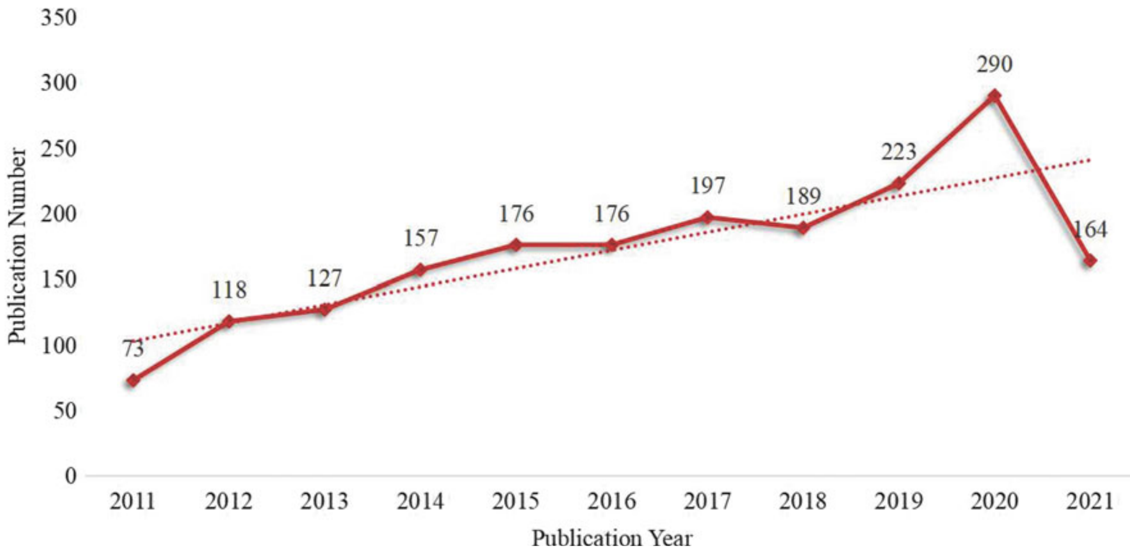
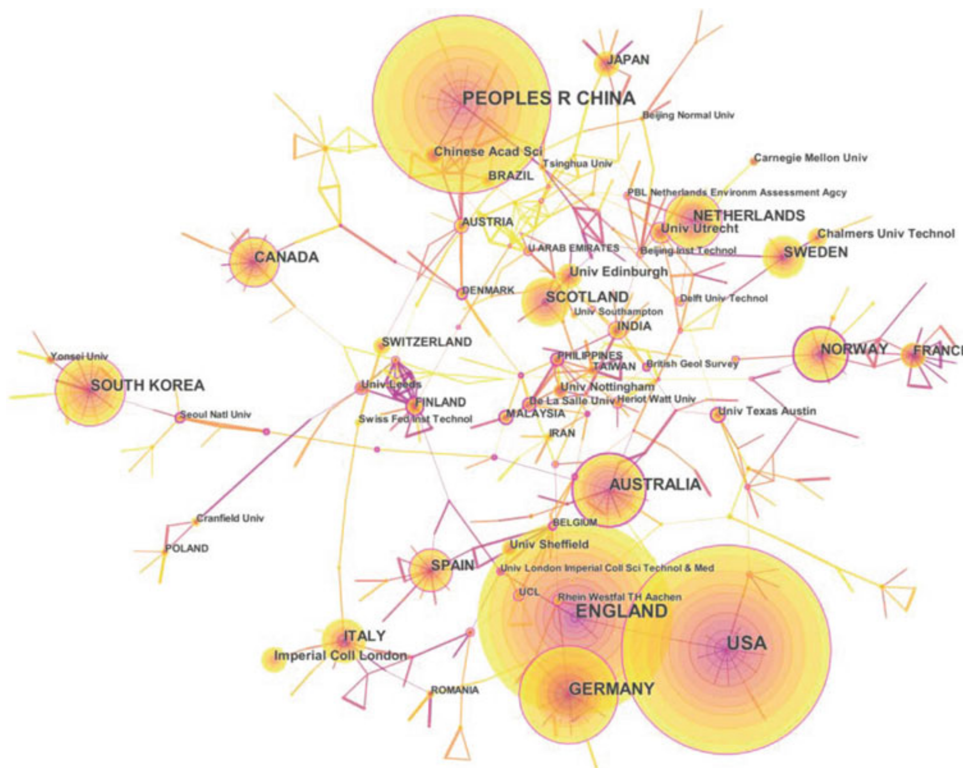


Fig. 4 The time distribution of annual publication records

Fig. 5 Cooperative networks of countries and institutions



We found that 71 countries (regions) and 346 research organizations participated in the CCUS study. Among them, 3 countries and 25 institutions have published the most papers. The United States (Number of publications [Count] = 356) is the main country, followed by the United Kingdom (Count = 339) and China (Count = 307).

As can be seen in Fig. 5, although the United States is the largest contributor to publications of all countries, the influence of the United Kingdom and China in the cooperative relationship network is almost the same as that of the United States. As the main contributors to publications, the three countries of the Netherlands, Australia, and South

Korea also have a great influence in the cooperative network relationship. In addition, China has close cooperative relations with almost countries that have amount of publications, such as the United States, the United Kingdom, the Netherlands, and Australia.

Figure 5 also shows the dedication and collaboration of research organizations in the CCUS study. There are a large number of research institutions in the UK, including the University of Edinburgh (Count = 48), Imperial College London (Count = 48), University of Nottingham (Count = 29), and University of Sheffield (Count = 29).

Research institutions in the United States mainly include the University of Texas at Austin (Count = 24) and Carnegie Mellon University (Count = 21). In contrast, Chinese research achievements come mainly from the Chinese Academy of Sciences (Count = 40) and Tsinghua University (Count = 20). Among them, the Chinese Academy of Sciences stands out, with 40 publications. Among the top five institutions in terms of the number of papers published, in addition to research institutions in the UK and China, there are also Utrecht University in the Netherlands (Count = 40) and Chalmers University in Sweden (Count = 37). The universities ranked at 6% of research organizations are mainly from countries which have a large number of publications, for example, the United States, the United Kingdom, China, and the Netherlands. Table 1 lists the top 6% of research institutions.

4.2.2 Network of Authors

The analysis of academic cooperation network reflects the productivity level of scientific researchers and their contribution to scientific research. The distribution of cooperation networks between countries and institutions is relatively concentrated. However, the authors' contributions to CCUS research are distributed in multiple groups in the network of co-authors (Fig. 6). Currently, 482 authors are studying CCUS, of which 68 authors have published more than 4 articles. As shown in Fig. 3, the authors with the largest number of publications in the CCUS field are Raymod R. Tan and Niall Mac Dowell (Count = 18), followed by Jin-won Park (Count = 15), Calincristian Cormos (Count = 13), and Dominic C Y Foo (Count = 11), as well as Edward S Rubin (Count = 10), Detlef P Van Vuuren (Count = 10), Xian Zhang (Count = 10), and Dongwoo Kang (Count = 9). Table 2 lists the authors who have published the most papers in CCUS research in recent years.

Through the network analysis of co-authors, it is obvious that the two research teams with the largest number of publications are Raymod R. Tan (Tan et al., 2012) from Philippines De La Salle University and Niall Mac Dowell

Table 1 Top 6% of institutions

Institutions	Count	Centrality	Percentage of total (%)
University of Edinburgh	48	0.17	13.9
Imperial Cole, London	48	0.01	13.9
Chinese Academy of Sciences	40	0.14	11.6
University of Utrecht	40	0.10	11.6
Chalmers University of Technology	37	0.01	10.7
University of Nottingham	29	0.00	8.4
University of Sheffield	29	0.01	8.4
The University of Leeds	25	0.11	7.2
University of Texas-Austin	24	0.05	6.9
De La Salle University	21	0.13	6.1
Carnegie Mellon University	21	0.01	6.1
Rhein Westfal TH Aachen	20	0.04	5.8
Cranfield University	20	0.01	5.8
Tsinghua University	20	0.06	5.8
Heriot-Watt University	19	0.14	5.5
University College London	19	0.02	5.5
Yonsei University	18	0.02	5.2
Swiss Federal Institute of Technology	17	0.08	4.9
Beijing Institute of Technology	17	0.13	4.9
Beijing Normal University	16	0.11	4.6
Technische Universiteit Delft	16	0.06	4.6

Fig. 6 Cooperative networks of authors

(Bhave et al., 2017; Dowell et al., 2017; Mechleri et al., 2017) from Imperial College London. The research direction of the previous research group is mainly the process integration of resource protection and carbon dioxide emission reduction. The other research group is mainly bioenergy systems and technologies, urban energy systems, and modeling and optimization of low-carbon technologies and systems. The second-ranked research team is composed of scholars from South Korea and is mainly focused on the development of low-carbon industries to reduce carbon emissions, as well as the conversion and application of carbon dioxide. The research team is led by Jinwon Park (Park et al., 2013), who is from Yonsei University. There are also Dongwoo Kang from Chungbuk National University (Kang et al., 2016) and Sangwon Park from Kyung Hee University (Park et al., 2014). Beginning in 2019, a research team has been committed to seeking the least cost-effective way to convert carbon dioxide in the atmosphere and to conduct economic evaluation of CCUS from all aspects (Fan et al., 2019, 2020). Scholars in this group are mainly from the China Agenda 21 Administration Center, China University of Mining and Technology, Beijing Institute of Technology, and Beijing Normal University. Among them, China University of Mining and Technology and Beijing Institute of Technology cooperate closely. Due to the needs of China's national conditions, the Chinese research team has been very active in the field of CCUS, constantly expanding the content and promoting the application of CCUS. China is the country with the largest CO_2 emissions, and its existing CCUS demonstration projects are small. The technical cost of CCUS is an important factor that affects its large-scale application, but with the rapid development of technology, the cost of CCUS technology in China has a large room for decline in the future (Yang et al., 2019). The co-author relationship only reflects the output and contribution of CCUS research results. Highly productive authors do not necessarily have a great influence on CCUS research. The author's level of influence is reflected by the analysis of co-citation in the literature.

4.3 Knowledge Base Analysis

4.3.1 Co-citation Clustering Analysis

Literature co-citation analysis is applied to measure the dependency relationship of formerly CCUS study. We found 64,065 co-cited articles among 1890 publications, of which 302 were cited more than twice (Supplementary File S2).

Table 2 The institutions of authors with more than 10 publications

Frequency	Year	Author	Institution
18	2013	Raymond R. Tan	Philippines De La Salle University
18	2017	Niall Mac Dowell	Imperial College London
15	2013	Jinwon Park	Yonsei University
13	2012	Calin-CristianCormos	Babes-Bolyai University
10	2013	Edward S.Rubin	Carnegie Mellon University
10	2014	Detlef P. van Vuuren	Utrecht University
10	2019	Xian Zhang	The Administrative Centre for China's Agenda 21

We found 6 primary clusters reflecting the CCUS research knowledge base. The clustering of co-cited documents is shown in Fig. 7. The Modularity is 0.8267, indicating that the various research fields of CCUS research can be clearly defined (Chaomei, 2017). The Mean Sihouette is 0.517, indicating that the cluster uniformity is normal.

Although our research time is from 2011 to 2021, there are related papers as early as 2006, and the "co(2) capture" cluster appears the earliest. The cited literature mainly focuses on the technologies and cases of recovery of carbon dioxide after combustion. The keywords used are post-combustion capture, carbon capture and storage, carbon dioxide removal rate, technological innovation, greenhouse gases, climate change, etc. It provides a wealth of case study references for CCUS research. "Environmental impacts" are clusters that appeared in 2007–2011. The former mainly includes low-carbon investment, state policy, CCS investment cost, real options, etc. The latter mainly includes life cycle assessment and bioenergy.

"Bioenergy with carbon capture and storage" has the longest clustering time (2012–2019). It forms the largest cluster and contains the most cited publications, reflecting the field's focus on research topics. The cluster mainly focuses on the technical method level, such as negative emission technologies, prometheus energy system model, energy system and integrated assessment models, and multi-criteria decision analysis. At the same time, the clustering also includes some theoretical methods, such as CO_2 footprint, energy system transformation, biomass resources, energy system decarbonization, and preference elicitation. The "membranes" cluster started in 2012 and lasted until 2020. The cluster mainly focuses on the chemical analysis and physical models involved in CCUS. The keywords used are decompression of real fluid, thermodynamic analysis, geothermal energy, computational fluid dynamics modelling, monte carlo simulation, lignite-fired igcc, and reversible solid oxide cells.

The "beccs" cluster mainly focuses on negative carbon emission technologies, combining bioenergy with carbon capture and storage technologies, and is currently regarded as one of the most feasible negative emission technologies. BECCS absorbs carbon dioxide from the air through the growth of crops or trees. This will not only release energy by burning these trees, but also capture the carbon emitted by the combustion. The captured carbon is sequestered underground to prevent it from returning to the atmosphere, and then, the whole process is repeated. However, the biggest concern about BECCS is that a large amount of land is needed to grow bioenergy first, which may compete with food supply or lead to deforestation. Therefore, more research is needed to verify and support BECCS technology.

"Carbon capture and utilization" started in 2014 and lasted until 2020. It was the last cluster that appeared during our analysis. As the "Double Carbon Action (carbon peak,

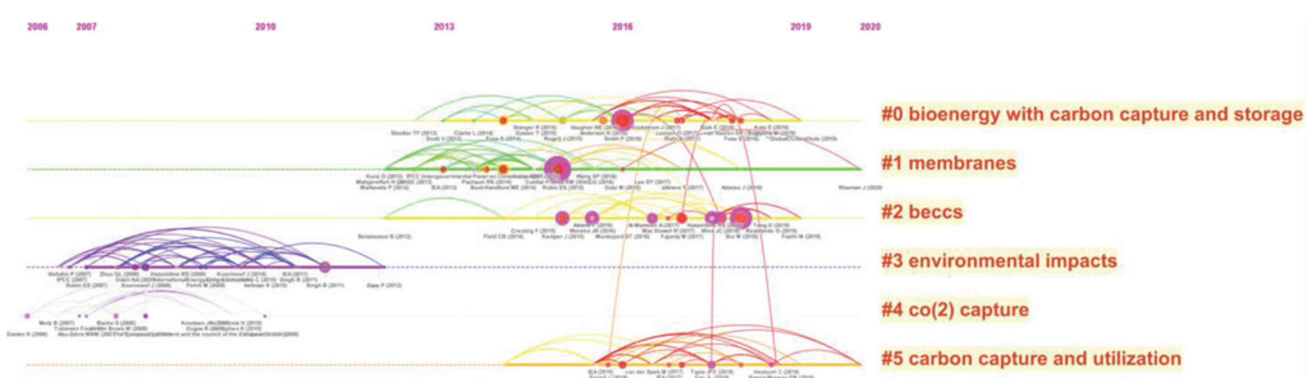


Fig. 7 Clustering of co-cited documents

carbon neutral)" has become the focus of international attention, a lot of research has appeared in related fields. At the same time, clusters #0 and #2 illustrate the necessity of interdisciplinary research and also prove that this field is currently a research hotspot of global concern.

4.3.2 Analysis of the Most Frequently Co-cited Publications

We found 21 papers with more than 20 citations in the co-cited image (Fig. 8). This picture fully demonstrates the general laws, interdisciplinary cooperation, and innovative methods of the development of the discipline to the present and promotes the accumulation of the CCUS research.

We found a book in frequently cited publications (IEA, 2013), which introduced the technical route of CCS and the development direction. It points out that CCS is a key solution to reduce greenhouse gases. Of these 21 papers, 61.9% are journal articles that provide literature reviews or opinions. These publications fully support the development of CCUS research from theoretical basis and other aspects. Energy & Environmental Science has a article by Bui et al. (2018). In this paper, they included the key negative emission technologies (NETs) of bioenergy and CCS (BECCS) and direct air capture in their research scope. Leung et al. (2014) reviewed all aspects of CCS technology, including the latest technologies in CO_2 capture, separation, transportation, storage, leakage, monitoring, and life cycle analysis. Cuellar-Franca (2015) comprehensively compared the environmental impact of CCS and carbon capture and utilization (CCU) technology. Except for GWP, CCS has a higher environmental impacts than CCU. Fuss et al. (2014) published a review article in Nature Climate Change. The review points out that BECCS is unproven. Kemper (2015) reviewed BECCS at the system level and discussed the sustainability issues in BECCS. Both Anderson K and Rogelj J's articles have been cited 26 times. Anderson (2016) raised questions worth thinking about in an opinion paper published in Science. Negative emission technology removes CO_2 from the atmosphere through technical means, but it is not an insurance policy. He believes that if carbon dioxide is not removed from the atmosphere at the level assumed by the Integrated Assessment Models (IAMs), or if it fails, then society will be trapped in the high-temperature channel. Rogelj et al. (2015) analyzed a comprehensive energy economic environment scenarios that keep warming to below 1.5 °C by 2100. In the fifth assessment report of the IPCC (2014) (Climate Change, 2014: Mitigation of Climate Change), Pachauri RK emphasized the importance of technological progress for stabilizing the concentration of greenhouse gases. The key role of CCS as a transitional technology with low or zero emissions in the future has been widely concerned by researchers. Mac Dowell (2017) made it clear that NETs have become the focus of climate science and policy discussions. Aminu (2017) clarified that CCS has been identified as an urgent, strategic, and indispensable method to reduce man-made carbon dioxide emissions and mitigate the serious consequences of climate change.

Cited papers dominated by models and methods accounted for 47.6% of the citation frequency. Among them, Smith et al. (2016) quantified potential global impacts of the different NETs on various factors to determine the biophysical limitations and economic costs. Fajardy et al. (2017) clarified the key leverage to enhance the sustainability of BECCS. Fuss (2018) evaluated the costs, potentials, and side effects of these seven technologies: BECCS, afforestation and reforestation, direct air carbon capture and storage (DACCS), enhanced weathering, ocean fertilization, biochar, and soil carbon sequestration. Perez-Fortes (2016) evaluated methanol (MeOH) produced from hydrogen and captured carbon dioxide through technical, economic, and environmental indicators. Riahi et al. (2016) used a multi-model approach to elaborate on the energy, land use, and emission trajectories based on the shared socioeconomic pathways. Middleton (2009) introduced a scalable CCS infrastructure model. By examining the sensitivity of CCS infrastructure to different carbon dioxide targets, the importance of CCS infrastructure system planning was emphasized, and the key research areas of CCS infrastructure in the future were determined.

The results of case studies accounted for 23.8%, and they provided references for future research. Rubin ES uses different power plants as research objects to evaluate the current cost of CCS for new fossil fuel power plants and compared these results with the costs reported in the IPCC Special Report on Carbon Dioxide Capture and Storage ten years ago. Boot-Handford et al. (2013) introduced the current pilot plants and demonstrations, as well as the importance of optimizing the CCS system as a whole. Koornneef (2008) used the life cycle assessment method to evaluate the environmental impact of three pulverized coal power supply chains with CCS and without CCS. Minx et al. (2018) used scientific measurement tools and conducted an in-depth evaluation of the quantitative and qualitative evidence in NETs.

4.4 Co-word Analysis

4.4.1 Network of Co-occurring Keywords

Co-occurrence keyword analysis provides essential information about core research content and contributes scholars to tracking the development of research topics at different phases. CiteSpace analysis results are as follows: N = 94, Link = 117, and Density = 0.0268.

High-frequency words can be identified from Fig. 9. "Carbon capture and storage" with a frequency of 366 is the

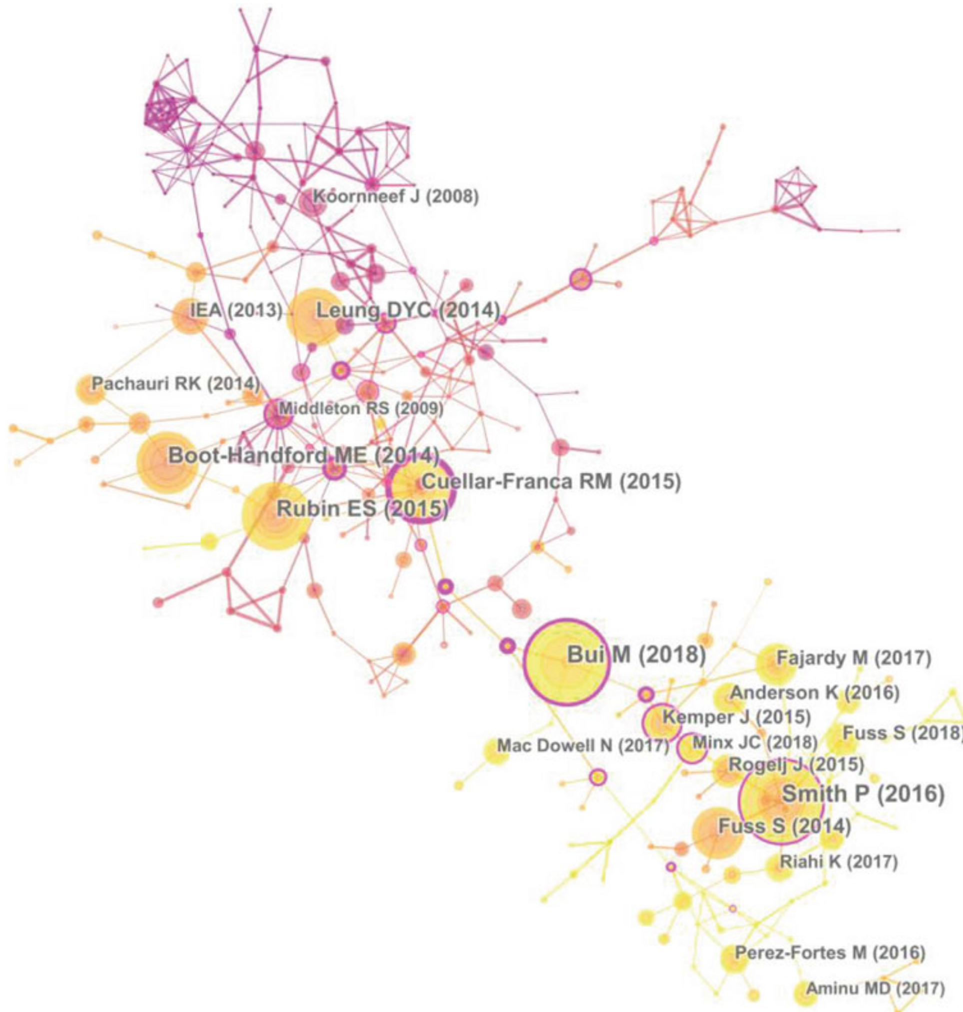


Fig. 8 Most frequently co-cited publications

most important keyword. Related high-frequency keywords are “storage” (Count = 312), “co2 capture” (Count = 296), and “cc” (Count = 277). Other frequently used keywords are “technology” (Count = 216), “carbon capture” (Count = 214), “carbon dioxide” (Count = 204), “capture” (Count = 181), and “co2” (Count = 168).

Keywords with high centrality are “Dioxide” (Centrality [Centr] = 0.80), “power plant” (Centr = 0.78), “life cycle assessment” (Centr = 0.55), “emission” (Centr = 0.43), and “plant” (Centr = 0.43).

In addition, the keywords closely related to research content of CCUS are “energy,” “cost,” “climate change,” “system,” “performance,” “model,” “impact,” “bioma,” “carbon dioxide capture,” “transport,” “bioenergy,” “chemical looping combustion,” “renewable energy,” and “coal.”

4.4.2 Network of Co-occurring Categories

According to the CiteSpace 5.6.R3, we found 27 topic categories, ten of which have a frequency of more than 100 times. The co-occurrence network analysis of the most common subject categories from 2011 to 2021 is shown in the Figs. 10 and 11.

Engineering is the largest node with a frequency of 1203, followed by Energy & Fuels (Count = 1026) and Engineering, Chemical (Count = 903). Among the top ten disciplines, Environmental Sciences has the highest centrality (Centr = 0.47) and plays a key role in the field of non-point sources 0. In second place is Engineering, followed by Environmental Studies (Centr = 0.26), Engineering & Environmental (Centr = 0.21), Green & Sustainable Science & Technology (Centr = 0.15), Engineering & Civil (Centr = 0.18), and Science & Technology-Other Topics (Centr = 0.17).

The earliest non-point source study involves Engineering & Environmental, Science & Technology-Other Topics, Green & Sustainable Science & Technology, and other fields, followed by Engineering and Environmental Sciences. Non-point source study covers fields ranging from

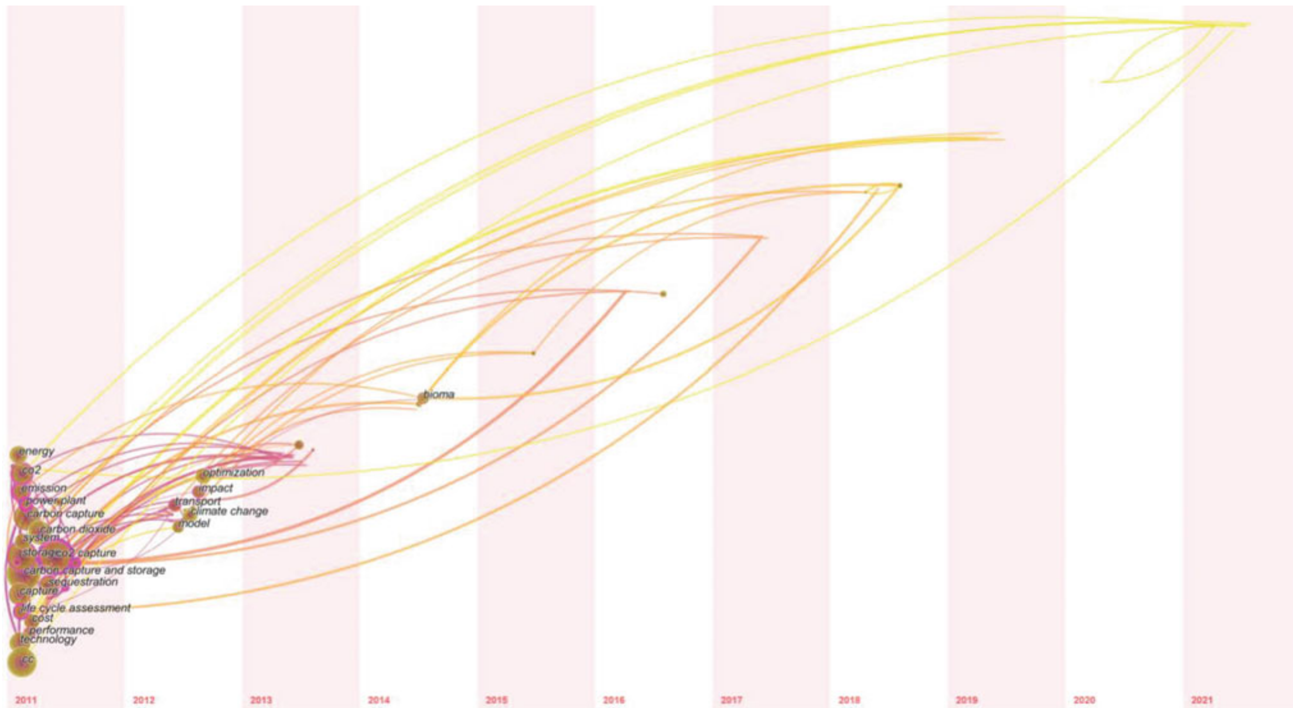


Fig. 9 Keywords co-occurrence time zone network

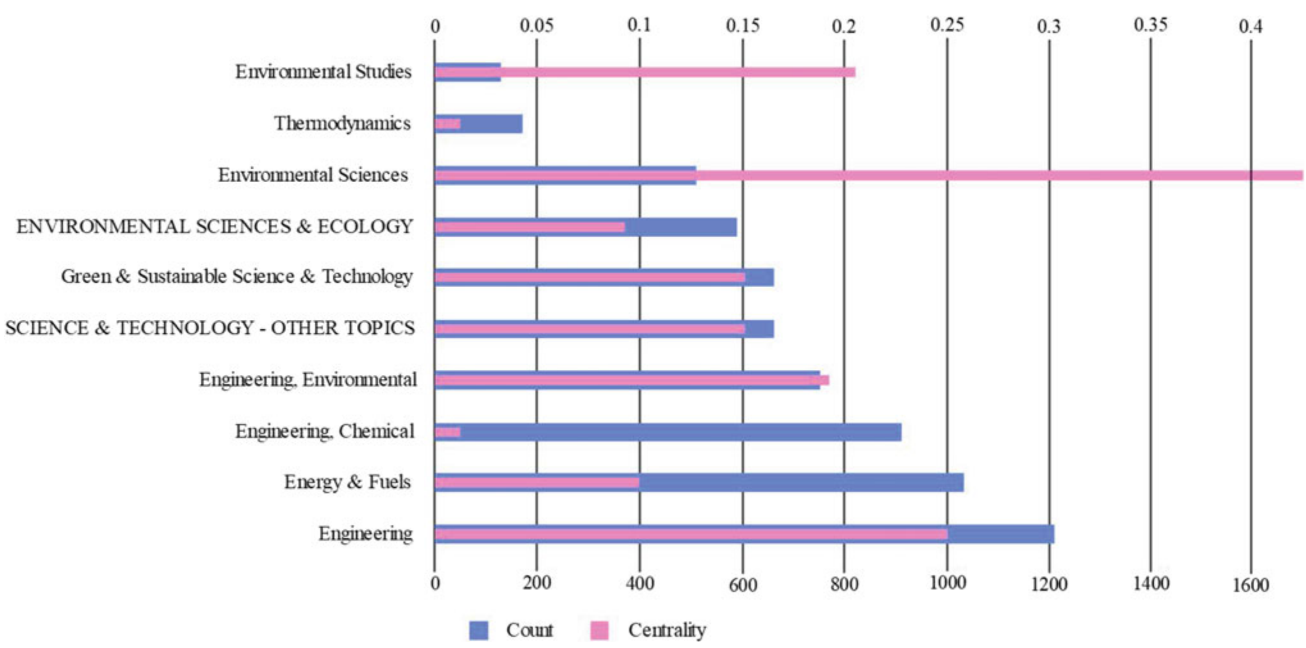


Fig. 10 Topic categories that have been cited more than 100 times

Environmental Sciences & Ecology to Meteorology & Atmospheric Sciences, Thermodynamics, Engineering, Electrical & Electronic, and Construction & Building Technology. The interdisciplinary development of various disciplines has made great contributions to the integration of CCUS research into multidisciplinary science.

5 Conclusions

Industry is the foundation of modern society and the source of economic development. While bringing economic benefits and job opportunities, it also brings many problems.

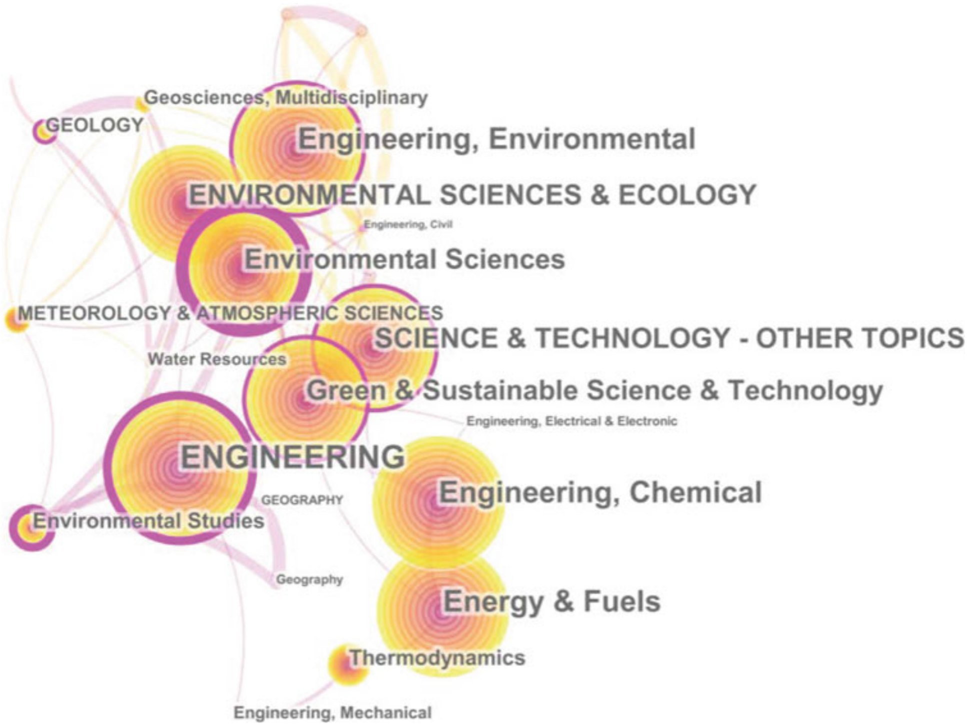


Fig. 11 The 27 categories of CCUS research

Industry consumes one-third of the world's energy, but produces one-third of the world's greenhouse gases. CCUS technology will play a vital role in the process of coping with global warming, achieving the goal of near-zero emissions, and achieving the roadmap for global temperature control of 1.5 °C in the future.

We use CiteSpace to conduct a quantitative and visual review of CCUS academic achievements and progress. The main findings of basic bibliometric analysis show that from 2011 to 2021, CCUS research on a global scale shows an accelerated growth trend. Among them, the United States is the country with the most publications. The United States has added 12 new CCUS commercial projects in 2020. The number of CCUS projects in operation increased to 38, accounting for about half of the total number of global operating projects, and the CO_2 capture volume exceeded 30 million tons. As the country with the highest carbon emissions, China's total carbon emissions are still increasing. From the point of view of the years to achieve "carbon neutrality," time is more pressing than in developed countries, and the slope of carbon emission decline is greater.

The results of literature co-citation analysis show that BECCS research is an important part of solving carbon emission problems. In addition, the capture and utilization of carbon dioxide and environmental impact have always been research hotspots; energy system transformation is essential to reduce carbon emissions. The subject category co-occurrence network analysis shows that the research subjects related to CCUS are cited and interrelated, which reflects the importance of the cross-development of various disciplines in scientific research.

This study has certain limitations. (1) Because CCUS covers a wide range of fields, we cannot get CCUS-related articles based on the criteria for selecting publications. As CCUS research becomes more abundant and complete, future bibliometric analysis can consider adding more databases and non-English publications in order to better provide development strategies for CCUS research. (2) Due to the data format setting problem of the CietSpace software, some small errors occurred during the research process. However, we try our best to avoid the interference of human factors and carry out research based on the latest data to ensure the reliability of the data. Based on this, in the future, we will conduct a more in-depth content interpretation and policy analysis based on the direction of this research.

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Using Air2water Model to Predict the Water Temperature of Fuxian Lake

Tingfang Jia and Yi Luo

Abstract

Lake surface water temperature (LSWT), known as the sentinel of climate change, is also a significant factor affecting the water ecological environment. The study found that the LSWT of global lakes increased at 0.03–0.04 °C/a, close to or exceeding the warming trend of temperature, resulting in serious water ecological problems. Therefore, it is urgent to understand the change trend of LSWT, so as to provide basis for relevant departments to formulate water policies. Air2water model only correlates the LSWT with the air temperature (AT), which can accurately capture historical long-term trends and inter-annual fluctuations. It could be used to monitor the lakes in answer to climate change. In this article, using the monthly average AT data of the Lake Fuxian basin in Yunnan Province from 1981 to 2020 and the MOD11A2 LSWT of Lake FuXian data from 2005 to 2018, the air2water model was used to predict the 40-year LSWT. The experimental results show that there is an alternating phenomenon of warm and cold cycles in the 40-year research interval, and the overall trend is increasing. The AT increases at approximately 0.0279 °C/a, using air2water Simulation LSWT at 0.0142 °C/a, but MOD11A2 LSWT increases at approximately 0.0337 °C/a. The reason may be that factors other than climate factors, such as human activities, are not considered.

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Keywords

Air2water model • Lake surface water temperature • Prediction • MOD11A2 • Air temperature

1 Introduction

Lakes have been called the climate change's sentinels and the lake water temperature, one of the main responses to climate change (Woolway & Merchant, 2017). It is very important to lake physics, chemistry and biodynamics (Williamson et al., 2009), and plays a crucial role in lake aquatic ecosystems (such as dissolved oxygen concentration, and fish growth.) (MacKay et al., 2009; Wetzel, 2001). LSWT refers to the water temperature in a lake ranging from 0 to 1 m (Sharma et al., 2015), which shows a rapid and direct response to climate forcing (O'Reilly et al., 2015), and it is known as a valuable index to evaluate the impact of climate change (Adrian et al., 2009). Moreover, because LSWT data are easier to obtain than other lake attributes, many scholars' studies on climate change focus on the long-term dynamic change trend of LSWT, especially for large lakes (Hampton et al., 2008).

Lakes contain about 87% of the fresh water on the earth's surface and are considered to be one of the most biodiversity ecosystems in the world. Long-term climate change causes a serious threat to lake ecosystems, especially the accelerated warming of average temperature in recent years (Kardol et al., 2018; Zheng et al., 2021). Research in recent decades has found that the LSWT of global lakes increased at 0.03–0.04 °C/a, close to or exceeding the warming trend of air temperature (AT) at 0.025 °C/a. The increase of LSWT has led to a series of eco-environmental problems, such as lake cyanobacteria outbreak and changes in biological community structure. (Kraemer et al., 2021). In addition, the study also found that there are huge spatial differences in the change trend of LSWT in many lakes around the world

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(Mason et al., 2016; O'Reilly et al., 2015; Schneider & Hook, 2010) and so far as to the opposite trend was observed (Zhang et al., 2014). Consequently, it is essential to conduct a regional study on the dynamic change of LSWT, so as to better explain the interaction between climate change and local hydrological conditions, reveal the causes of LSWT change, and provide a basis for the formulation of water use and water treatment policies designated by relevant departments.

2 Study Area

Lake Fuxian, as shown in Fig. 1, is located 5 km south of ChengJiang and more than 70 km away from Kunming. It is a famous fresh water lake in China. The elevation of the lake is 1722.5 m; the lake area is 214.6 km^2; the deepest point is 158.5 m, and the average depth is 87.8 m. The water storage capacity of the lake is 20.62 billion cubic meters, accounting for 72.8% of the total water storage capacity of the nine lakes on the Yunnan Plateau and 9.16% of the total water storage capacity of the national freshwater lakes. The water quality of Lake Fuxian is Class I, a national first-class drinking water source, and is one of the natural lakes with the best water quality in China. In December 2013, the 2013 river and lake ecological environmental protection work organized by the Ministry of Finance and the Ministry of Environmental Protection was approved, and it was included in the national 15 key lakes support scope. It is particularly important to study the trend of water temperature changes in Lake Fuxian and to provide a basis of controlling and improving regional ecological environment.

3 Data Sources

3.1 AT Data

In this article, the air temperature (AT) data used are ERA5-Land monthly averaged data from 1981 to present (https://cds.climate.copernicus.eu/). It was generated by re-running the terrestrial portion of the ECMWF ERA5 climate reanalysis. Reanalysis combines model data with observations from around the world, using the laws of physics, to form a globally complete and consistent dataset. The reanalysis produced data going back decades, providing an accurate picture of past climates. This paper uses the 2 m temperature variable in the dataset.

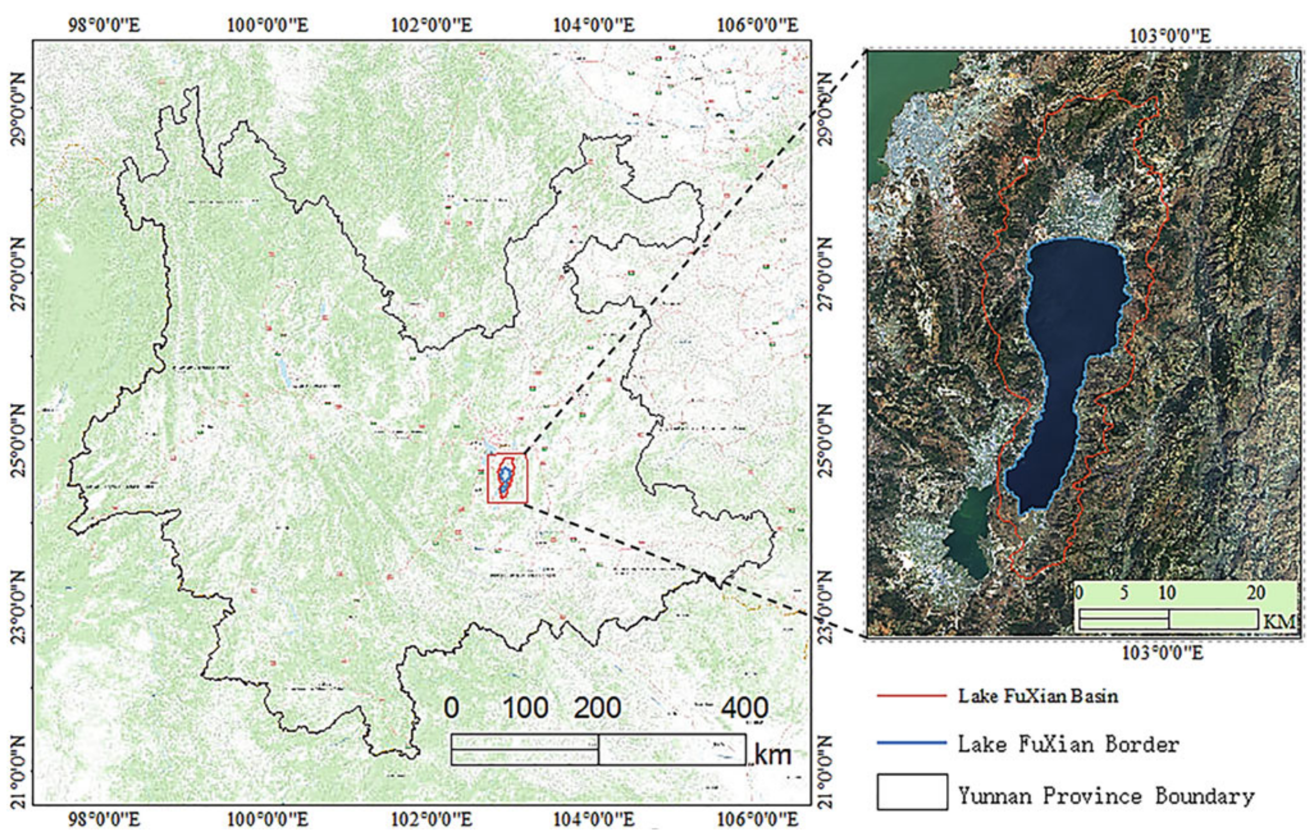

Fig. 1 Lake Fuxian

3.2 LSWT Data

Although the situ observation of LSWT has high accuracy, but most of these data are short-time, intermittent, and sparse local observation data. It is difficult to meet the requirements in spatial resolution and time resolution, and the accuracy of data can't be guaranteed. With the development of space RS technology, a variety of RS images can greatly overcome the limitations of in situ monitoring. Land surface temperature retrieve based on RS image provides the only possibility for global LSWT measurement. MODIS has high time resolution and free reception. It can obtain atmospheric, land, glacier, and hydrological information at the same time. It has a great application prospect in LSWT remote sensing monitoring. The water temperature data used in this article are based on the monthly average LSWT data from 2005 to 2018 based on MOD11A2 data. The MOD11A2 Level-3 MODIS land surface temperature (LST) and emissivity 8-day products are composed of the data from the daily 1-km LST product MOD11A2 is comprised of day (10:30) and night (22:30)' LST.

4 Air2water Model

Air2water is a hybrid model based on physics/statistics in which LSWT can be simulated and predicted only by knowing AT data (Piccolroaz, 2016). The model can accurately capture long-term trends and interannual fluctuations of historical or future LSWT and is suitable for longer time scales (from month to year) (Piccolroaz et al., 2013).

The air2water model has the form of ordinary differential equations, contains several parameters (different 4, 6, or 8 parameters), which illustrates the overall heat exchange with the atmosphere and the deep layer of the lake through a simplified relationship. Use AT and water temperature measurements for calibration. The calibration of the parameters allows one to estimate the influence of the main processes controlling the thermodynamics of the lake in a comprehensive manner and recognizes that the AT is the primary factor actuating the evolution of the system. As a matter of fact, under certain assumptions, changes in AT implicitly contain correct information about other main processes, so they are regarded as the only input variable in this method (Piccolroaz et al., 2013, 2015, 2017; Piccolroaz, 2016).

It was found that the performance achieved by the air2water model was fully comparable to that achieved by more complex process-based models (Piccolroaz, 2016), but process-based models require a large amount of input data, which are often very difficult to obtain. Piccolroaz et al. (2017) applied this model in different temperature datasets, and the research results show that the water temperature accuracy simulated by air2water model is very good regardless of the input dataset (root mean square error of monthly calculation ≤ 0.58 k) (Piccolroaz et al., 2017).

Using air2water model to predict LSWT, the series of observed AT data must be complete. To predict LSWT using the air2water model, the AT data column must be full daily resolution data. It can't have gaps or no data. If the AT data are incomplete, it can be filled with linear interpolation. Water temperature data can be discontinuous. If the water temperature data are not available, it needs to be filled with the value −999. The specific processing flow is shown in Fig. 2.

4.1 The Processing Steps for AT Data

- Since the downloaded temperature data format is.nc, you need to use the "Select by Dimensions" tool in the ArcGIS software for batch processing to obtain 480 AT image maps for each month from 1981 to 2020.
- Use ArcGIS software to extract the Lake Fuxian basin.
- Use the vector map of the Lake Fuxian basin as a mask to clip the images of step 1 to obtain monthly mean AT images of this basin. Use the average temperature of the basin rather than lake surface, taking into account the influence range of climatic factors.
- Write a Python script in the ArcGIS software to create a tool (named "raster mean tool") that can calculate the average value of all raster image pixels of a specified file type (such as .tif) under a given folder path. Calculate the average value of AT in this basin for each month from 1981 to 2020.

4.2 The Processing Steps of MOD11A2 LSWT Data

- Use MRT tool to reproject MOD11A2 LSWT data.
- Use ArcGIS software to spatially interpolate the empty value area in the LSWT data.
- Synthesize the 8-day daytime and nighttime LSWTs data to obtain the monthly average images of the LSWT for each month from 2005 to 2018.
- The normalized difference water index (NDWI) is used in ENVI software to extract the boundary of Lake Fuxian.
- Use the vector map of the lake boundary as a mask to clip the image in step 3 to obtain the LSWT image of Lake Fuxian.
- Use "raster mean tool" to calculate the average value of LSWT of Lake Fuxian for each month from 2005 to 2018.

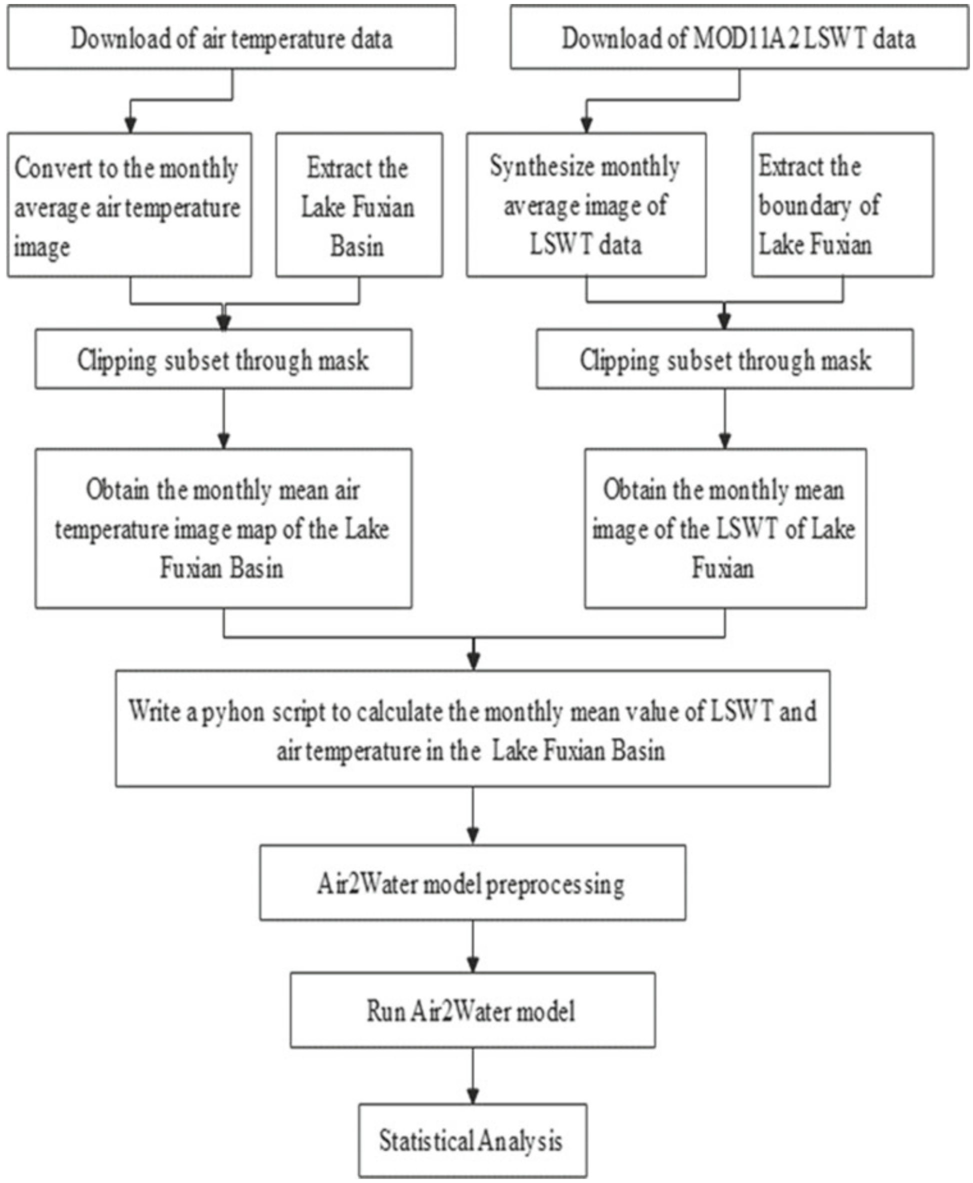

Fig. 2 LSWT predicts processing flow

4.3 Preprocessing of Air2water Model

This process requires running the parameter preprocessing script in MATLAB, inputting the average depth of Lake Fuxian, and estimating the reasonable variation range of the eight parameters in the model, as the Table 1.

4.4 Run Air2water Model

Use the AT data obtained in 4.1 and the LSWT temperature obtained in 4.2 as input data. In this article, considering 14 years of MOD11A2 LSWT data, the first 9 years' data were used for model calibration, and the data of the last 5 years were used for model validation.

5 Result

Figure 3a is a scatter plot of AT data, MOD11A2 LSWT data and simulated LSWT data by air2water from 2005 to 2018. It can be seen that the LSWT of Lake Fuxian with an average depth of 87.7 m exhibits obvious hysteresis cycle changes. The RMSE between MOD11A2 LSWT and Simulation LSWT is 0.916 °C, and the reason may be caused by the superposition of the error retrieved by MOD11A2 and the error of the air2water model itself. Figure 3b shows that there is an obvious linear correlation between MOD11A2 LSWT and Simulation LSWT.

Figure 4 is the month mean analysis line chart of AT data, MOD11A2 LSWT data, and air2water simulation

Table 1 Variation range of 8 parameters

Parameter	a_1	a_2	a_3	a_4	a_5	a_6	a_7	a_8
Minimum value	−0.26758	0.00134	0.00227	1.00000	0.00000	0.00000	0.00000	0.00000
Maximum value	2.00000	0.07864	0.31115	20.89056	4.58118	1.00000	150.00000	0.50000

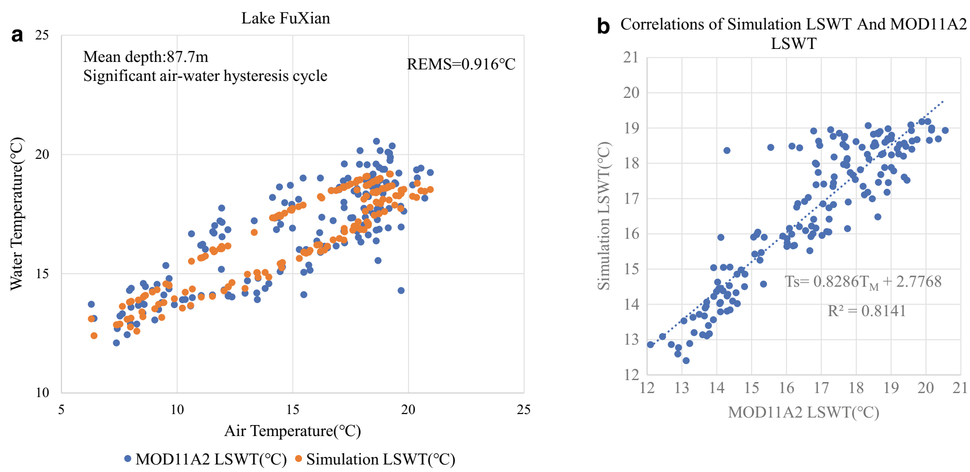

Fig. 3 Scatter plot of Simulation LSWT data, MOD11A2 LSWT data, and AT data

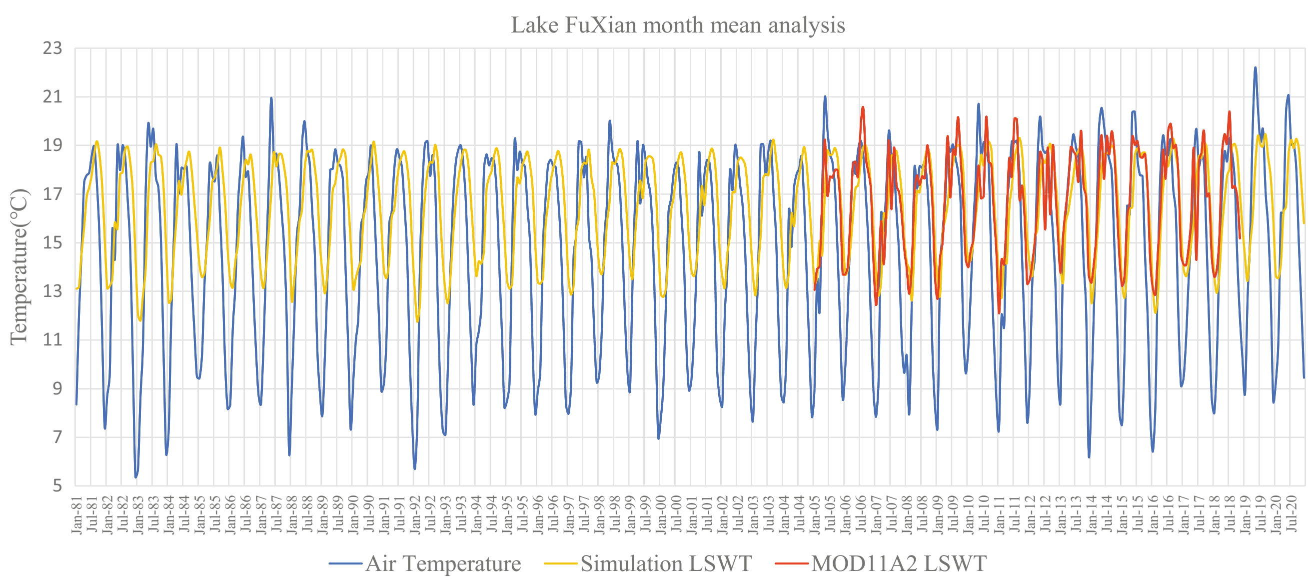

Fig. 4 Month mean analysis line chart of simulation LSWT data, MOD11A2 LSWT data, and AT data

LSWT data from 1981 to 2020. It can also be seen that LSWT and AT have significant hysteresis cycle. The figure shows that the low temperature value generally lasts relatively short in December or January each year, and the high temperature value generally lasts from May to September each year and lasts longer. Compared with AT, LSWT has obvious lag, which is related to large and deep lakes with large thermal inertia.

Figure 5 shows a line chart of the annual average analysis of AT data, MOD11A2 LSWT data, and air2water simulated LSWT data from 1981 to 2020. It can be seen from this figure that warm years and cold years alternate in this 40-year interval, and the overall trend is increasing. The AT is increasing by about 0.0279 °C/a and the air2water Simulation LSWT is increasing by 0.0142 °C/a. The MOD11A2 LSWT grows at a rate of approximately 0.0337 °C/a.

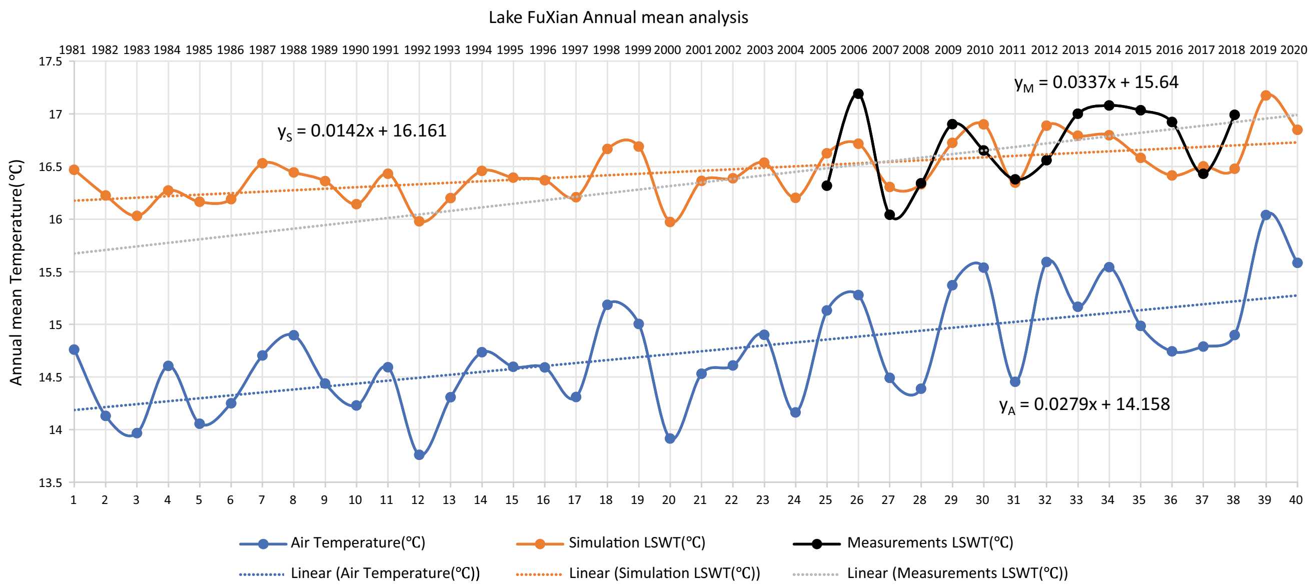

Fig. 5 Annual mean analysis line chart of simulation LSWT data, MOD11A2 LSWT data, and AT data

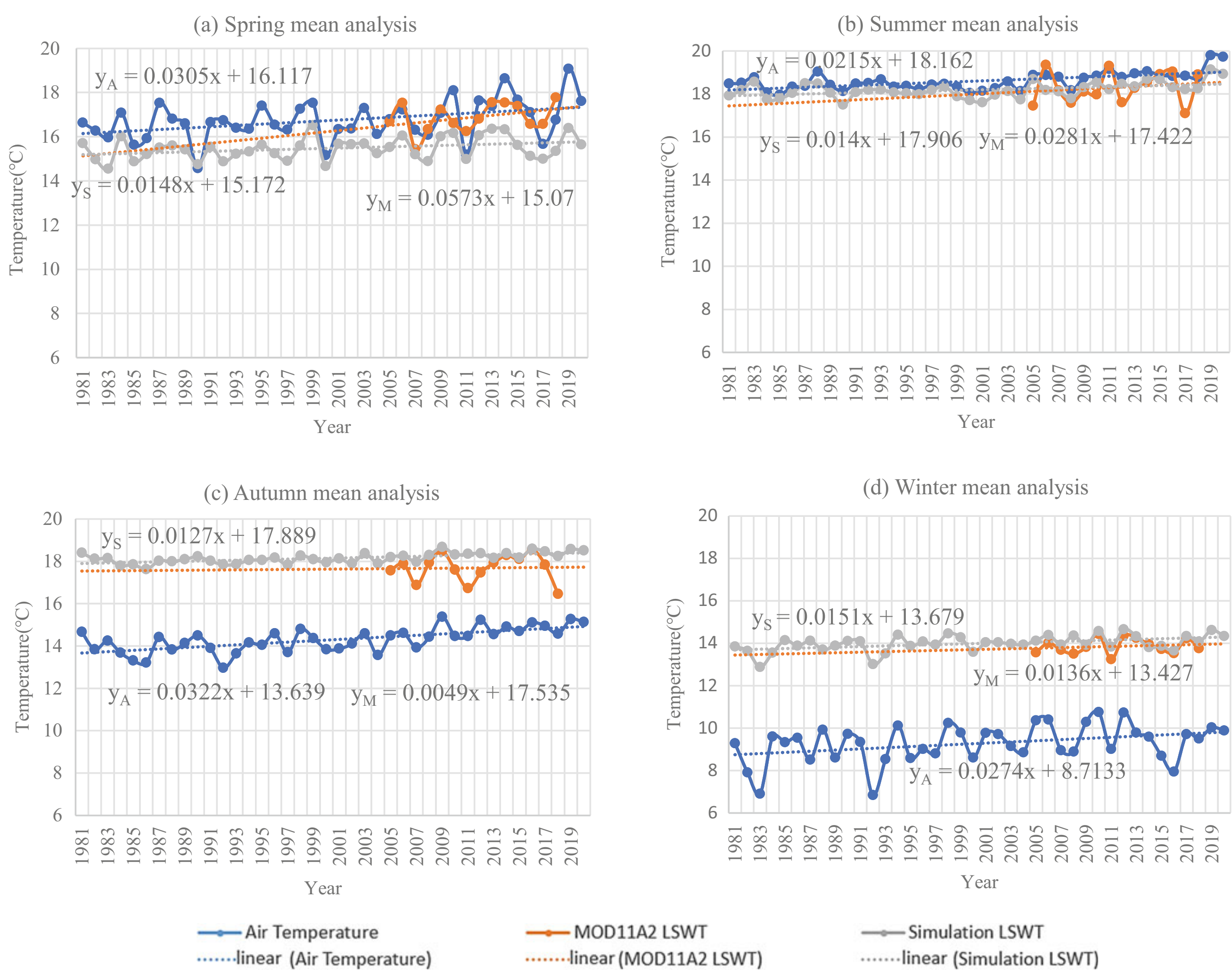

Fig. 6 Season mean analysis Line chart of Simulation LSWT data, MOD11A2 LSWT data and AT data

Figure 6 is a line chart analyzed by season. It can be seen from the figure that the highest growth rate of MOD11A2 LSWT in spring in this region is 0.0573 °C/a, and the change rate of AT is relatively high at 0.0305 °C/a; the highest growth rate of AT in autumn is 0.0322 °C/a, while the growth rate of MOD11A2 LSWT is the lowest; the growth rate of Simulation LSWT in each season is basically the same; the temperature difference between AT and LSWT in spring and summer is small, while the temperature difference between autumn and winter is the large. The minimum temperature difference between AT and LSWT in summer is less than 0.6 °C, and the maximum temperature difference in winter is more than 4 °C.

6 Conclusion

Air2water is a simple tool that can promote scholars without modeling or physics background to use the model to quickly simulate and predict the changes of LSWT. Using the air2water model to predict the Lake Fuxian LSWT, it can be seen that LSWT has been on the rise for nearly half a century. The increased rate of MOD11A2 LSWT is significantly higher than that of AT, especially higher than that of air2water Simulation LSWT. The reason may be caused by the superposition of the error retrieved by MOD11A2 and the error of air2water model itself. The error of MOD11A2 data mainly comes from the error of retrieval model, and the lack of data caused by problems such as cloud coverage. The main reason for the error of air2water model is that it does not consider factors other than climate factors, such as land use classification, increase and distribution of impervious surface area, population distribution, and economic development. Due to time reasons, this article uses the monthly average value of AT to simulate LSWT. If you use shorter time scale daily AT data to simulate, the effect may be better. Later, work will add in situ data to verify the predicted LSWT and MOD11A2 LSWT data and further analyze and study the factors that affect the LSWT increase, hoping to improve the lake ecology provide a basis for governance.

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Impact of Urban Park Allocation on Local Geothermal Environment: Case Study of Chaoyang, China

Zi-qi Zhao, Li-du Shen, Li-guang Li, Hong-bo Wang, Jing Liu, Xian-li Zhao, and Bao-Jie He

Abstract

This study analyzed the composition and cooling effect of six green parks in Chaoyang City, China. Based on land surface temperature retrieved from Landsat 8 thermal images during different periods, the relationship between park composition and their temperature, and the cooling effect on surrounding environment were investigated through buffer analysis. The results indicated that the park with more healthy and robust trees had lower temperatures in hot seasons. Vegetation status was a main contributor to the park cooling effect which varied with seasons. Season had a large impact on the surface temperature and cooling effect of the park.

Keywords

Landsat 8 • Land surface temperature • Urban park • Cooling effect • Park composition

1 Introduction

With urban population increase and urban structure modification, many areas undergo urban heat islands (UHIs) that cities are warmer compared to their surrounding rural or suburban areas. Urban warming problem has serious impacts on urban system and ecological environment, such as the increase in energy and water use, the increase in morbidity and mortality, human thermal comfort reduction and ecosystem deterioration (Oke, 1995). Moreover, UHIs have been a common challenge of urbanization and almost all cities are experiencing UHIs (Stewart, 2011). Nevertheless, urbanization is keeping increasing and it is estimated that the urbanized ratio will reach 66% in 2050, implying that UHIs will be further aggravated with high possibilities (United Nations, 2014). Previous studies have verified that the increase in impervious surfaces (buildings and roads) and the decrease of the urban permeable surfaces (green space and water body) contribute largely to the formation and aggravation of UHIs (Zhao et al., 2017).

Mitigation techniques and strategies have therefore received much attention for addressing UHI challenges, such as cool roofing and pavement materials, water bodies, green space and urban form (He et al., 2021). In particular, there has been numerous studies on cooling performance of green space. For instance, Ca et al. (1998) found that surface temperature of green spaces was 19 and 15 °C lower than that of asphalt and concrete, by measuring the temperature inside and outside a park in Tokyo, Japan. Feyisa et al. (2014) analyzed the cold island effect of 21 large parks in Denmark, pointing out that the cold island intensity of park green space could reach 6.72 °C and cooling range could

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reach 240 m. Moreover, urban green infrastructure has attracted much attention because of its cost-efficient advantages, water and air purification, reducing urban noise reduction and providing public recreational spaces (Zhang & He, 2021). In urban planning and design, therefore, green space construction will be an important mean to alleviate UHIs. Generally, the cooling performance of green space relies on the transpiration and shading effect of vegetation (Ng et al., 2012); However, the cold island effect and cooling range of urban green space mainly rely on the composition and layout traits of green space (Feyisa et al., 2014; Ren et al., 2013). The cold island effect of urban green space has been widely investigated in the contexts and climates of Beijing, Shanghai, Guangzhou and Changchun, concluding that park area, perimeter, shape index, vegetation coverage, green plant distribution and vegetation type can influence cold island intensity and cooling ranges (Chen et al., 2012, 2014; Yang et al., 2017a, 2017b).

However, previous studies have mainly analyzed the influence of the traits of large green space, while the impact of the surrounding environment of green spaces on cooling ranges and the variations of outer cooling performance has been rarely analyzed. Wong and Yu (2005) studied the cold island effect of a large park in Singapore, and found that the cold island effect was stronger when building density around the park was low. However, when the area around the park was the central urban area, the cold island effect was not obvious. Lin et al. (2017) studied 12 parks in high-density areas in Hong Kong, and found that the green space and the surrounding architectural features jointly influenced the local UHIs. Overall, analyzing the relationship between surrounding environment of the park and the cold island effect will help to understand how to improve the cooling effect of the park and extend the sphere of cold island effect. This study is therefore designed to support this by the case study in Chaoyang City, a national forest pilot city in Liaoning, China. This study will answer the following questions: What is the impact of the local environment around the park green space on the cold island effect? How to adjust the layout of surrounding buildings to enhance the intensity of green space cold island effect and extend the range of green space cold island effect?

1.1 Methods

1.1.1 Study Area

Chaoyang, located at the border of Hebei, Inner Mongolia and Liaoning provinces, with a total area of 19,698 km^2, is an important part of the Bohai Economic Circle (Fig. 1). On the one hand, the northern part of Chaoyang City is greatly influenced by the high pressure of Mongolia Plateau, while the southeastern part of Chaoyang City is blocked by Yanshan Mountains, which makes the warm and humid air flow in Bohai Sea unable to flow into the territory, thus making it semi-arid and semi-humid and prone to drought. Therefore, the annual average days with high temperature, heatwaves and severe high temperatures in Chaoyang City are much higher than those in other cities in Liaoning Province.

Chaoyang is located in the northern temperate continental monsoon climate region. Although the southeast is affected by the warm and moist ocean, a semi-dry, semi-humid and easily dry area is formed due to the frequent invasion of dry and cold air in the northern Inner Mongolian plateau. There are four distinct seasons, rain and heat in the same season, sufficient sunshine, large daily temperature difference and less precipitation. The annual average temperature is 5.4–8.7 °C, annual average sunshine duration is 2850–2950 h, annual precipitation is 450–580 mm and the frost-free season is 120–155 days. Spring and autumn are windy and prone to drought. The wind force is usually level 2–3. The temperature is high in summer, and the northwest wind prevails in winter. All built-up areas have a green area of 14.8321×10^6 m^2, a green coverage area of 15.1437×10^6 m^2 (27.80%).

Six parks including regular and irregular parks in the center of Chaoyang City were selected to complete the research aim of this study. As shown in Fig. 1, the composition and structure of such six parks are different. The Renmin Park (rmgy) is in the central area of the city. It was built earlier and the trees are flourishing. It is a place for nearby residents to relax, entertain and relieve summer heat. Beita Park (btgy) and Shangzhi park (szgy) are similar in their square shape, and the road pavement area in the park higher than others. Linghe Park (lhgy) and Qilin park (qlgy) are newly-built riverside parks, near the river embankment. The trees are transplanted in recent years. Yandu park (ydgy) is in the central newly-built urban area of Chaoyang City. It is similar to the park form of square. It will be basically completed around 2020. At present, the planting of some trees is still in progress.

1.1.2 Land Surface Temperature (LST) Retrieval

LST information and the studied area information were derived from Landsat 8 images (at the path/row of 121/31). To explore the monthly variation of LST and SUHII, we downloaded 12 remotely sensed thermal infrared images (resolution: 30 m) (Table 1) collected by the United States Geological Survey at the website http://earthexplorer.usgs.gov, to show the thermal information at 10:27 am local Chaoyang time with a cloud coverage below 0.1% (Zhao

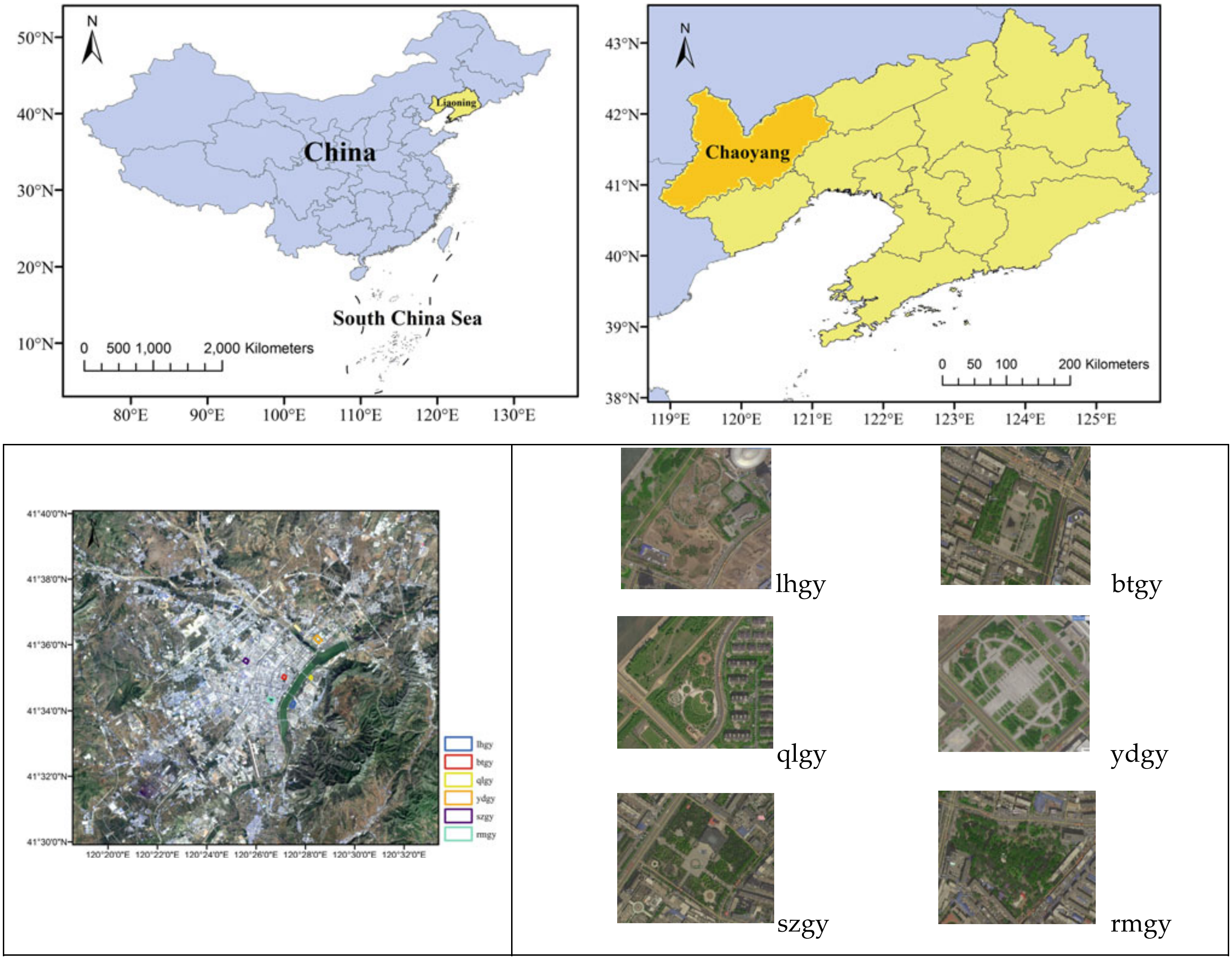

Fig. 1 Location of the study area and the six parks

Table 1 Date list and weather conditions for different months corresponding to 5 thermal infrared imageries

Date	Air temperature/°C	Relative humidity/%	Maximum temperature/°C	Minimum temperature/°C
2020–03–30	15.0	26	18	5
2020–05–01	29.6	36	35	17
2020–07–20	27.9	35	34	19
2020–08–21	22.2	47	23	19
2020–10–24	10.1	35	19	9

et al., 2021). Additional meteorological conditions from 10:00 to11:00 am (UTC + 8) were collected from the local Bureau of Meteorology (Table 1).

The split window algorithm proposed by Qin et al. (2001) was used to retrieve LST from the only spectral band of Thermal Infrared Sensor (TIRS) 10 in Landsat 8. The calculation of surface temperature theoretically requires correction of emissivity and atmosphere. Therefore, the LST was calculated after the atmospheric correction of reflective and thermal bands. Based on the retrieval algorithm of image, it is approximately considered that the influence degree of atmosphere is consistent (Ding & Xu, 2008) when there is no cloud and the study area is small, and the emissivity is corrected (Eq. (1)).

$$T_a = \frac{T_b}{1 + (\lambda \times \frac{T_b}{\rho}) \ln \varepsilon} \quad (1)$$

where T_a is the surface temperature, and T_b is the surface bright temperature. T_b was obtained by thermal infrared remote sensing recorder which particularly collects the sum of radiation emitted by surface objects, environment and atmosphere. Image-based inversion algorithm (Ding & Xu, 2008) was employed for extracting brightness temperature from TM/ETM + 6 band and 6L data. The digital number (DN) was converted into the corresponding thermal radiation intensity value, and T_b was expressed by Eq. (2).

$$T_b = \frac{K_2}{\ln\left(\frac{K_1}{L_\lambda} + 1\right)} \quad (2)$$

where K_1 and K_2 are constant. In Landsat 5 TM, K_1 = 607.76 W/(m^2 sr m), K_2 = 1260.56 K. In Landsat 7 ETM+, K_1 = 666.093 W/(m^2 sr m), K_2 = 1282.7108 K.

$$L_\lambda = L_{\min} + \frac{L_{\max} - L_{\min}}{255} \mathrm{DN} \quad (3)$$

where $L_{\max}$ and $L_{\min}$ are, respectively, the highest and lowest radiation values that can be detected by the detector in this band, which can be gotten from the parameters of L1T header file. DN value is the value of band 6 of TM data and ETM+ data is the value of band 6L.

In Eq. (1), λ = 11.5 μm is the central wavelength of thermal infrared band. In ρ = h × c/σ (1.438 × 10^{-2} mK), the speed of light c = 2.988 × 10^8 m/s and Planck constant h = 6.626 × 10^{-34} Js, Boltzmann constant σ = 1.38 × 10^{-23} J/K and ε is the urban surface emissivity shown in Eq. (4) (Qin et al., 2004).

$$\varepsilon = \varepsilon_m R_m (1 - \mathrm{Pv}) + \varepsilon_v R_v \mathrm{Pv} + 0.003796\ \mathrm{Pv} \quad (4)$$

where the emissivity of building surfaces ε_m = 0.970 (Qin et al., 2004), the temperature ratio of building surfaces $R_m = 0.9886 + 0.1287\ \mathrm{Pv}$ (Qin et al., 2004), the emissivity of vegetation surfaces ε_v = 0.986 (Humes et al., 1994), the temperature ratio of vegetation surfaces $R_v = 0.9332 + 0.0585\ \mathrm{Pv}$ (Qin et al., 2004) and Pv is the vegetation coverage of pixel, as shown in Eq. (5).

$$\mathrm{Pv} = \left(\frac{\mathrm{NDVI} - \mathrm{NDVI_s}}{\mathrm{NDVI_v} - \mathrm{NDVI_s}}\right)^2 \quad (5)$$

where NDVI is normalized difference vegetation index, $\mathrm{NDVI_s}$ and $\mathrm{NDVI_v}$ are NDVI values of bare soil and vegetation, respectively.

1.1.3 Calculation of NDBI, NDVI, MNDWI

Normal Differential Built-up Index (NDBI), Normal Differential Vegetation Index (NDVI), Modified Normal Differential Water Index (MNDWI) as shown in Eqs. (6)–(8).

$$\mathrm{NDVI} = \frac{\mathrm{TM}_4 - \mathrm{TM}_3}{\mathrm{TM}_4 + \mathrm{TM}_3} \quad (6)$$

$$\mathrm{NDBI} = \frac{\mathrm{TM}_5 - \mathrm{TM}_4}{\mathrm{TM}_5 + \mathrm{TM}_4} \quad (7)$$

$$\mathrm{MNDWI} = \frac{\mathrm{TM}_2 - \mathrm{TM}_5}{\mathrm{TM}_2 + \mathrm{TM}_5} \quad (8)$$

TM_2, TM_3, TM_4, TM_5 are the 2, 3, 4, 5 band data of TM and ETM+ data, respectively.

1.2 Results and Discussion

1.2.1 LST and Park Configuration

The internal configuration of three parks is shown in Table 2. The surface temperature of the park is greatly influenced by weather conditions, with the highest temperature in sunny summer and a cooler one in cloudy days. The rmgy is the only park with water body, and it is a park with long construction time and good maintenance. The lhgy and qlgy are riverside parks built in recent years. Combined with the LST in Fig. 2, it is found that rmgy was the park with the lowest LST among the three parks. But lhgy the temperature was higher in spring, qlgy was a park with high temperature in summer and autumn.

1.2.2 Impact of the Park on Surrounding LST

Figure 3 shows the LST dynamics within 450 m around four parks (rmgy, ydgy, szgy, btgy). The buffer zone method was used to establish 15 concentric rings with an interval of 30 m centered on the park. The temperature anomaly in Fig. 3 was the difference between the average LST in each ring and the overall temperature of the park. Different parks had different change characteristics. The temperature in the park was lower than outer temperature in summer and higher than the ambient temperature in autumn (24,102,020). The cooling effect on surrounding areas was about 180 m. The rmgy is a well tree maintenance park with relatively high vegetation

Table 2 Park internal configuration

Name	Area/m^2	*Macrophanerophytes*	*Frutex*	Gardens piece/m^2	Lawn/m^2	Flowers/m^2	Water/m^2	Water permeable brick/m^2	Bunkers/m^2	Asphalt road/m^2	Tartan/m^2	Buildings/m^2
rmgy	68,000	584	291	2097	13,327	894	7898	41,096	–	–	–	1777
lhgy	58,641	3497	256	7452	10,680	18,477	–	10,734	653	6222	984	–
qlgy	16,032	408	87	2770	5405	3802	–	3433	177	–	–	–

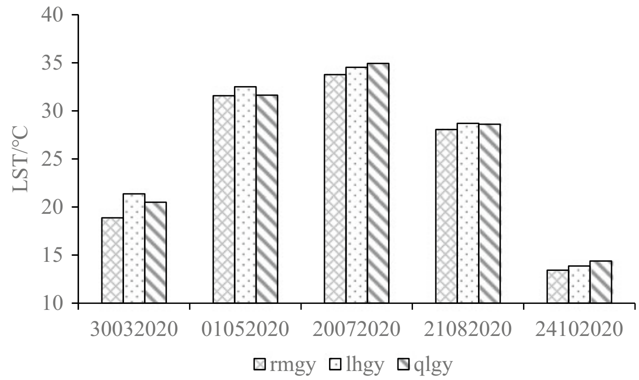

Fig. 2 Parks' land surface temperature

density. Its cooling effect was more obvious in summer (20,072,020 and 21,082,020) and relatively poor in spring. The ydgy is a newly-built Park mainly composed of square and grassland, which had no obvious cooling effect on the surrounding environment. The maximum temperature difference between the rmgy and the surrounding environment was 3.58 °C in July. From a seasonal point of view, the park in summer (July and August) was cooler that in the surrounding areas, except ydgy. The rmgy had the largest temperature difference, followed by btgy and szgy. In autumn, after the trees fell leaves, the temperature in the park was gradually higher than the surrounding ambient temperature. In summer, szgy and btgy have obvious cooling effect on the surrounding environment. However, in other times, there were obvious irregular conclusions.

1.3 Conclusion

The composition of the park was one of the main factors affecting the internal temperature and its cooling degree. From the perspective of park configuration, the park with more healthy and robust trees had lower temperatures. To sum up, vegetation status (trees) was one of the main factors affecting the cooling effect of the park, which varied with seasons (plant conditions, such as fallen leaves). The change of seasons had a huge influence on the surface temperature and cooling effect of the park.

Green space is recognized as an effective way of land use to alleviate UHIs. Although the overall green coverage rate of Chaoyang City is 15%, the green space is mainly distributed around the city and newly-built urban areas, while the green space area in the central urban area only accounts for 2.44% of its construction land area, resulting in a per capita public green space area of 0.38 km^2 in Chaoyang City, which is a green poverty-stricken area. How to rationally allocate green space (vegetation structure and garden design scheme) and surrounding environment

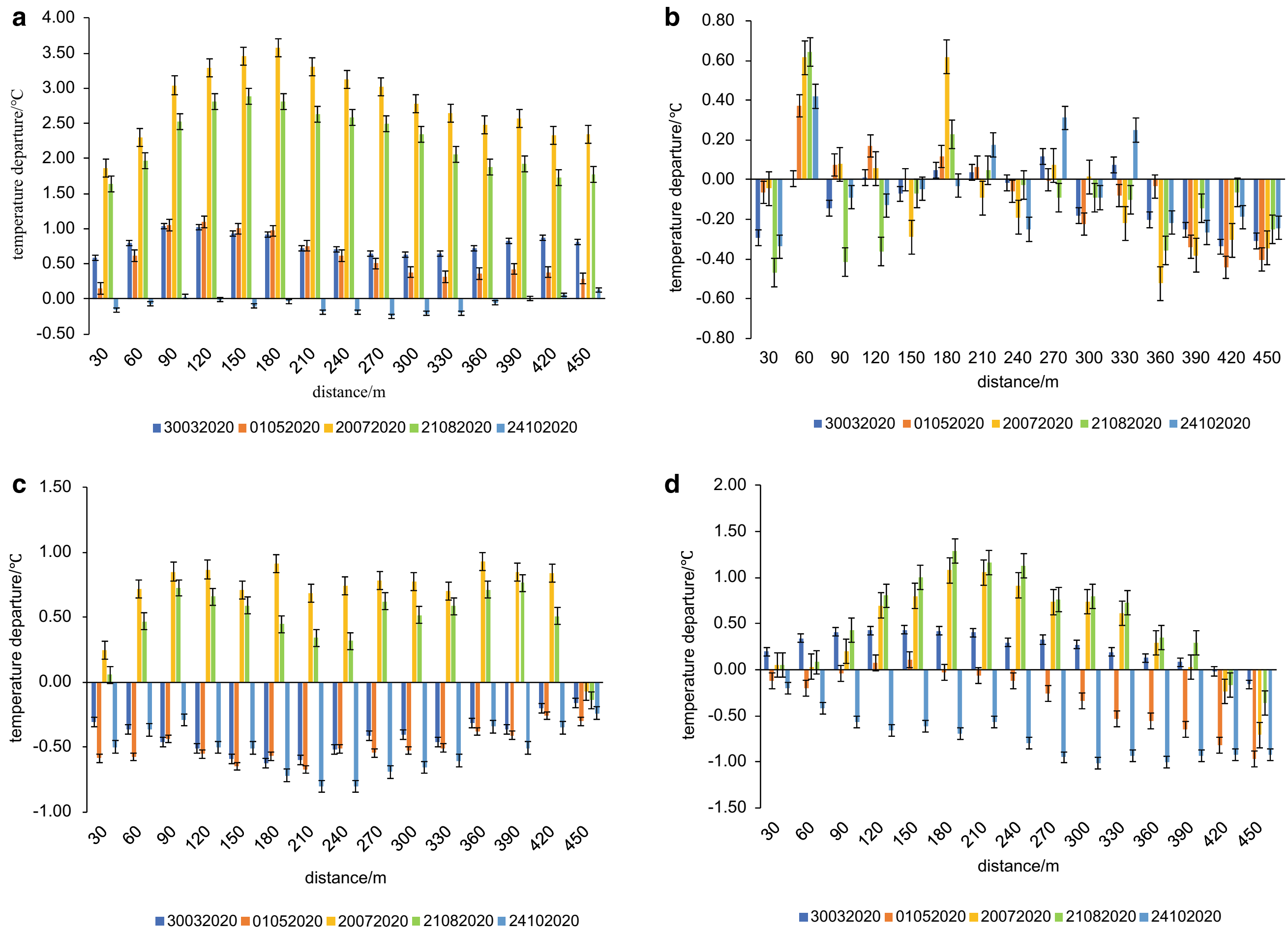

Fig. 3 rmgy (**a**), ydgy (**b**), szgy (**c**) and btgy (**d**) temperature departure

(building utilization mode), optimize urban green space, enhance the cooling and humidifying effect of urban green space, improve the livability of the city and reduce the further enhanced heat island effect in the future is of great significance.

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Mitigating the Impacts of Drought via Wastewater Conversion to Energy, Nutrients, Raw Materials, Food, and Potable Water

Simrat Kaur, Fatema Diwan, and Brad Reddersen

Abstract

Water management has become extremely challenging due to worst impacts of the climate change on the hydrological cycle due to unpredictable precipitation patterns. The harsh reality in some parts of the world today is that the daily showers and flushing of the toilets with the potable water has become unaffordable. Many cities in the world are facing the "Day zero" when millions of settlers are without adequate water both for households and industries. This scarcity is driven by ill-management of water resources by multiple parties, vulnerability to climate change, and the fast pace of economic and population growth. The single-biggest user of water worldwide is agriculture, followed by energy production, industry, and in last place household use. The climate crisis has multiple impacts, including from increasing heat and rising sea levels tied to global melting of the cryosphere. The draining of the aquifers and related saltwater intrusion from the oceans is already depleting freshwater resources at an increasing rate. While freshwater can be sourced via desalination, that path is expensive and energy intensive, effectively countering much of the good it might offer. It is for this reason efficient treatment and reuse of wastewater is the current best hope to mitigate this global crisis. Agriculture-based economies which are exporting "virtual waters" must increase the share of wastewater to meet their internal needs. This is even more imperative for the world's most populated countries, India and China, as they work to stay the water scarcity crisis within their own lands. Besides that, these countries will benefit from just water resource alone, building into the process an energy recovery capability helps achieve sustainability in the water reclamation process. This paper presents how wastewater can be channelized into green energy resource such as biogas, microbial fuel cells, and biodiesel; and how it is transformed into various bio products, nutrients, food, and potable water in order to combat severe impacts of droughts. Furthermore, even while it has become the norm to measure carbon footprints to minimize global heating aspects of production and consumption, we propose instituting the new concept of calculating the "water footprint" for each of our future actions. This footprint includes consideration of what are referred to as green, blue, and grey water, as they related to intake from precipitation, the surface or groundwater, and polluted water at the point-source as well as runoff. Understanding of the water footprint is not only relevant for government bodies, policy makers, and industry, but also for us as individuals within our communities. Doing so could help transform our total available supply of water for all uses. It could also shift our thinking of water as something we consume to something which is genuinely renewable.

Keywords

Biorefinery • Climate change • Circular economy • Drought • Green energy • Mitigation • Wastewater • Water footprint

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1 Introduction

The "Blue Planet" has plenty yet vastly unavailable amounts of water on its surface. As considerably large fraction (96.5%) which is present in the oceans is unsuited for consumption by the freshwater organisms. The 70% of the remaining 2.53% freshwater resources is blocked in the

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snow packed glaciers, polar snow covers, and permafrost (Shiklomanov, 1990). Therefore, only a modest fraction of about 1% freshwater is available for the consumption by the freshwater organisms. Apprehensively, by the end of 2100, the active glaciers which store hydrologically valuable solid state of water or permafrost are expected to recede rapidly due to global warming (Wagner et al., 2021). The unprecedented socio-economic advances due to mushrooming human and livestock populations cause drastic loss of freshwater biodiversity and disappearance of the wetland ecosystems, thereby thickening our water footprints (Albert et al., 2021). The rate of water withdrawal is more than the rate of replenishment of freshwater in the aquifers and ground waters. More than half of the world's largest rivers have witnessed the reduction in stream flow (Albert et al., 2021). According to an estimate, the rate of water withdrawal is likely to increase by 50% in developing countries and by 18% in the developed countries by 2050; creating more water deficit that will push two-third of the world's population towards water crisis (Pal, 2017). The defined factors responsible for global water crisis are over exploitation of aquifers, domestic and industrial pollutant discharges into the rivers, intensified groundwater extraction, degradation of upstream ecosystems, old infrastructure causing leaks and losses, sewage seepage to the groundwater, saltwater intrusion due to sea level rise, inefficient water use policies such as no user charges, rapid urbanization, climate change, and drought (Ghosh & Ghosh, 2021).

The droughts resulting from the water deficit are outcome of various climatic and anthropogenic processes. The severity and longevity of drought due to atmospheric and climatic events are driven by the changes in surface sea temperatures (SST) which has global impact. The oceans play an enormous role in the regulation of earth's climate by absorbing and redistributing the solar heat energy via oceanic currents. The Pacific Ocean which is world's largest contain more than 50% of the free water that play an influential role in bringing mega decadal droughts. The regional dry spells in many parts of the world are highly driven by the dynamics of atmospheric and surface ocean phenomena. For example, the strong El-Niño events were found to be associated with the dry years in the North East Brazil (de Medeiros & Oliveira, 2021). A very recent global hydroclimate reconstruction study based on the climate model derived from the assimilation of archival and paleoclimate proxy data established the co-occurrences of the El Niño/Southern Oscillation or ENSO events and the coupled megadroughts in North American Southwest and South American Southwest (Steiger et al., 2021). The strong El-Niño event in United States in 1998 was followed by the rapid emergence of drought which subsequently caused wildfires in Florida and million dollars of agricultural losses in many southern states (Wilhite & Svoboda, 2000).

Apart from Pacific Ocean, the SST anomalies on the two sides of the Indian Ocean create a climatic phenomenon called Indian Ocean Dipole (IOD) which has historically influenced the Australia's worst drought events. The deprivation of normal rainfalls and the many multiyear historical droughts in southeast Australia including the "Big Dry" or the Millennium drought that lasted from 1996 to 2012 has been attributed to the lack of the negative phase of IOD (Ummenhofer et al., 2009).

The damages caused to the communities and environment by the droughts are massive and irreversible. The extreme deficiency of the water during the drought has significantly pushed the world towards adopting treated wastewater as the source of freshwater. The wastewater serves as a potential candidate to be converted into a source of energy. Significant progress in energy-producing systems such as biofuel, microbial fuel cells, and biogas production has suitably used the wastewater as a substrate to obtain renewable energy. The wastewater can be significantly converted into energy through the process of "anaerobic digestion" (generation of biogas) and "transesterification" (generation of biodiesel). The energy recovery from the wastewater forms a crucial component in achieving sustainability in the developmental plans for alleviating climatic stresses such as drought and formulating a better future. The wastewater treatment provides the most vital portion—the sewage sludge, which is largely utilized as the feedstock for anaerobic digester to produce "biogas", which after further processing acts as a decent source of heat and electricity. Furthermore, the sewage sludge provides an excellent source for the growth of oleaginous organisms producing lipids which by transesterification technology is converted into biodiesel. The biodiesel hence obtained can be employed as green fuel in automobiles. The process of conversion of wastewater into a valuable source of energy also includes the microbial fuel cell (MFC) which utilizes the electrogenic nature of certain bacteria to simultaneously treat the wastewater and produce electricity.

The wastewater treatment plants have become an inseparable part of our society now, as they not only treat the wastewater, which is highly recommended prior to its dumping in the aquatic bodies but also provide energy. The additional energy generated shall be further utilized to compensate for the reduction in energy production due to the disruption of hydropower stations with the advent of droughts. The wastewater conversion system provides a decent answer to overpopulation, extreme scarcity of fresh water, and climate crisis. The paybacks of wastewater conversion to energy are tremendous including energy production for supporting the expanding cities and their energy needs; cheap, renewable, and affordable methodology for the production of energy; harnessing of methane which is considered 30 times more potent than carbon dioxide as a greenhouse gas; pollution reduction due to dwindling need of incineration of the waste and economic benefits from the sales of gas and solid digestate. Several innovations and thoughtful practices in terms of the economic feasibility of water conversions shall aid the mitigation of droughts and supports the waste-to-resource technology.

2 Biography of Drought

Drought is intricate and multidimensional phenomenon influenced by various physical parameters such as rainfall pattern, humidity, and the rate of evaporation. It is a creeping phenomenon as the effects of drought persists for longer period even after the culmination of actual drought event (Wilhite & Svoboda, 2000). Droughts are defined as the abnormally long period of acute water shortages with below normal levels of precipitation. They are one of the grave outcomes of global climate change. Apart from causing direct impact, drought imposes many secondary impacts such as famines, epidemics, and wildfires. It has potential of causing huge economic loss which robs the region of its basic amenities for survival. The exploration and innovations in the field of science and technology have still not safeguard humans from the devastating impacts of droughts. Understanding drought and its causes is essential for developing the mitigation strategies and planning which can combat the impacts of persistent droughts. Around 30% of the world's population is impacted by drought. The 2.5 billion people who are inhabitants of the dry areas are the most vulnerable. The droughts can be appropriately differentiated into natural droughts (majorly caused due to environmental factors) and anthropogenic droughts (caused due to human-induced environmental modification). The anthropogenic droughts are of major concern as they could be easily being avoided by following several thoughtful practices and evading the exploitation of nature by humans. The population explosion in both developing and developed nations with increase in living standard aggravates the anthropogenic droughts due to high demand and limited water supply. For instance, the population increase in California over the past century has induced the development of major infrastructure and water transfer projects. Extensive research and exploration are necessary to formulate a detailed system for assessing the impact of anthropogenic droughts on the natural ecosystem and wildlife. This becomes very essential for the sustainable development of the environment and socio-economic gains. A conjugated team of scientists, researchers, and policymakers should be involved for this purpose.

3 Impacts of Drought on Various Sectors

The drought has equally and substantially impacted many sectors. The ripple effect created by the dry condition can impact the entire nation as agriculture and industrial economies are interconnected. The ill effects of drought on a few of the sectors are discussed.

3.1 Socio-economical

Droughts lead to shortages of the domestic supply of water and thus, directly impact the socio-economic framework of the society. The major water-dependent economic sectors such as irrigation, hydroelectricity production, and agro-industries face severe losses due to water shortage. Likewise, the capital invested for the implementation of a mitigation plan and to alleviate the impacts of droughts contributes to the economic cost of drought. There occurs competition among the different sectors as the water becomes scarce. The tax revenue tends to decrease due to the decline in income, employment, and export (Chand & Biradar, 2017). Similarly, the rise in crime due to provisional unemployment, migration, and increased poverty imparts huge pressure on the law and order services of the nation.

Agriculture is the major sector impacted by the droughts due to water scarcity and alteration in the soil parameter. This is an input-intensive sector (in terms of hybrid seeds, modern irrigation, and farming techniques) that increases the initial investment of the farmers, which is generally credit based. The farmers facing the loss of crop yield are incapable of repaying their loans and get trapped in the vicious poverty circle. Acute water shortage and limited intake of food have severe effects on human health causing malnutrition, anxiety, depression, respiratory disorders, infectious food-borne diseases caused by *Escherichia coli* and *Salmonella*. The limited availability of food resources, and reduction in the daily intake of essential minerals (such as calcium), and vitamins (vitamin B1 and vitamin A) further deteriorates human health. The livestock rearing sector is equally impacted by the droughts. The droughts substantially reduce the grazing land for the livestock. The farmers are compelled to feed their livestock on the roadside growth of weeds and field bunds. The partial loss in crops (i.e. the stunted crop yield) is also fed to the livestock. These practices adversely impact the health of the livestock leading to extremely low production. Likewise, the acute shortage of water makes it unavailable for the livestock. In many cases, contaminated water is utilized for the drinking purposes of livestock, which makes them prone to many diseases. The innovations in developing alternative livestock feed from wastewater are discussed in later sections of this article. The drought distress also induces the sale of the livestock at marginal prices. There occurs migration on large scale from the rural areas to the urban settlements in search of jobs. Many farmers and labourers seek low-skilled jobs in the cities and are economically exploited. The younger generation of the society, i.e. the schooling children are robbed of their basic right of schooling as the schools and other educational institutes cannot cope with the water crisis. The reduction in the size of water bodies and water stagnation acts as the breeding grounds for a certain type of mosquitoes and increase the incidence of vector-borne diseases. The extreme shortage of water has adversely impacted and reduced the recreational activities in the water bodies. The socio-economic setup is intricately balanced with the environmental parameters that are quite vulnerable to the changes in the availability of environmental goods and services.

3.2 Environmental

Drought affects several components of ecosystems and the environment. There occurs a drastic reduction in the water levels of the wetland areas (such as lakes, rivers, and ponds) along with a reduction in the groundwater levels. Even the aquifers are not replenished, which dries them up. The droughts effectively reduce the soil moisture contents. Additionally, biodiversity entirely depends upon the environment for the supply of water. The intensity and the scale of drought may cause permanent and temporal impacts on biodiversity. The unavailability of water and food (during the droughts) alters the supply of food to different life forms, subsequently altering the food web (Kala, 2017). Likewise, the distribution of the species is also adversely impacted. The species having a narrow distribution range and low population size will decline further due to droughts. There occurs a loss of aquatic communities due to reduced and altered water flow, accumulation of pollutants, higher water temperatures, and reduced concentration of oxygen. The elevated temperatures melt the glaciers and reduce the size of glaciers. This in turn lowers the availability of water in the river basin over a period. The unexercised withdrawal of groundwater causes its depletion and other ecological disturbance such as land subsidence. The quality of the air reduces due to the abrupt and extensive increase in the level of dust and chloride levels during the drought. These impacts disseminate even in the areas having moderate dry conditions. The elevated levels of temperature and acute water shortage are disastrous for all the natural ecosystems that disrupt the natural balance of the environment.

4 Drought Mitigation Measures

The only way to combat the severe water crisis and drought is to conserve the available freshwater. There are numerous ways to conserve water at social levels.

4.1 Recycling of Water

The water can be conserved at the individual level by recycling the indoor and outdoor waters. The recycling is done by installing a greywater recycling system. The wastage of water can be minimized in bathrooms, kitchens, and laundry. The efficiently serviced leaks in the plumbing system prevent considerable amounts of water loss. Few stringent conservational goals (for example, utilization of only 40 gallons of water per person per day for indoor water uses in the US) should be implemented. The drip irrigation system should be used for irrigating the landscaping. Additionally, rainwater should be harvested for landscaping. The wastage of water can also be minimized by employing an adjustable nozzle or sprayer to regulate the water flow during the washing of vehicles.

4.2 Ways to Enhance Soil-Crop Efficiency and Reduce Water Demand in Agriculture

Agriculture is the major economic sector that uses the maximum amount of freshwater resource and which is equally responsible for polluting vast amounts of water. Water conservation in agriculture can be achieved by implementing well-known traditional practices and by adopting innovative measures. Conventionally, well-structured soils with a high infiltration rate can substantially conserve water in agricultural farming. The improvement in physical and hydraulic properties of soil by the application of polyacrylamides minimizes soil erosion (Kebede et al., 2020). The newer techniques such as laser levelling off the field boost uniform infiltration and decrease the runoff. The selection and cultivation of native drought-tolerant plants requiring less water are also a critical factor in water conservation at regional levels. The traditional method of cover crops plantation to trap the surface water reduces evaporation and runoff. The tailwater (i.e. water that drains to the lower sections of fields) must be recycled back in the fields. The most efficient way to conserve water in agriculture is capturing rainwater and stormwater for irrigation and other purposes. Apart from implementing these best farming practices, the novel agrivoltaic systems wherein the photovoltaic panels are mounted within the agricultural fields to perform dual functions of electricity generation and food production, have the potential to reduce water demand along with the improved water productivity of crops such as tomatoes (AL-agele et al., 2021).

4.3 Industrial Water Use Efficiency

The manufacturing industries such as food, chemical, paper, petrochemical refinery are required to recycle and reuse the water efficiently. Government and other organizations can provide financial incentives to the industries to establish water-saving practices. The industries should undertake water use or water footprint assessments to represent their pressure on surface and groundwater resources considering the units of water used and polluted. Currently, the best approach to lower the impact of industries on water resources is to create a circular economy of water (Sauv´e et al., 2021) based on the treatment and reuse of grey or polluted water in parallel sectors of the economy. The greywater footprints of the raw industrial effluents decrease with each level of treatment and eventually become negligible when the tertiary treated wastewater is reused as means of irrigation (Lahlou et al., 2021).

4.4 Role of Public Education and Awareness

Public awareness and education play a vital role in the conservation of water in different sectors. Public awareness and education can be achieved by conducting awareness campaigns on the conservational techniques and the existing regulation for the management of the coastal areas and ocean environment which supports the economic gains of the country (Kumari & Singh, 2016). The opportunities for interactions between the communities, policymakers, regulating agencies, NGOs, researchers, etc., must be developed and improved. The tools used for policies and decision-making should be improved, which would further enhance the abilities of the professionals, government, and non-government organizations to conduct regional and community-level action programmes.

5 Green Wastewater Conversion Technologies

The global water scarcity crisis and ever-expanding greywater footprint across the planet have triggered the developments and redevelopments of waste water treatment technologies that integrate biological systems to additionally harness various forms of green energy and bioproducts.

5.1 Microbial Fuel Cell (MFC) Technology to Harness Green Electricity

MFC represents one breakthrough development in the wastewater treatment process that directly generates bio-electricity. Diverse forms of wastewater provide substrate to the MFC which operates on the catalytic conversion of organic waste to electrical energy using complex microbial communities (Agrawal et al., 2019). The MFC comprises of an anode (in an anaerobic environment) and cathode (in the aerobic environment), separated by a cationic selective membrane and linked together with an external conductor through a load. The input of organic fuel from the wastewater into the anodic chamber (comprising of microbes) results in the oxidation of the substrate by microbes to generate ATP that fuels the cellular machinery forming electrons, protons, and carbon dioxide as the by-products. The electrons produced pass from the anode to the cathode through an external load connection, generating an electric current. At the same time, the protons migrate to the cathode chamber from the anode chamber freely through the protonic selective membrane separating the two chambers. Several variants of MFCs can be possibly used such as the double-chambered biofilm MFC. A typical double-chambered biofilm MFC with reactions occurring at anode and cathode is shown in Fig. 1.

The reactions occurring at anode and cathode are using a typical example of acetate as a substrate is as mentioned in Fig. 2.

As observed in the reaction, along with electricity, carbon dioxide, and water from the substantial by-products of the reaction.

MFC anode

The anode present in the anodic chamber forms a confined area for microbes, which forms the biofilm on the surface of the anode. The fuel cell's activity relies on the number of bacteria occurring on the anode and thereby, on the surface of the anode. For optimum performance, an appropriate selection of electrode material is a mandate which facilitates bacterial adhesion, electron transfer, and electrochemical efficiency. Several carbon-based electrodes are utilized including carbon paper, carbon fibre such as carbon-nanotube-based composites to obtain the maximum power yield. Furthermore, the utilization of bamboo charcoal has displayed satisfactory outcomes, illustrating all the required characteristics of an ideal anode. A few supplementary advantages of bamboo charcoal involve rapid growth, lower manufacturing cost, minimum carbon footprint, reuse, and easy disposal (Sato et al., 2021).

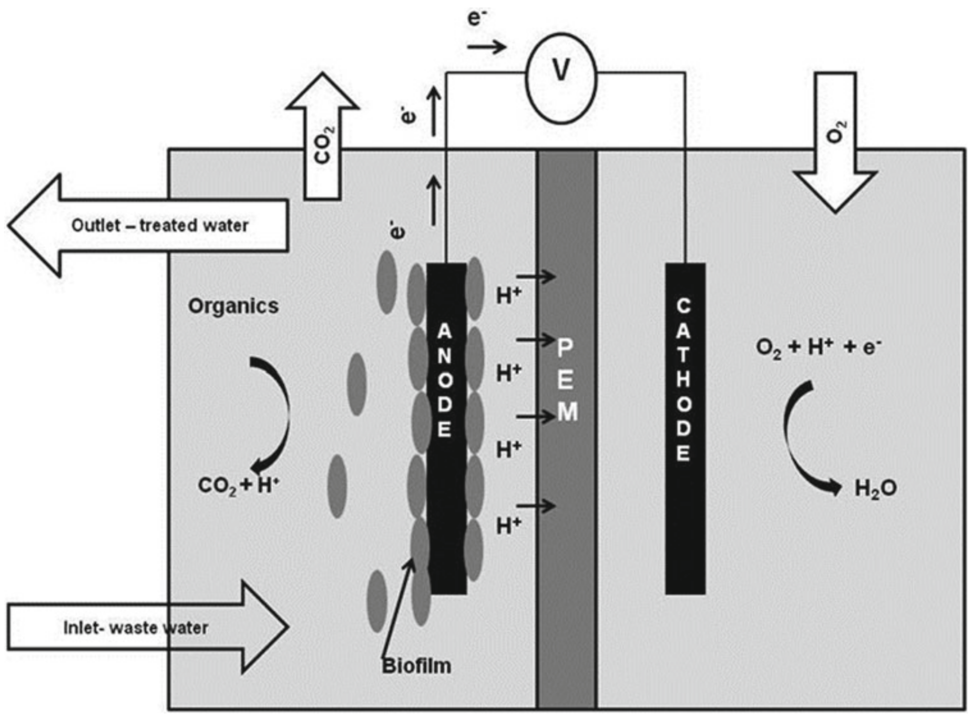


Fig. 1 Typical double-chambered biofilm MFC

Anode reaction: $CH_3COO^- + H_2O \xrightarrow[\text{Anaerobic environment}]{\text{Microbes}} 2CO_2 + 7H^+ + 8e^-$

Cathode reaction: $2O_2 + 8e^- + 8H^+ \longrightarrow 4H_2O$

Overall reaction: $CH_3COOH + 2O_2 \rightarrow 2CO_2 + 2H_2O$ + Electricity

Fig. 2 Reactions occurring at anode and cathode (using acetate as a substrate)

MFC cathode

Cathodes are involved in the reduction of oxygen to water and materials selected for the construction of cathode must facilitate the reaction. Platinized carbon cathodes can be generally utilized in MFC. The high cost of Pt is usually replaced by nonprecious electrodes like Mn_2O_3 and Fe_2O_3.

The oxygen (electron acceptor) present in the cathode chamber combines with hydrogen ions and electrons to form water, hence completing the reaction. This reaction can be significantly facilitated by a catalyst such as platinum.

A few examples of microbes utilized in MFC are *Pseudomonas aeruginosa, Escherichia coli Shewanella sp., Nocardiopsis sp., Streptomyces enissocaesilis, Geobacter metallireducens, Enterococcus gallinarum, Leptothrix sp., Brevibacillus agri, Vibrio sp, Pseudoalteromonas sp. Shewanella oneidensis, Clostridium cellulolyticum, Geobacter sulfurreducens, Cupriavidus basilensis, Pseudoalteromonas sp., Marinobacter sp., Oseobacter sp., Bacillus sp., Thiobacillus ferrooxidans, Klebsiella variicola, Methanocorpusculum, Mycobacterium, Enterobacter, Stenotrophomonas, Enterobacter cloacae, Staphylococcus sp., Virgibacillus sp., and Aeromonas hydrophila* (Agrawal et al., 2019).

The applicability of the MFC is still a matter of extensive research and development as long-term future goals. Currently few of the applications of MFC include wastewater treatment, seawater desalination, hydrogen production, source of power, and as remote sensors. The MFC treated wastewater can likely be used for irrigation purposes to compensate for the scarcity of water during the drought. The potential use of MFC is a reclamation of wastewater for irrigation and electricity production. The MFCs have illustrated a high degree of potentiality in terms of treating not only the wastewater from the household but also from several different industries. For instance, double-chambered typical MFC illustrates the percentage of chemical oxygen demand (COD) removal from chemical wastewater and food leachate of 63% to 85%, respectively (Kumar et al., 2017). Likewise, the wastewater rich in organic materials such as carbohydrates, proteins, lipids, and fatty acids acts as an optimum substrate for the metabolism producing electrons and protons and further improving the efficiency of the production of electricity. Furthermore, the removal of COD is assisted by the mesophilic temperatures as well as the fed-batch mode. Several studies have shown not only bacteria but even algae can produce with the same efficiency in the MFCs. (Ghazi et al., 2020). MFC is beneficial in drought-prone regions where electricity costs are skyrocketing, and therefore, the technique could be more economically feasible than conventional wastewater treatment.

The utilization of MFCs as biosensors serves as a pollution detector in water, which can be united with the wastewater treatment process. The MFC-based biosensor displays several advantages over the conventional biosensors in terms of cost, maintenance, shelf-life, stability, and reliability. (Kumar et al., 2017).

Several upsides of MFC include generation of energy from organic waste, direct conversion of substrate to electricity, low production rates, reduced emission of GHGs, self-generation of microbes, resistance to environmental stress, and low carbon footprint. These are the crucial advantages to mitigate the climate crisis.

However, additional understanding and knowledge for scaling up the MFC system are needed to overcome the challenges occurring due to unstable bacterial biofilm formation, low power density in the case of low organic input, high cost of selective proton membrane with low efficiency of proton transfer, and lack of durability and strength of electrodes (Khoo et al., 2020). The MFC parameters are needed to be adjusted with the different types of wastewater for its adequate treatment.

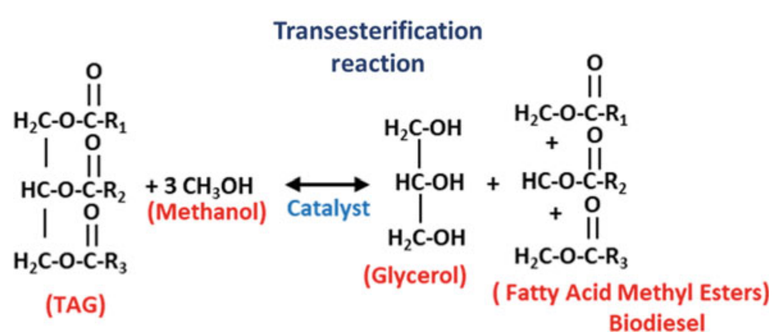
5.2 Wastewater as Renewable Resource of Biofuels

With the ever-increasing consumption of fossil fuels and constant reduction of their quantities from the earth, a shift to cleaner and greener energy becomes quite essential. One of such alternatives to fossil fuels is the generation of biofuels (biodiesel) from the wastewater to fulfil the demands of fossil fuels. The first-generation biodiesel uses virgin edible vegetable oil such as soybean, rapeseed, sunflower, palm, and coconut oil as feedstock. The second-generation biodiesel utilizes jatropha, castor, neem, tobacco, and rubber seed oil, which decrease the dependence on edible oils. However, the third generation of biodiesel eliminates the drawbacks of both, the first and second generation of biodiesel majorly in terms of arable land and cost. It involves the production of biodiesel by utilizing the microbial lipids extracted from bacteria, yeasts, microalgae, and fungi.

In the wastewater treatment process, sewage sludge forms an imperative component. The types of sludge produced during the wastewater treatment include the primary sludge (a blend of organic and inorganic matter with a gas bubble trapped within the suspension) and the secondary sludge also termed activated sludge (comprising of the microbial cells and suspended solids generated during the aerobic biological wastewater treatment) (Cea et al., 2015). The heterotrophic microbial population of activated sludge consumes the organic compounds of the wastewater (hence, treating it) to grow and convert them into high-energy storage carbon compounds such as triacylglycerol (TAG). The TAG is generally synthesized by oleaginous species belonging to the order Actinomycetales (e.g. *Mycobacterium, Streptomyces, Nocardia, and Rhodococcus)* and green microalgae to yield biodiesel. Microalgae are cultivated in a specialized algal pond to yield biodiesel. These ponds aid the treatment of wastewater and cultivate microalgae. These organisms can accumulate the lipid to around 20% of their biomass. The accumulated lipids can be then being extracted by various extraction methods. The extracted lipids (from microalgae and microbes) are then trans-esterified in the presence of short-chain alcohol and in presence of an acidic or basic catalyst to produce biodiesel. The reaction involving trans-esterification is depicted in Fig. 3.

Various methods for lipid extractions involve ultrasound, microwave, supercritical fluid extraction, agro-solvent, accelerated solvent extraction, enzyme-assisted extraction, instant controlled pressure drop, pulse electric field, etc.

Fig. 3 Esterification reaction yielding biodiesel



(Meullemiestre et al., 2015). The obtained biodiesel is further subjected to purification to obtain the end-product.

A few of the advantages of utilization of microbes for the production of biodiesel include utilization of the sewage sludge, elimination of arable land for the cultivation of feedstock, the rapid doubling time of microbes, low energy requirements, efficient bioremediation of the wastewater, and reduction in the waste generated. However, the stringent growth requirements, sophisticated extraction techniques, and easy contamination of the system lead to further exploration and development in this sector.

5.3 Wastewater Sewage Sludge to Biogas

Biogas is generated by the anaerobic digestion of organic matter such as sewage sludge, animals, and municipal waste (Demirbas et al., 2016). Treating the wastewater to obtain energy and other valuable products aids the economic gains during the tough times of droughts. The valuable products include the "residue" of the digestion termed as "digestate", which can be further utilized as soil conditioners to improve the fertility of the soil. Biogas forms a vital source of energy in heat and electricity generation along with being the worthiest renewable source of energy globally. The biogas comprises of methane (55–60%), carbon dioxide (35–40%), hydrogen (2–7%) hydrogen sulphide (2%), ammonia (0–0.05%), and nitrogen (0–2%).

Conversion of organic matter (sewage sludge) into biogas through a series of reactions (Fig. 4) accomplished by several groups of bacteria in an anaerobic condition (anaerobic digestion). A device offering a conducive environment for organic feedstock conversion into a gas (biogas) through a procedure known as anaerobic digestion is referred to as "anaerobic digester". The anaerobic digester functions on the step-wise reactions occurring during the degradation of organic waste by the specified group of microorganisms—the anaerobic digestion (Abbasi et al., 2012).

The process initiates with the pretreatment of sewage sludge from primary and secondary water treatment. Before entering the anaerobic digesters, the sludge undergoes sieving followed by thickening to adjust the dry solids up to 7% to evade the very high consumption of energy for heating due to excessive water content. Once inside the digester, the feedstock (treated sewage sludge) is acted upon by a wide array of microorganisms to degrade the organic matter, with a retention time of 20–60 days and with mesophilic temperature ranges. The biogas obtained at the end of the process largely comprises methane and other gases. The methane is purified through a scrubbing process that removes other gases. The purified methane can be combusted in the combined heat and power (CHP) plant to produce electricity and heat simultaneously. The production of biogas from the wastewater fills in the gap created between the demand and supply of electricity due to droughts. The biogas-powered cogeneration units contribute up to 60% of electricity demand while generating surplus heat (Masłoń, 2019).

Some of the microorganisms involved in each stage are acidogenesis microorganisms such as *Bacteriods, Clostridium, Butyrivibrie, Eubacterium, Lactobacillus, and Bifidobacterium; acetogenesis—Desulfovibrio, Syntrophobacter, Wolinii, Syntrophomonas; and methanogenesis—Methanobacterium, Methanosprillum, and Methanosarcinae*

Biogas provides an economical clean, green, and renewable source of energy (Fig. 5) which is widely used in many parts of the world.

The production of biogas through anaerobic digestion aids the production of digestate that discovers its place as enriched fertilizers that efficiently reduces the usage of chemical fertilizers. This technique allows significant utilization of wastewater to produce electricity, which

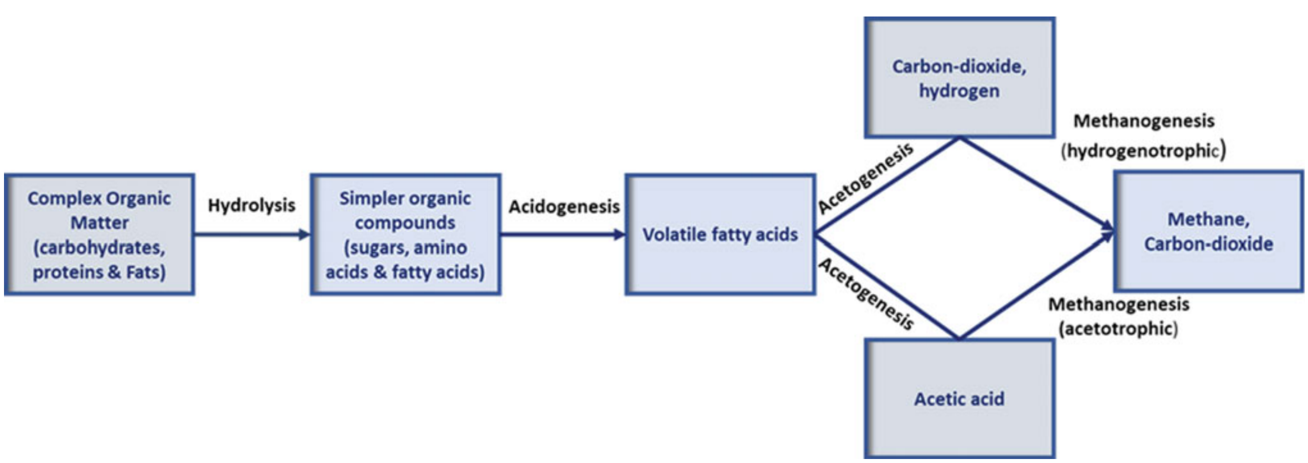


Fig. 4 Series of reactions that occur during anaerobic digestion

Fig. 5 Advantages of biogas

otherwise gets dumped in the aquatic bodies leading to aquatic pollution. Likewise, the revenue generated from the sale of electricity and digestate serves as an added advantage during droughts. However, the system requires the stringent maintenance of optimum growth parameters such as the absence of oxygen and the purification of methane.

5.4 Reorienting Wastewater Towards Food Production

The increase occurrences of droughts globally have widened the gap between the supply and the water demand drastically causing threats to the human existence. Therefore, researchers and scientists all over the globe are working to come up with innovative techniques for reenergizing the use of wastewater. One of the ways to overcome the water crisis, especially in the agricultural sector is to reuse the wastewater for agricultural purposes and to produce food. This food will help to curb hunger during droughts. In the developed countries, the wastewater (generally the municipal) is treated to an adequate level for its application in irrigated land for the growth of fodder, fibre, and seed crops, and lesser extent, for the irrigation of orchards, vineyards, and other crops. However, in developing countries, such as India, China, and Mexico, though the stringent regulations are not followed, the wastewater is used for agriculture (Hussain et al., 2002). The wastewater must be treated to meet the international guidelines for the permissible levels of microbes and chemicals present in the treated water. WHO guidelines on the safe use of water for agriculture and aquaculture states the following for the microbiological contamination. Restricted irrigation (irrigation not intended for the crop used for direct human consumption): not more than one viable human intestinal nematode egg/litre of wastewater (Hussain et al., 2002). Unrestricted irrigation (irrigation intended for the crops used for direct human consumption): includes the limit of restricted irrigation and not more than one thousand faecal coliform bacteria/100 ml of effluent.

The widely adopted treatment processes involved three stages namely the primary sedimentation process, secondary aerobic biological treatment, and tertiary disinfection treatment. However, these treatments are cost-intensive, high maintenance, and with high technological requirements, which renders them ineffective in most developing countries. These countries are now adopting more cost-efficient land-based systems for wastewater treatment. These systems involve waste stabilization ponds. Wastewater stabilization ponds (WSPs) are large man-made ponds where the wastewater is treated naturally under the influence of sunlight, carbon dioxide, wind, microorganisms, and algae (Dorothee, 2014). The ponds occur either individually or are combined in the series for improving the treatment process. The three different types of ponds utilized are anaerobic ponds, facultative ponds, and aerobic ponds, each with different designs and characteristics. The ponds are a cost-efficient system with low operation and maintenance costs but high biological oxygen demand (BOD) and pathogen removal efficiency. The wastewater treated by such ponds can be utilized for agriculture; however, the water is not utilized for direct surface water recharge. The two most significant concerns regarding the utilization of ponds for wastewater treatment include the large demand for land and the high evaporation rate. One more approach includes the utilization of wetland and aquatic plants, such as water velvet and duckweed for treating the sewage water before being used in agriculture.

The utilization of wastewater for irrigation must be implemented only after assessing its impact on human health, crops, soil, and groundwater resources, social and economic sectors. The treatment of wastewater for utilizing it for irrigation purposes forms a significant alternative for food production during the dire situation of droughts with an acute shortage of water.

Utilization of wastewater for agriculture increases food security, supports the nutrient recovery of the wastewater to improve the crop yields, reduces the issue of eutrophication, aids the all-year-round irrigation producing two or more crops per year, assists the growth of a variety of crops especially in during the droughts, reduces the water and fertilizers related costs, accelerates the recharging of aquifers through infiltration and reduces water competition among the drought struck population (Jiménez & Navarro, 2013).

6 Rejuvenation of Wastewater into a Potable Water

The increasing water scarcity and drought conditions throughout the globe have resulted in the unavailability of clean drinking water to a large segment of the population. Many places are currently involved in the reclamation of this sewerage wastewater to be utilized for drinking purposes by the technique known as potable water reuse. The indirect potable reuse (IPR) process reclaims the freshwater that is sent to the sewage treatment plant and is wasted. The existing IPR includes (a) unplanned IPR which involves the release of the treated water into the natural environment—aquatic bodies, where it can be utilized by the cities downstream as a potential drinking water source, (b) planned IPR that releases the treated water from the treatment plant at a very high degree into the groundwater system or aquatic body which can be used as the source of drinking water. IPR has been the approach to reclaimed wastewater for several decades. However, another concept of direct potable reuse (DPR) has been adopted in the US, Australia, and South Africa. This approach involves further treatment of wastewater treated in the sewage treatment plant and is directly released into the drinking water distribution system, closer to where water is needed. There occurs no discharge of treated water into the natural environment like in IPR. A few of the advantages of DPR include the availability of drinking water close to the point of consumption and eliminating the cost associated with pumping the water from long distances which is an energy-efficient process.

The basic wastewater treatment and the reuse involve the primary treatment, where the sewage enters the sedimentation tanks and 80% of the solids are removed, and the effluent may be released into the ocean. However, instead of releasing the water into the environment and intending to reuse it, the water is further treated in the secondary treatment stage (Cho, 2011). This stage involves the biological degradation of wastewater by the bacteria. Consequently, the water is subjected to tertiary treatment. This stage filters the water to remove any of the remaining solids and disinfects the water with chlorine. For IPR, the tertiary treated water undergoes the advanced water technologies (microfiltration, reverse osmosis, and disinfection by U.V. or hydrogen peroxide), remains in the groundwater or surface reservoirs (for about six months for further purification of the water by natural processes) and undergoes the standard water purification process for drinking water, before being used.

A few of the challenges associated with reclamation of wastewater in near future include the effectively coupling of advanced wastewater treatment facilities with seawater desalination facilities, which would substantially increase the amount of water available in the drought conditions; incorporation of efficient methods to assess the health risk and environmental impacts and implementation of stringent reuse regulations, which would be applied in varied situations to promote the reuse of water (Angelakis et al., 2018).

The reuse of the wastewater for drinking purposes will become the only alternative for drinking water across the globe very soon. If the population is not currently involved in reclaiming the wastewater for drinking purposes, they will be doing it soon. The wastewater passes through stringent treatment processes and technologies before making it available for drinking purposes. The reclaimed water tastes like regular drinking water. However, there are a few concerns regarding the use of reclaimed water for drinking purposes. A large group of the population globally fails to understand the importance of wastewater reuse for drinking purposes and hesitate to adopt the approach based on the "yuck factor". The idea of drinking the water from the toilet disgusts them. The advocacy of wastewater for drinking purposes also has political issues. The governing party promoting the reuse of wastewater faces criticism and disappointments. Likewise, the health impact of reusing wastewater has been researched for several years. Few of the health-related issues due to chlorine by-products are now eliminated by using current methods which produce fewer chlorine by-products. People are also concerned about the economics of wastewater reuse. The involvement of technology at each stage of treatment makes the process cost-intensive. There is a compelling need for innovative green technologies that effectively treat and convert wastewater to infinite resources. Conducting campaigns and projects illustrating the safety of wastewater reuse can significantly reduce people's concerns and trust issues over utilizing wastewater for drinking.

We are going to drink the wastewater in some way to combat the water crisis. However, new and innovative techniques will still find their way among the other techniques that are already being used for recycling purposes. The 2017 WHO and US EPA census states the reusing of wastewater for drinking purposes is conducted by Australia, California, Texas, Singapore, Namibia, South Africa, Kuwait, Belgium, and the United Kingdom. In Brazil and India, several projects of water recycling are under consideration with several stringent regulations for the application.

7 Innovations in Water Sector

Tapping novel freshwater sources, apt infrastructure, innovative designs for reducing water dependence, efficient use of technologies, water reuse, recycling (Wehn & Montalvo, 2018), and up cycling are some of the technological challenges for conceiving water management. Innovations in the water sector are needed at water resource management level which relies on scientific knowledge and information and communication technology (ICT) and in building infrastructure and services that ensure infinite supply from the finite water resources. Wehn and Montalvo have discussed various innovative path dependencies to ensure better distribution and management of water supply related to the dynamics of water innovation (Wehn & Montalvo, 2018). Some examples are sensors, monitoring networks, novel construction materials including pipes, compressors, transfer systems, mixers, pumps, controllers, chemical reagents, and coagulants which are required in the water treatment processes.

The effluents from waste water treatment plants which are generally discharged into the nearby freshwater bodies blends with the stream flow. Ideally, the municipalities treat this water that may contain health hazardous agents and supply as potable water. When the upstream waste water treatment process is efficient, it provides high quality potable water to household, industrial, and agricultural sector (Tortajada & Nambiar, 2019). Further, this water is supplied either through indirect potable system, wherein the treated water is stored in surface or groundwater environmental buffers from where it is re-abstracted, retreated, and supplied; or it is introduced to municipalities without any environmental buffer upon post extensive treatment and monitoring for water quality standards (Tortajada & Nambiar, 2019).

Some of the cutting-edge technologies adopted by Singapore for recycled drinking water which is termed as NEWater includes efficient membrane filters with reactors that harness energy from bacteria, incorporation of nanotechnology for faster and cost-effective treatment and the downstream processing using the reverse osmosis technique and the ultra violet radiation (Tortajada & Nambiar, 2019). The Changi Water Reclamation Plant of Singapore is one of the world's largest and most advanced reclamation facility commissioned in 2008 which produces treated effluents that further get ultra-cleaned into high-grade NEWater to meet 30% of total water demand of the country. Other water reclamation techniques involve the use of chemicals such as chlorine and cleaning agents like charcoal and sand and further elimination of biological hazardous agents is achieved via ozonation, membrane filters, UV, and reverse osmosis.

7.1 Wastewater as a Resource to Mitigate Water Scarcity

The Sustainable Development Goal 6 in the 2030 sustainable development agenda of the United Nations is an obligation for the countries to reduce their grey water footprint and to ensure safe clean water and sanitation (U.N., 2020). The leading wastewater producing nations are Asian countries, Europe, and North America that produce around 159, 68 and 67 trillion L/year, respectively (Goswami et al., 2021). The wastewater is loaded with nutrients which are both in the form of inorganic such as nitrates (NO_3^-), ammonium (NH_4^+), urea, phosphates ($H_2PO_4^-$, $HPO^2{}_4^-$), heavy metals, micronutrients, and organic compounds namely sugars, fatty acids, amino acids, steroids. The raw wastewater discharge containing these toxic and harmful components primarily causes water pollution that jeopardizes humans, animals, and environmental health. Secondarily, the excessive nutrients in the wastewater lead to the eutrophication in freshwater lakes, rivers, ponds, and marine waters. The remediation of effluent discharge is critical to protect the inherent natural purification potential of coastal waters where the eutrophication cause chronic stress to the benthic microbial communities and drastic shift in the trophic assemblages (Meyer-Reil & Koster, 2000). Dual mitigation strategy that target both nitrogen and phosphorous loadings is key to tackle the issues of coastal water pollution that globally impact the fisheries, tourism, and economy (Ngatia et al., 2019). The harmful algae blooms associated with coastal eutrophication critically impact the aquaculture industry worldwide (Trottet et al., 2021). Therefore, the need of hour is to redirect the nutrient loadings towards an integrated high efficiency nutrient reclamation biorefinery processes.

High energy consumption, economic and environmental costs, climate resilience, and building capacity to meet the demand of growing population are some of the challenges associated with the conventional waste water treatment plants. Processes involved in the conventional waste water treatment include anaerobic digestion, sedimentation, coagulation, adsorption, UV-radiation, membrane filtration, nitrification, and denitrification (Goswami et al., 2021) that require aeration and produce ample amounts of sludge which does not co-produce value-added products to support the economics and sustainability.

An alternative approach of biorefinery can reduce the costs and burden on environment by converting the waste water feedstock to economically valuable resources. Various types of micro- and macro-organisms such as bacteria, fungi, algae, and plants are exploited in the biological water treatment and reclamation processes along with co-production of renewable bioenergy and bioproducts via conversion of the organic and inorganic nutrients into biomass. The waste water biorefinery is an example of circular economy in which raw material and final products are obtained from within the same process cycle.

Biomass is a renewable resource that offers sustainable solution in the form of biorefinery where by, each of the constituents is effectively processed into variable products. The biomass obtained through water treatment and reclamation process, it is termed as waste water biorefinery. Important considerations during the setting up of waste water biorefinery include the composition and complexities of the waste waters and the market assessment for the co-products recovered from the biorefinery (Kusch-Brandt & Alsheyab, 2021). For example, the baker's yeast wastewater or the vinasse has very high COD of 29,000 mg/l with acidic pH of 4–5 is a cost-effective substrate for fermentation growth of the protein rich filamentous fungi which is subsequently grown with suitable bacteria for further breakdown of organic nutrients via anaerobic digestion. Thus, in a two-step waste water biorefinery process, the COD is lowered with co-production of protein rich biomass and methane rich biogas (Hashemi et al., 2021).

7.2 The Need to Address the Issue of Water Scarcity Across Various Sectors

Municipality wastewater which has low COD values such as 250–290 mg/l are used in the alternative technology of agriculture irrigation for non-food crops called Phyto-filtration. Depending upon the geographical regions, various crops can be selected that have low nutrient requirement, grow faster, and produce valuable co-products. For instance, willow plantations in Quebec, Canada when irrigated with primary effluent municipal wastewater with COD of 290.3 mg/l and pH 7.1 for hypofiltration treatment process resulted in better yields of willow trees with biomass rich in glucose, lignin, and diverse phytochemicals (Sas et al., 2021). The exploitation of photosynthetic organisms such as microalga are widely chosen for phosphate removal and co-production of multiple bioproducts as discussed in the next section.

8 Wastewater-Algal Biorefinery: Path Towards the Circular Bio-economy

In comparison with other micro- and macro-organisms, the microalgae present unique characteristics such as (a) their abilities to drive nutrition photo-, hetero- and mixotrophically, (b) pollutant scavenging, (c) CO_2 assimilation and sequestration, (d) synergistic growth with bacteria, and (e) production of numerous bioproducts. Due to these advantages, microalgae can be simultaneously exploited for treating wastewater from industries, agriculture, and municipalities along with the co-production of industrial products. On the other hand, the commercial production or microalgae farming have several constraints such as high production cost and nutrient and water requirement. In the light of water scarcity, conventional microalgae farming has high environment footprint. The need for phosphorous which is a non-renewable resource also make it unsustainable in future (Delrue et al., 2016). Therefore, wastewater becomes a necessity for sustainable and economical farming of microalgae. Therefore, the "marriage" of microalgae and wastewater treatment is inevitable.

8.1 Bioremediation Using Microalgae

Microalgae have a high tolerance to nutrients and salt stresses (Catone et al., 2021). Microalgae uptake inorganic nutrients in the form of nitrates, ammonium, phosphates, potassium, from variety of sources such as industrial, agricultural, and domestic wastewaters to support the growth and biomass production. In addition, microalgae can incorporate and disintegrate several forms of micropollutants such as pharmaceutical and personal care products (PPCP), endocrine disrupting compounds (EDC), and heavy metals (Delrue et al., 2016) as they possess catabolic genes for degrading pollutants (Subashchandrabose et al., 2013). Some conventional waste water treatment plants are inefficient to tackle the micropollutants; therefore, microalgae present an alternative method of treatment for these harmful and toxic chemicals. Being ubiquitous in nature, microalgae including blue green algae, or the cyanobacteria can thrive in variety of diverse habitats and niches which present a plethora of bioresource wealth that can be exploited for diverse forms of wastewater sources. The bacteria and fungi led breakdown of organic pollutants is disadvantageous due to associated increase in the atmospheric carbon pool (Subashchandrabose et al., 2013).

The ability of microalgae to grow hetero and mixotrophically makes them suitable candidates for treating wastewaters with phenolic compounds as algae grown under this mode of nutrition can reduce the toxicity of these pollutants. For examples, the microalga *Ocromonas danica* possess metabolic pathway that can catabolize phenol to pyruvate and CO_2; microalgae namely *Ankistrodesmus braunii* and *Scenedesmus quadriquada* can degrade various forms of phenolic compounds by 70%, the green microalgae *Chlorella vulgaris* photodegraded an endocrine disruptor phenolic compound called bisphenol. Algae can also convert toxic pollutants to non-toxic forms (Subashchandrabose et al., 2013).

8.2 Waste Water Treatment and Sustainable Co-production of Value-Added Bioproducts

Microalgae utilize inorganic nitrogen and phosphorous from the wastewaters for its growth and cell division along with the production of molecular oxygen when they are cultivated in phototrophic mode. The filamentous nitrogen fixing cyanobacterium called *Aulosira fertilissima* can accumulate up to 85% (dry cell weight) of poly-β-hydroxybutyrate (PHB), an elastomeric, water insoluble, biocompatible, and safe bioplastic with high degree of polymerization. (Samantaray et al., 2011) have shown a high nutrient removal capacity of *A. fertilissima* with significant increase in dissolved oxygen (DO) content in a recirculatory aquaculture system while yielding valuable PHB. Cyanobacteria especially the heterocysts forms are well documented for their capability to act as potent biofertilizers. The production of high value compounds is economical and sustainable in comparison with biofuels that are dependent on high-water demanding agriculture commodities. The naturally occurring lipids, proteins, and carbohydrate-based compounds in the microalgae can be extracted and processed in biorefinery (Ansari et al., 2017), to derive an extensive range of bioproducts from the waste water.

The demand for livestock products is increasing globally which is the driving factor for shift in livestock sector from small scale mixed farming towards large industrial production units. The environmental footprints associated with this shifting of meat production are huge in terms of greenhouse gas emissions, increasing agriculture land and grey water generation. The latter two also lead to freshwater scarcity. Poultry, cattle, and sheep are the global dominant livestock types as major source of protein (Ritchie & Roxer, 2017). With growth in their production, the demand for animal feed rich in protein with high feed conversion ratio to improve the quality of meat is increased. Some countries such as Europe rely on the imports of high vegetable protein meals such as soybean for which the other countries like China would no longer be self-reliance to meet their growing demands (Patsios et al., 2020). The import of vegetable meals for the expanding livestock sectors carries the environmental burdens of carbon and virtual water footprint. Other crop-based protein feedstock such as rapeseed meal have even higher environmental impact; therefore, non-food crop alternatives that can be cultivated everywhere on non-agricultural land achieve the sustainability targets. Some of these novel sources of animal feed protein are derived from algae, seaweeds, single cell protein such as yeast, bacteria, and fungi (Patsios et al., 2020). The production of these novel animal feed attains sustainability when they are looped into the bio-based circular economy using agro-industrial or livestock generated wastewaters (Fig. 6). In coastal regions, the marine macroalgae and seaweed have immense potential to provide high quality animal feed with lesser environmental impacts. Another advantage of using seaweed animal feed is their ability to absorb minerals from sea water which is higher than that found in the land plants and are used as mineral supplements for farm animals (Morais et al., 2020) (Øverland et al., 2019).

9 Role of Water Footprint Assessment in Decision and Policy Making

The basic idea of water foot printing is to improve water use efficiency through sparking the water consciousness at hierarchal levels (individual, society, community, and national) and across the various economic sectors (industrial, agricultural, and communication). Water is a renewable resource provided that the atmospheric water stock is regenerated about every ten days; the average regeneration time of a river is 16 days, and the renewal periods of the glaciers, groundwater, ocean, and large lakes are 100 s to 1000 s years (Meran et al., 2021). The phenomenon of precipitation has high spatial and temporal variability. In terrestrial ecosystems, the water which is utilized through "photosynthesis" for conversion into the biomass and lost via "transpiration" process is termed as "green water". On other hand, the precipitated water which is not evaporated but becomes the part of surface water bodies (rivers and lakes) and ground water aquifers is termed as "blue water"(Meran et al., 2021). Hence, based on water uses, utilization and conversion to wastewater, the footprints can be categorically sub divided into (1) Green water footprint which is the water used and utilized by the rain-fed agricultural crops, forests wood/timber, forest crops, and horticulture plants. This is basically the water obtained from rainfall. (2) Blue water footprint which is the water majorly consumed for drinking and used in various domestic

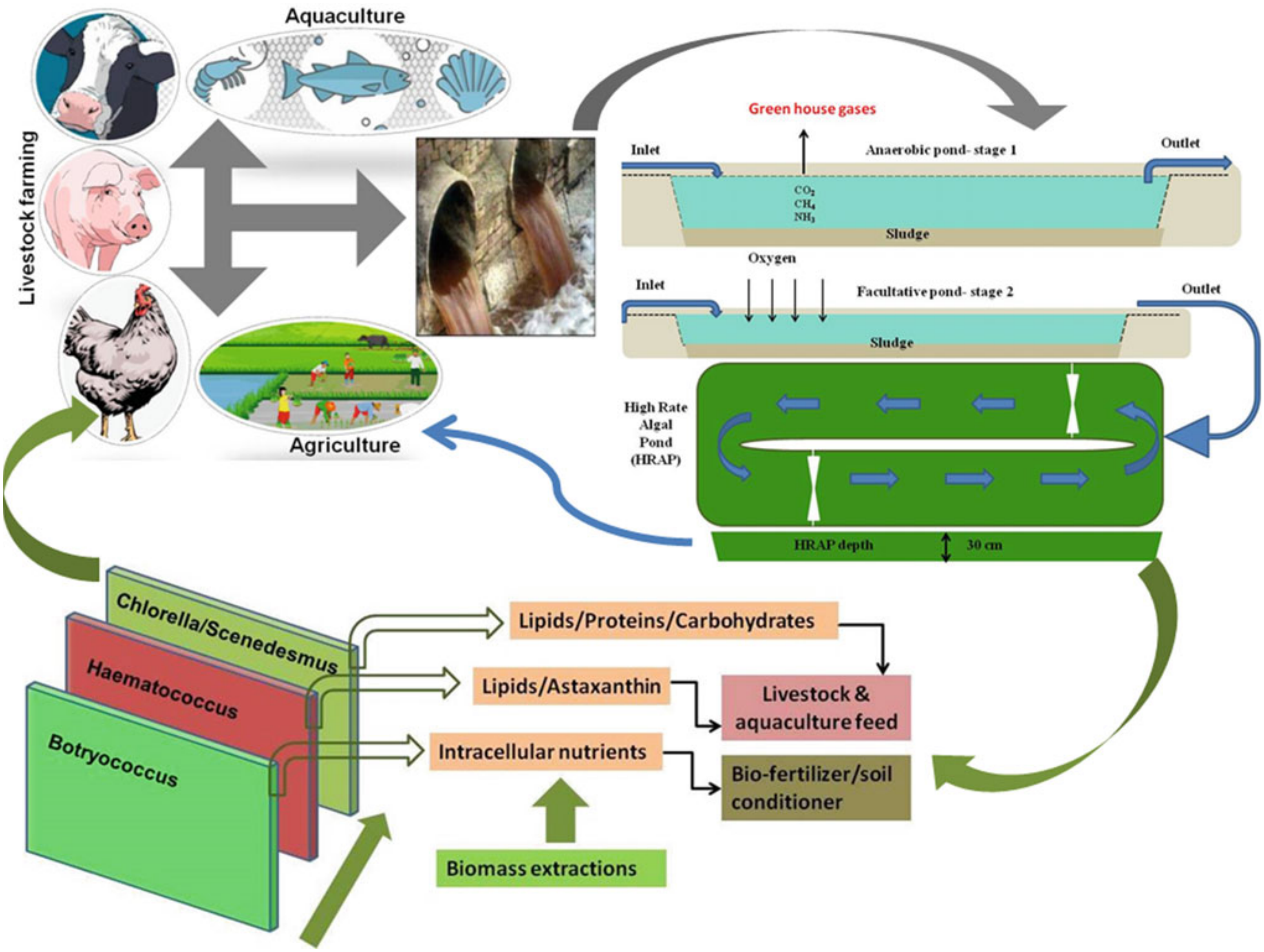


Fig. 6 Example of algae-based circular economy. Wastewaters from agriculture and livestock farming treated at primary stages using microorganisms followed by nutrient conversion into biomass with high nutritive value utilized back into agro-livestock farming

activities, utilized by agriculture through various means of irrigation, utilized to harness electricity and used for industrial purposes. This is the major water resource present in the rivers, aquifers, and groundwater. (3) Grey water footprint which is the water polluted by individuals, society, farmers, industries, and companies. The polluted water is then being discharged into the freshwater sources such as rivers through sewage, agriculture runoff, and in groundwater sources through seepage.

The sustainability of the green water footprint measures the allocation of freshwater. The production of agriculture-based products such as food, feed, fibre, wood, biofuel consumes significantly large fraction of green water and consequently this sector of the economy has a large green water footprint. This footprint fundamentally involves the allocation and does not consider the local impacts. The sustainability of green water footprint is closely linked with sustainable land use. The land use and green water for human activities are not considered as sustainable until a minimum area of unaltered land is being secured in the eco-regions of the production forests (Chapagain, 2017). The available green water forms the sustainable resource when there is a balance between the production of forest products or crops and an uninterrupted natural flow cycle. Environmental sustainability in terms of water quality can be obtained by comparing the grey water footprint with total assimilation capacity to understand the level of water pollution. The higher grey water footprint than the assimilation capacity indicates the higher pollution of water as compared to the accepted standards. Water footprint assessment is key water management approach that considers the sustainable utilization of water resources. Although, it was created mainly to assess the agricultural and food production, it is mandatory for various industries and manufacturing process to assess water footprints and formulate the conservation strategies.

10 Conclusions

Drought is an outcome of the disequilibrium in natural phenomenon due to the climate change. Timely monitoring through combination of various drought and climatic indices is foremost and crucial step to measure the water deficit in surface, soil, groundwater, and at mountain tops under the current and future climate change scenarios. Following the assessment of multiple drought indicators, the vulnerability and risk assessment management allow the implementation of various mitigation methods. The mitigation strategies should primarily restore the ecosystem balance to preserve the freshwater resources on the surface of the earth which subsequently safeguard global economies. The fundamental needs of water management through innovation are conservation of freshwater resources, minimizing wastage, and recycling of waste water. Several water conservation techniques are formulated to minimize water loss and to preserve the available water resources. Water conservation techniques aim to effectively balance the demand and supply of water. Under water-energy nexus, the hybrid nature-based waste water treatment systems that involve phyco- and bio-remediation such as waste stabilization cum high rate algal ponds and the energy generation using microbial fuel cells respectively support the circular economy and subsequently mitigate the impacts of drought on agriculture, livestock, and energy sectors.

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Analysis of Characteristics and Influencing Factors of Land Surface Temperature Change in Yunnan Province

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Abstract

As an important environmental element, land surface temperature (LST) can be used as a reference for climate change, and it also has an important impact on agricultural production. It is significant to study LST changes for understanding climate change and guiding agricultural production. The data in this article uses the high-quality 2003–2017 MODIS LST data reconstructed by Zhao Bing's team as the data source. Based on the climate tendency rate and geodetector, the characteristics and influencing factors of LST changes in Yunnan Province are analyzed. We finally got three results: (1) From the overall distribution of LST, the in Yunnan Province gradually increases from north to south. (2) The minimum LST varies greatly in each season, and the maximum LST varies less. Generally speaking, the LST of Yunnan Province is showing an upward trend. (3) The factor detector of the geodetector revealed that air temperature ($q = 0.731$), elevation ($q = 0.657$), and precipitation ($q = 0.458$) are the main factors affecting the LST of Yunnan Province. The interactive detector further revealed that temperature and precipitation ($q = 0.762$), temperature, and DEM ($q = 0.745$) jointly drive the characteristic pattern of LST in Yunnan Province. This study can provide a certain reference for related research, and it can also provide a certain reference for the agricultural planning of Yunnan Province.

Keywords

Land surface tempreature • Yunnan Province • Change characteristics • Geodetectors • Influencing factors

1 Introduction

As an important environmental parameter, the land surface temperature (LST) is controlled by the interaction and energy flow between land and air. It is also an important element for high temperature and aridity prediction models on different spatial scales (Zhao et al., 2020). LST is affected by many factors (Xie, 2016), which also affects human agricultural production and life (Zhang & Ji, 2019). Therefore, studying the LST of a region is of significance to the study of climate change in the region. The research on the LST mainly focuses on the factors that affect the LST and the retrieval of the LST. From the perspective of factors affecting LST, Zhang and Sun (2019) took two major urban areas in Canada as the research area to discuss the impact of urban land use on LST. However, this paper only considers the impact of land use change on LST, without considering other human factors or natural factors. Zhang and Liang (2018) considered the satellite data of coverage and conversion of multiple land use types China and explored how they affect the LST and the extent to which they affect the LST through changes in biophysical processes. The LST is affected by many factors, and the selected factors in this paper are also less, only focusing on the impact of land use change on LST. Chi et al. (2020) taking the Yellow River Delta as the research area, analyzing the spatio-temporal pattern of LST in different seasons in the past 30 years and its relationship with NDVI and soil moisture content. This paper only considers the influence of NDVI and soil moisture content on LST, without considering the impact of other natural or human factors on LST. From the retrieval of LST, Haynes

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et al. (2018) take Australia as the research area and propose a method based on MODIS that can continuously estimate the LST in space. Zhao et al. (2020) use MODIS LST data to reconstruct China's LST and analyze the spatio-temporal evolution of China's LST. Choi and Suh (2020) developed a nonlinear split-window LST inversion algorithm, which compared with MODIS LST and concluded that there was a smaller deviation at night. Research by Ma et al. (2018) shows that agricultural technical efficiency in Yunnan Province has increased significantly over the past 11 years, but there is still much room for improvement. Yunnan Province has attracted much attention at home and abroad for its unique natural agricultural resources advantages, and its agricultural products are known as 'green and ecological' (Qing et al., 2014). In recent years, extreme weather has occurred frequently, China has a large land area, and climate change is deeply manifested in China (Shi et al., 2017). The continuous drought in Yunnan Province in recent years shows climate change (Li et al., 2019; Wang et al., 2020; Yang et al., 2019). We choose several natural and humanistic factors which have great impact on the LST to study the influencing factors of LST in Yunnan Province. On the basis of analyzing the trend of LST in Yunnan Province, we explore the main influencing factors of LST in Yunnan Province, which is of great significance to understand the climate change in Yunnan Province, and can also provide some reference for the sustainable development of agriculture in Yunnan Province.

2 Materials and Method

2.1 Study Area

The location of Yunnan Province is shown in Fig. 1. Yunnan Province has a large undulating terrain and diverse climate types, which are mainly dominated by plateau monsoon climate and tropical rain forest climate. Therefore, there are both high temperature and rainy tropical rain forests and snow mountains in Yunnan Province, which can develop a variety of agriculture. The daily temperature range in Yunnan Province is relatively large, but the annual temperature range is relatively small. From the perspective of precipitation in Yunnan Province, it is unevenly distributed in seasons and regions, but the dry and wet seasons are distinct. The wet season is from May to October, concentrating 85% of the annual rainfall; the dry season is from November to April of the following year, with precipitation accounting for only 15% of the year. In addition, the population of Yunnan Province is mainly concentrated in the capital of Kunming and several surrounding cities, and the rest of the area is scattered.

2.2 Data Sources and Processing

The main data includes LST data, annual temperature, annual precipitation, annual NDVI, population density, and DEM data. The LST data comes from the high-quality

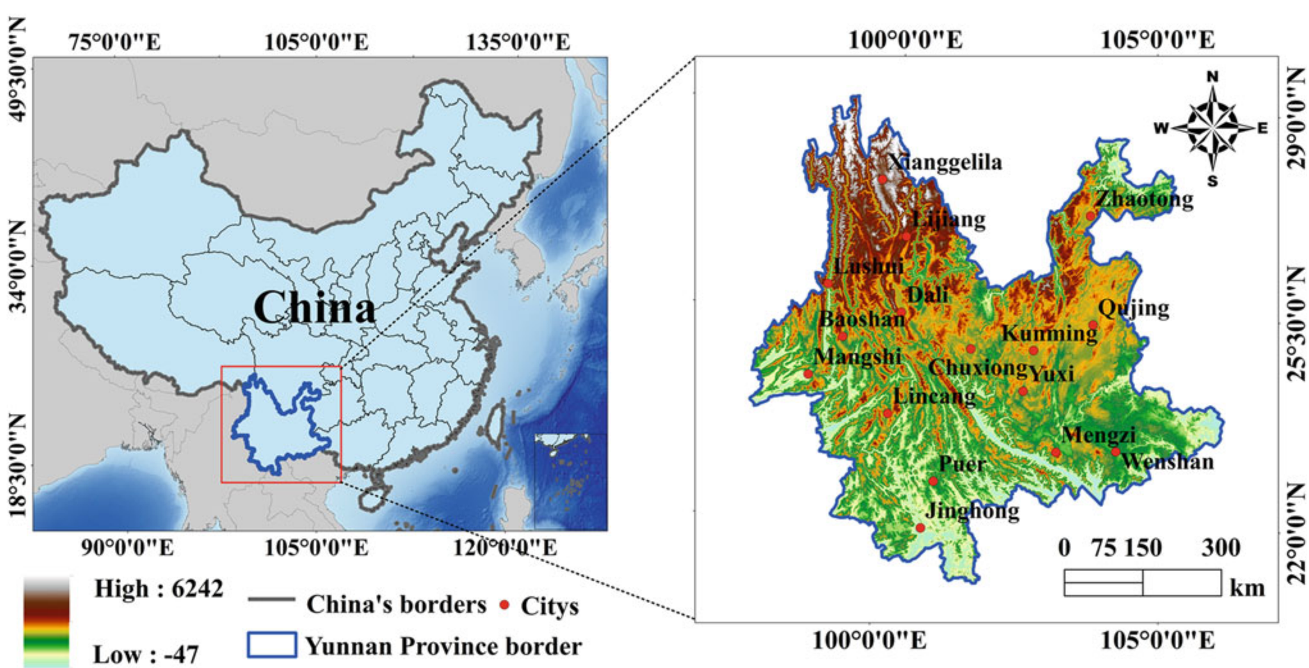

Fig. 1 Location of Yunnan Province

2003–2017 MODIS LST data set reconstructed by Zhao Bing's team. After verification, the root mean square error of this data for the six regions of China is between 1.24 and 1.58 °C, the mean absolute error is between 1.23 and 1.37 °C, and the R^2 is between 0.93 and 0.99 (Zhao et al., 2020). This data is monthly data. In this paper, we focus on the analysis of seasonal and annual LST in Yunnan Province, so we use the ArcGIS10.3 platform to synthesize seasonal and annual data from monthly data. The annual temperature, precipitation, and NDVI data are obtained from the https://www.resdc.cn/. Temperature and precipitation are obtained after processing the observation data of meteorological stations. The NDVI data set is based on the SPOT/VEGETATION PROBA-V 1 KM PRODUCTS ten-day 1 KM vegetation index data. The population density data is downloaded from the Worldpop Website (https://www.worldpop.org/). The DEM is ASTER GDEM data, downloaded from http://www.gscloud.cn/. The resolution of these data is 1 KM.

2.3 Method

2.3.1 Climate Tendency Rate

The trend rate of LST in Yunnan Province is calculated based on the unary linear regression equation, which is used to analyze the change trend of LST in Yunnan Province. The formula is as follows:

$$\mathrm{LST} = bt_i + a \tag{1}$$

In formula (1), t_i is the time series, b is the tendency rate, and a is the constant term.

2.3.2 Geodetector

Geodetector by Wang (Wang & Hu, 2012), the geodetector can be used to detect the impact of NDVI, precipitation, temperature, population density, and DEM on the LST in Yunnan Province. In ArcGIS, the LST layer and each driving factor layer are spatially overlapped and analyzed, and the factors are reclassified to obtain type variables. The value range of q is [0, 1], indicating that the explanatory power of LST is increasing from 0 to 1. The principle of the software is as follows:

The factor detector is used to quantitatively detect whether NDVI, precipitation, temperature, population density, and DEM are the reasons for the spatial difference of LST in Yunnan Province and the weight of each factor. The interactive detector separately calculates and compares the q value of each single factor, the q value after the two factors is superimposed, and it can judge whether there is an interaction between the two factors. If there is an interaction, it can further judge the strength of the interaction between the two factors. The model is as follows:

$$q = 1 - \frac{\sum_{h-1}^{L} N_h \sigma_h^2}{N\sigma^2} = 1 - \frac{\mathrm{SSW}}{\mathrm{SST}} \tag{2}$$

$$\mathrm{SSW} = \sum_{h-1}^{L} N_h \sigma_h^2 \ \mathrm{SST} = N\sigma^2 \tag{3}$$

In Formulas (2) and (3), $h = 1, \ldots, L$ is the strata of LST or several other influencing factors; N_h means strata h, N is the number of units in the whole region; ${\sigma_h}^2$ and σ^2 are the variances of a certain strata in Yunnan Province and the whole province of Yunnan Province. SSW represents the in sum of squares of the strata, and SST represents the total sum of squares.

The ecological detection is used to compare whether there is a difference between the impacts of two influencing factors on the spatial distribution of LST in Yunnan Province. The formula is as follows:

$$F = \frac{N_{X1}(N_{x2} - 1)\mathrm{SSW}_{X1}}{N_{X2}(N_{x1} - 1)\mathrm{SSW}_{X2}} \tag{4}$$

$$\mathrm{SSW}_{X1} = \sum_{h=1}^{L1} N_h \sigma_h^2 \ \ \mathrm{SW}_{X2} = \sum_{h=1}^{L2} N_h \sigma_h^2 \tag{5}$$

In Formulas (4) and (5): N_{X1} and $N_{X2,}$ respectively, represent the sample size of two of the five influencing factors. SSW_{X1} and $\mathrm{SSW}_{X2,}$ respectively, represent the sum of the intra-layer variance of the stratification formed by the two influencing factors of LST; $L1$ and $L2$, respectively, represent the number of layers of the two LST influence factors.

3 Results

3.1 General Characteristics of LST in Yunnan Province

Figures 1 and 2 show that the distribution of LST in Yunnan Province is opposite to the topography of Yunnan Province. The terrain of Yunnan Province decreased gradually from north to south, while LST increased gradually from north to south. The northern part of Yunnan Province is Hengduan Mountains with high terrain, while the southern part of Yunnan Province is low. Therefore, in Yunnan Province, the LST is still lower than 0 °C in some areas in the hottest summer, while it is close to 20 °C in some areas in the coldest winter.

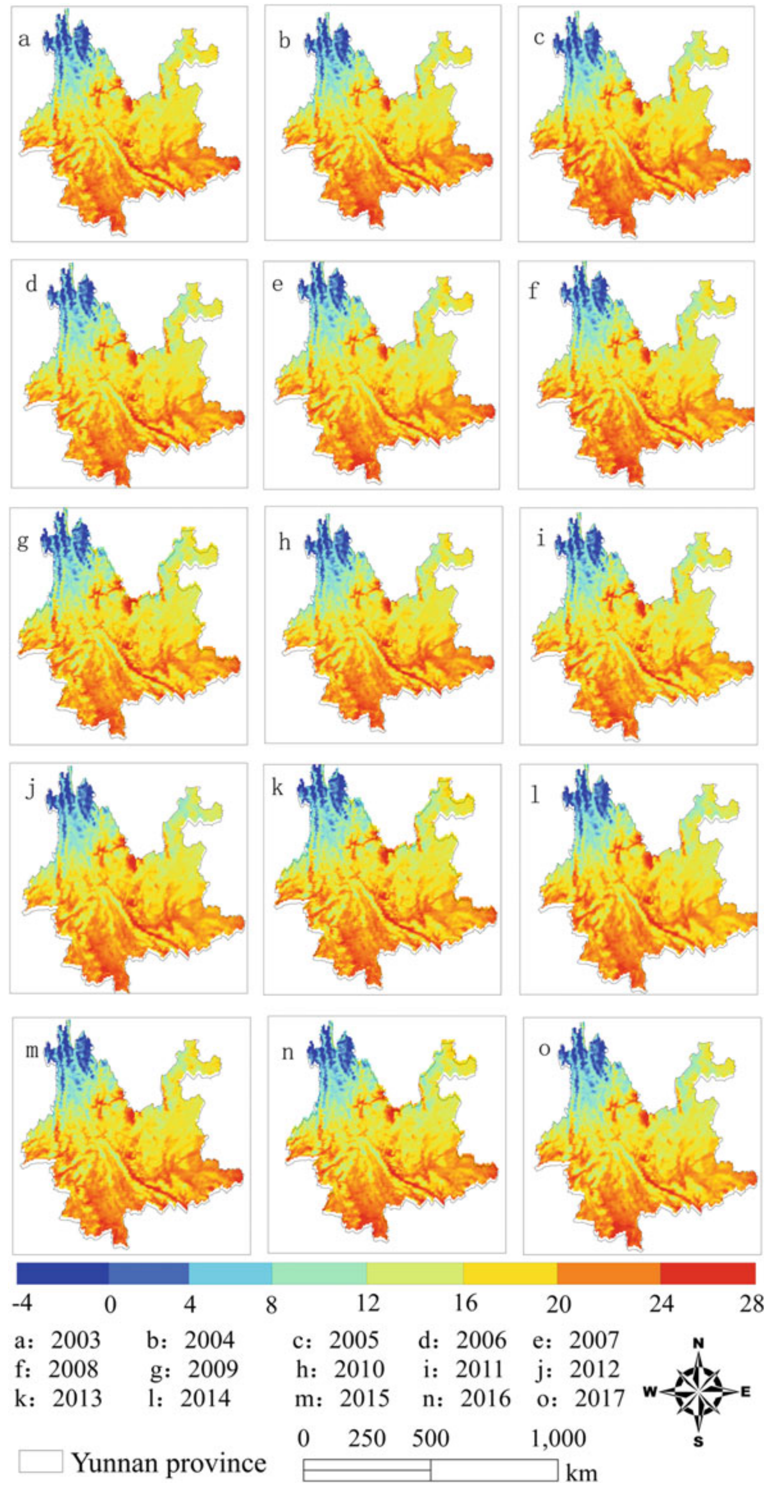

Fig. 2 Temporal and spatial distribution of LST in Yunnan Province from 2003 to 2017

3.2 Characteristics of LST Changes in Yunnan Province

On the whole, Yunnan Province has relatively small changes in the highest LST, lowest LST, or average LST in each season. Relatively speaking, the change in the lowest LST in each season is larger than the highest LST and average LST. The LST in Yunnan Province generally shows rising trend.

It can be seen from Fig. 3 that the minimum LST (LST-min) change range in each season is larger than the maximum LST (LST-max) and the average LST change range. The variation range of the LST-min was more than

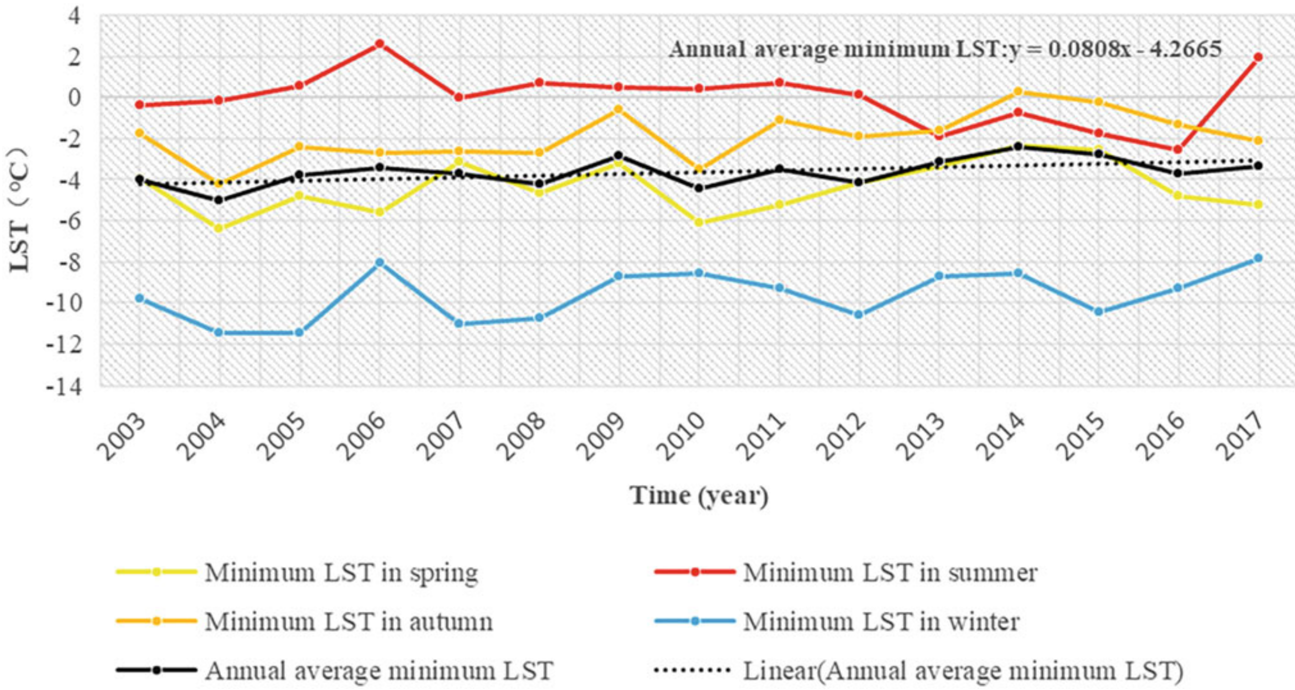

Fig. 3 Minimum LST in the year and each season

4 °C, which was manifested as the LST-min in spring of 2004 was −6.41 °C, while that in spring of 2014 was −2.35 °C. It can also be seen that even in summer, the LST-min in Yunnan Province is below 0 °C in most years, and the range of change also exceeds 5 °C. The LST-min in spring was on average 2.5 °C higher than that in autumn. The LST in winter also showed fluctuating changes, the average LST was −9.64 °C, and the variation range of the LST in winter was less than 3.7 °C. The LST-min of each season is consistent with the temperature of each season, that is, the highest in summer, the lowest in winter, and the LST-min has a gradual upward trend.

As can be seen from Fig. 4, from the perspective of the LST-max in each season, the LST in autumn and winter is in line with the temperature, while the LST-max in spring and summer is relatively close. There are even some years where the LST in spring is greater than the LST in summer. The inter-annual LST-max varies between 28.30–34.18 °C, and the average LST-max is 31.26 °C. It can also be seen from Fig. 4 that both the average LST-max in each season and the annual average LST-max show a fluctuating upward trend, but the upward trend is relatively small.

From Fig. 5, we can see the annual average LST and the average LST of each season. On the whole, the change of average LST and annual average LST in each season is small, and the change range of average LST in each season is less than 2.4 °C. The average LST in spring is similar to the average LST in summer. The average LST in autumn is similar to the annual average LST. The annual average LST shows an upward trend, but the rate of increase is slower.

Figure 6 shows the statistical graph of the temperature difference of the LST-max and LST-min in Yunnan Province and the statistical graph of the temperature difference of the annual average LST-max and the annual average LST-min. As a whole, the temperature difference between the LST-max and the LST-min in the year shows an upward trend, but the upward trend is very small. The difference between the annual average LST-max and the LST-min shows a downward trend, but the decline is also very small. On the whole, there are fluctuations in the temperature difference between the LST-max and the LST-min in the year, or the temperature difference between the annual average LST-max and the annual average LST-min, indicating that the LST is not stable. It can be seen from the figure that the temperature difference between the LST-max and the LST-min reached 60 °C in 2011, which is related to the LST-min of the year, and the data may be incorrect. The LST-min in 2011 was −28.76 °C. The minimum temperature difference between the LST-max and the LST-min appeared in 2003, and the temperature difference was 40.11 °C. The temperature difference between the annual average LST-max and the LST-min has a small variation range. The lowest temperature difference was 27.26 °C in 2007, and the highest temperature difference was 29.78 °C in 2010.

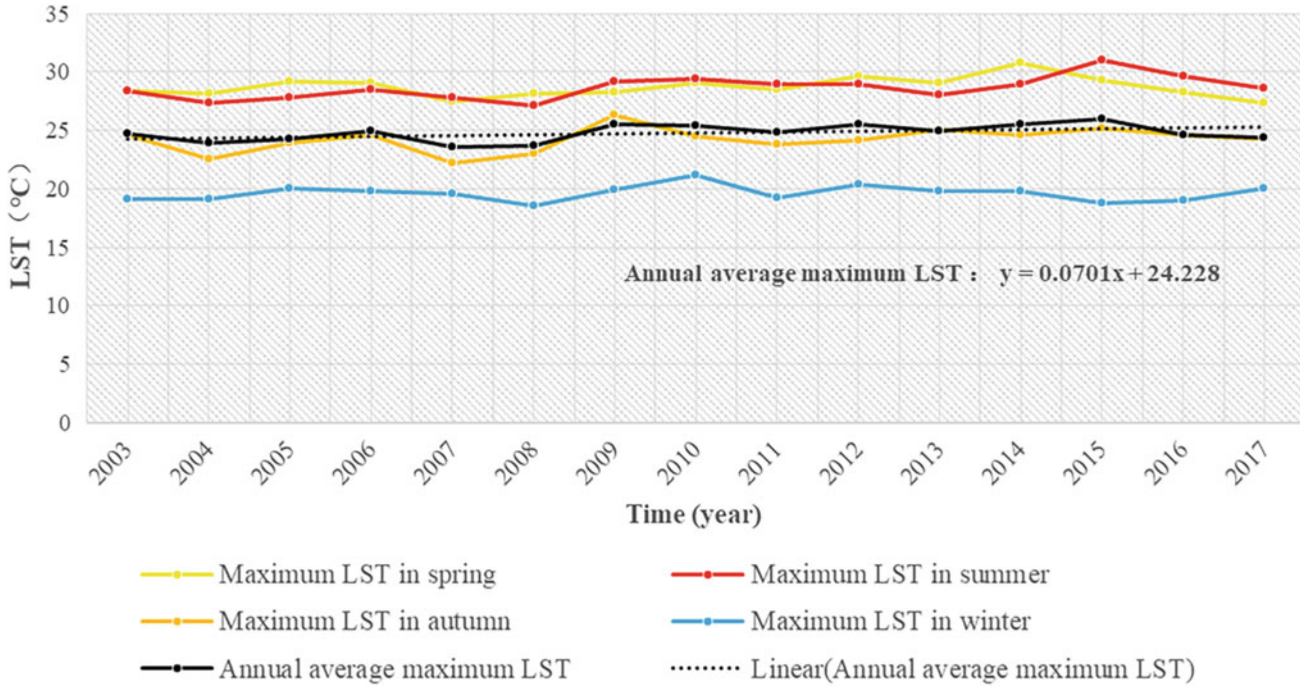

Fig. 4 Maximum LST in the year and each season

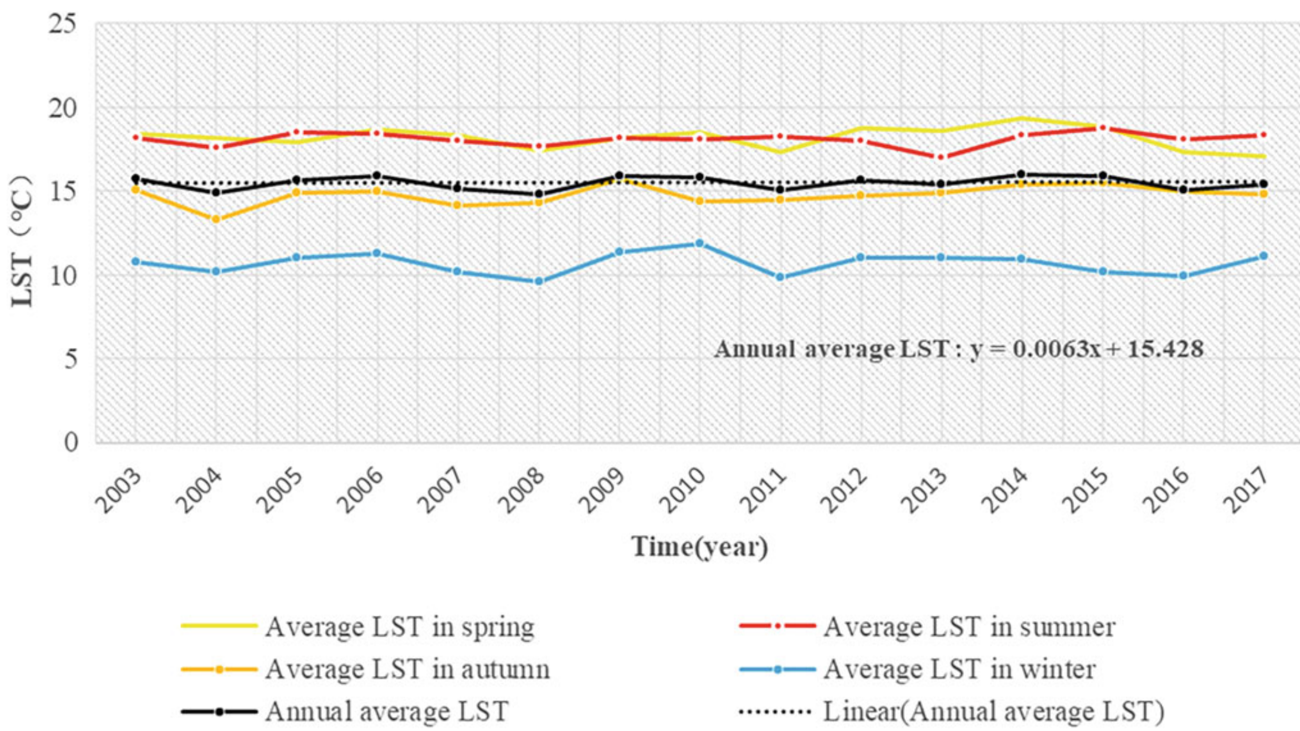

Fig. 5 Average temperature in years and seasons

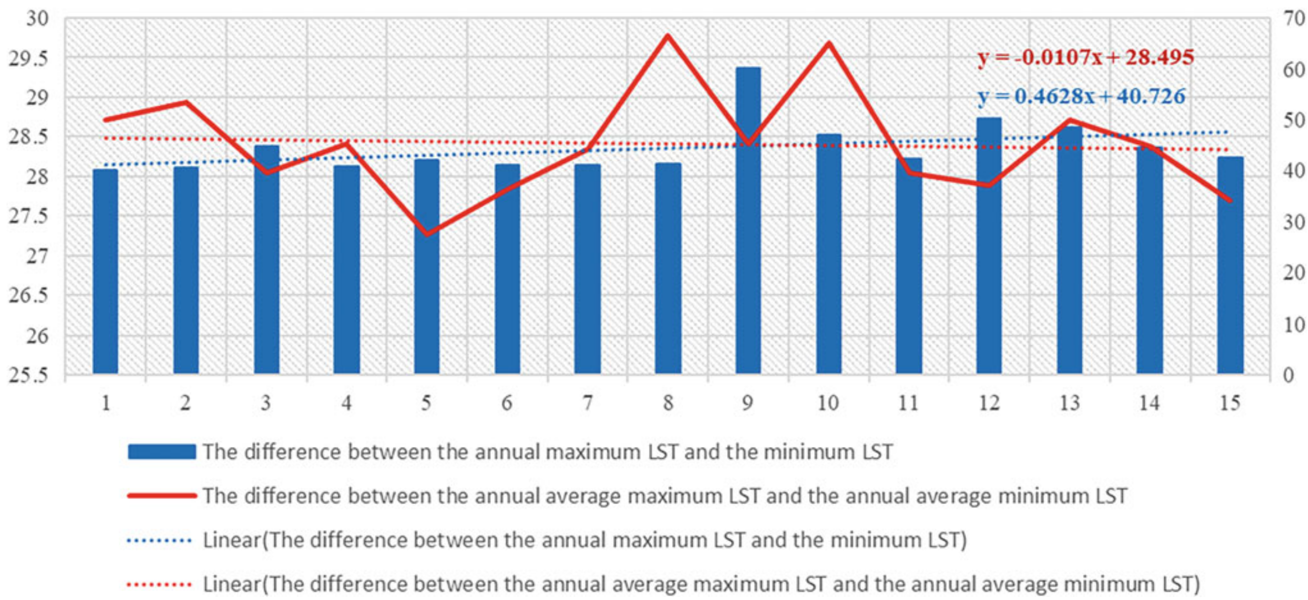

Fig. 6 Temperature difference between annual maximum LST and annual minimum LST and between annual average maximum LST and annual average minimum LST

3.3 Analysis of Factors Affecting LST

3.3.1 Single Impact Factor Analysis

Table 1 shows that the weight of the influence of various factors on LST is temperature (0.732) > DEM (0.657) > precipitation (0.458) > NDVI (0.023) > population density (0.003).

3.3.2 Combined Impact Factor Analysis

From Table 2, it can be found that the two interactive driving factors with greater explanatory power are temperature ∩ precipitation (q = 0.762) and temperature ∩ DEM (q = 0.745). At the same time, it can be seen that the interaction of any two variables on the LST of Yunnan Province is greater than the single effect of a single influencing factor.

Combining the results of the factor detectors in Table 1 and the results of the interactive detectors in Table 2, we can see that among the several influencing factors we have selected, whether precipitation, temperature, and DEM are single factors or combined factors, the q value is greater than other single or combined factors, these three influencing factors are all natural factors, and it can be seen that the q of a single factor of population density is only 0.003. In addition, among the three main influencing factors, the interactive driving factor value of precipitation and temperature is the largest, Reaching 0.762, which shows that the main influence on the pattern of LST characteristics in Yunnan Province is mainly natural factors, while the influence of human factors is relatively small.

3.3.3 Ecological Detector Results

The results of the ecological detector are shown in Table 3. It can be seen that except for the two factors of population density and NDVI that have no significant difference in the spatial distribution of LST in Yunnan Province, and the

Table 1 Results of factor detectors

	NDVI	Precipitation	Temperature	Population density	DEM
q	0.023	0.458	0.732	0.003	0.657

Table 2 The results by interactive detector

	NDVI	Precipitation	Temperature	Population density	DEM
NDVI	0.023				
Precipitation	0.483	0.458			
Temperature	0.737	0.762	0.732		
Population density	0.046	0.462	0.733	0.003	
DEM	0.667	0.709	0.745	0.658	0.657

Table 3 Ecological detector results

	NDVI	Precipitation	Temperature	Population density	DEM
NDVI					
Precipitation	Y				
Temperature	Y	Y			
Population density	N	Y	Y		
DEM	Y	Y	Y	Y	

other two factors have significant differences in the spatial distribution of LST in Yunnan Province.

4 Discussion

Different crops have suitable growth environments, and growth in suitable environments can promote the sustainable development of agriculture. For the development of agriculture, LST is an important factor affecting agricultural development. It can be seen from the literature cited in the introduction that there is still much room for agricultural development in Yunnan Province, and reasonable planning will be conducive to the sustainable development of agriculture in Yunnan Province. From Figs. 3, 4, 5 and 6, we can see that the LST in Yunnan Province shows an overall upward trend, which is bound to have a certain impact on agricultural development in Yunnan Province. In addition, it can be seen from Sect. 3.3 that the main factors affecting the LST in Yunnan Province are temperature, precipitation, and DEM. Among the five selected factors, population density is the smallest factor affecting the LST in Yunnan Province. Therefore, the natural factor has a greater impact on the LST in Yunnan Province. In the three major factors of temperature, precipitation, and DEM, DEM is generally in a constant state, and temperature and precipitation are the main embodiment of climate change. Therefore, the change of LST is also a reflection of climate change to a certain extent, so the single factor of observation of LST actually takes into account the change of multiple factors. We therefore call on relevant departments to pay attention to changes in LST as a reference for agricultural adjustment.

By studying the changes in LST in a region, the research on climate change in the region can be promoted to help guide agricultural production. This paper analyzes the variation characteristics and influencing factors of LST in Yunnan Province. Among the influencing factors, we mainly consider the five influencing factors of NDVI, precipitation, temperature, population density, and DEM. In the actual situation, the LST should be more many influencing factors, so in future research, we will consider more influencing factors to enrich the research content.

5 Conclusion

Based on climate tendency rate and geographical detector, this paper analyzes the variation characteristics of LST in Yunnan Province and the factors affecting LST. The conclusions are as follows.

1. The LST in Yunnan Province gradually increased from north to south; the terrain in Yunnan Province is decreasing from north to south. The main terrains in northern Yunnan are mountains and plateaus with high altitudes. Some mountains have snow all year round. Even in summer, the minimum temperature in Yunnan province is still below 0 °C. The terrain in southern Yunnan Province is relatively low. In some low-hot valleys and Xishuangbanna, even in winter, the minimum temperature is still above 0 °C. Therefore, even in winter in Yunnan Province, there are still some areas of LST above 0 °C.
2. From the perspective of change characteristics, the LST of Yunnan Province is showing an upward trend; the LST fluctuates in each season. Except for the large variation range of the LST-min, the variation range of the LST-max and the average LST in the seasons is small. Whether the annual average LST-max, the annual average LST-min, or the annual average LST has an upward trend.
3. Through the detection of geodetectors, it can be seen that temperature, elevation, and precipitation are the main influencing factors of LST in Yunnan Province. At the same time, the interactive detection results of temperature, elevation, and precipitation also show that the q value between these three factors is higher than the interactive detection results of the other two factors. The results of ecological detector showed that except for the two factors of population density and NDVI that did not significant difference the spatial distribution of LST in Yunnan Province, the other two factors have significant differences in the spatial distribution of the LST in Yunnan Province.

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Is It Possible to Achieve Carbon Neutrality in Palm Oil Production?

Joni Jupesta, Keigo Akimoto, and Rizaldi Boer

Abstract

Achieving carbon neutral consumer goods is dependent on reducing the greenhouse gas (GHG) emissions from one of their major ingredients–palm oil. This crop has become one of the most controversial today because, despite its high productivity, high applicability and ability to alleviate poverty, palm oil development also comes at the cost of deforestation, which causes GHG emissions and biodiversity loss. This study aims to assess the possibility for the palm oil sector to move toward carbon neutrality to support the United Nations' Sustainable Development Goal (SDG) 13 (climate action). In this paper we assess the pathways to reduce the GHG emissions from palm oil by using the tool Palm GHG Calculator from Roundtable on Sustainable Palm Oil (RSPO). The current Business as Usual (BAU) GHG emissions from palm oil are 0.6 tonCO_2eq./ton Crude Palm Oil (CPO). The study shows that in four scenarios: Land Use Change (LUC), Palm Oil Mill Effluent (POME) utilization technology, new planting materials, and nutrient (fertilizer) management could contribute to GHG emissions reduction. The estimated reductions are: 0.36 tonCO_2eq./ton CPO, 0.15 tonCO_2eq./ton CPO, 0.3 tonCO_2eq./ton CPO, and 0.06 tonCO_2eq./ton CPO, respectively. Altogether, those four scenarios suggest negative GHG emissions at value −0.37 tonCO_2eq./ton CPO. This study is useful as the guidelines to decarbonize palm oil industry derivates such as biofuels and oleochemicals industries.

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Keywords

Carbon neutral • Consumer goods • Palm oil • Climate action • GHG emissions

1 Introduction

There are importance to assess technological options and policies against the United Nations' Sustainable Development Goals (SDGs) as emphasized in the IPCC Special Report on the Impacts of Global Warming of 1.5 °C (Roy et al., 2018). Looking at alternative policy proposals and their effect on the SDGs, there are both good and bad effects. For example, there are negative effects (tradeoffs) from mitigation options across energy supply and demand and land use related were particularly related to SDG 1 and 2 (zero poverty and no hunger) and SDG 6 and 15 (clean water and sanitation and life on land), while there are positive effects (synergies) on the SDG 3 (good health), SDG 7 (affordable and clean energy) and SDG 13 (climate action) (McElwee et al., 2020).

In last decades the rising global demand for vegetable oil has led to a dramatic increase in the land use changes toward oil palm (Quaim et al., 2020). In Southeast Asia, while the oil palm boom has contributed to economic growth, but this rapid development also brings the unintended consequences such as negative environmental and social impacts. Oil palm is one of the most productive oil crops in the world in terms of oil yield per area. It had high applicability (used in wide range of processes); from fast food, chocolate spread and cereals to toothpastes, and animal feed (Rochmyaningsih, 2019). Palm oil is regarded favorably in the sustainable development context due to its ability to address poverty alleviation by creating jobs and generating income for smallholder farmers. In 2019, the total production of palm oil products in Indonesia was 51.8-million-tons; 47.2-million-ton crude palm oil and 4.6-million-ton palm

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kernel oil (Republika, 2020). The export of crude palm oil of Indonesia in 2019 was 36.2-million-tons valued at US$19 billion; this represents approximately 11% of Indonesia's entire exports in 2019. In the same year, the industry employed as many as 6 million Indonesians (about 5% of the total Indonesian labor force) and utilized a land area of 16.4 million ha (about 8.2% of the total land area in Indonesia). This crop has nonetheless become one of the most controversial today because, despite its high productivity, high applicability and ability to alleviate poverty, palm oil development is most often at the cost of deforestation, which causes greenhouse gas emissions and biodiversity loss (Curtis et al., 2018).

The notion of carbon neutral has been echoed as 'natural-based solutions' that by harnessing the power of nature in the fight against climate change (Griscom et al., 2017). While the 5th Assessment Report of the Intergovernmental Panel on Climate Change (IPCC) (2014) has provided a good overview of the role of Negative Emissions Technologies (NETs) for stringent climate stabilization targets, there is still a gap on how to achieve the NETs in sectoral based. Hence, the recent 6th IPCC Assessment Report of the IPCC (2022) will be providing reviews on the potential of combining natural and technological solutions in sectoral base. Figure 1 depicts the taxonomy of carbon dioxide removal (CDR) by using natural and technological pathways that will be published in the latest IPCC 6th Assessment Report (Babiker et al., 2022). It shown that natural/ecosystem-based CDR pathways are less costly, closer to deployment, and more vulnerable to reversal compared to technological CDR pathways.

Recently, there has been a major development with several major consumer goods companies making public pledges to move toward carbon neutrality. For example, since 2019, global brands such as L'Oréal, Starbucks, Nestle, Unilever, Procter and Gamble (P&G) declared carbon neutral targets (Wolk-Lewanowicz, 2020). P&G for example set a target to become carbon neutral by 2030. Given the role that palm oil plays as an ingredient to so many consumer goods then considering its carbon impact is key to achieving this target.

There are several studies has been published on the palm oil GHG emissions in Indonesia. The conversion of peat swamp forest and mineral forest to oil palm will brings different amounts of GHG emissions. The carbon stock study was conducted by Novita et al. (2021) focuses on the peat land tropical forest conversion to oil palm while the study on and Guillaume et al. (2018) focused on the mineral soil tropical forest conversion to oil palm. Since oil palm requires significant fertilizers, the study from Wiloso et al. (2015) assessed the impact of using empty fruit bunches (EFB) as organic fertilizer to reduce GHG emissions.

Bessou et al. (2014) analyzed the GHG emissions in pilot study that conducted by Rountable Sustainable Palm Oil (RSPO). The tool of this study is PalmGHG. PalmGHG is a spreadsheet tool that made by RSPO to measure the GHG emissions and sequestration for palm oil products. RSPO already conduct a pilot study in 2011 involving nine of its

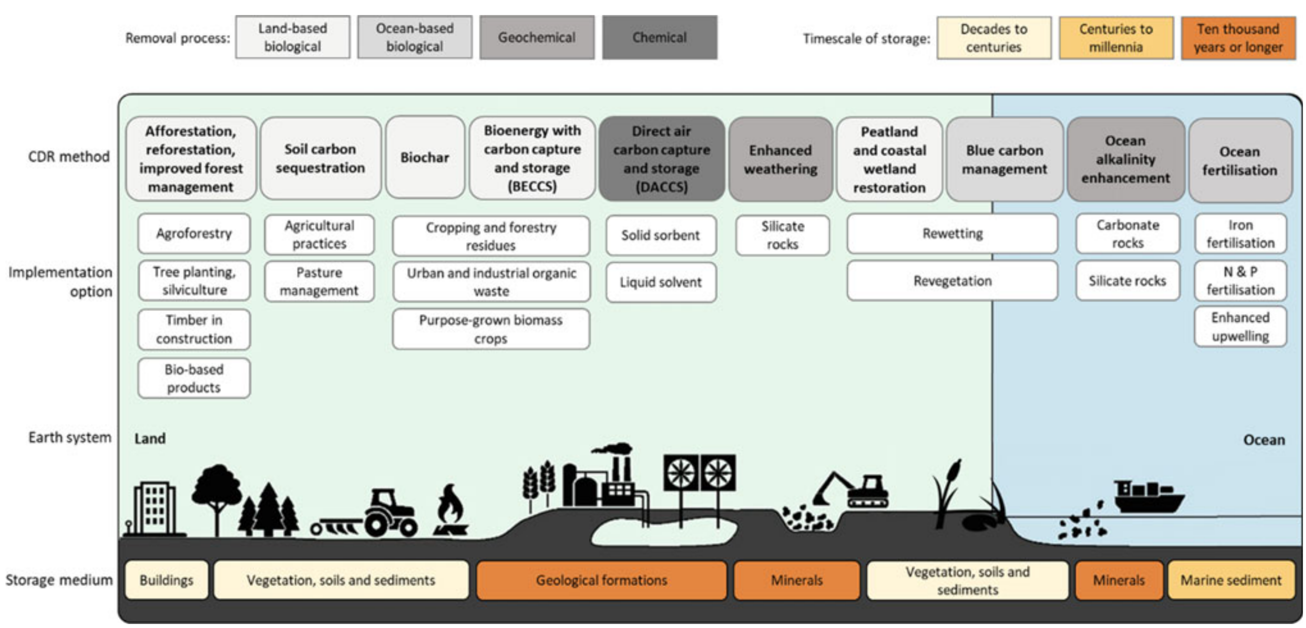

Fig. 1 The taxonomy of carbon dioxide removal (Babiker et al., 2022)

member companies that found that the average of GHG emissions of CPO is 1.67 t CO_2e/t crude palm oil (CPO), ranges from −0.02 to 8.32 t CO_2e/t CPO. Previous land use history and the area of peat soil for palm oil cultivation were the main determination factors for the huge variation. Gan and Cai already studied the GHG emissions of oil palm ranges from different commercial certifications schemes of oil palm: RSPO, ISCC and ISPO (2016). Its further calculated in detail based on RSPO Palm GHG Calculator method (2017).

While all the study focusses on GHG emissions measurements, there is no comprehensive study on the GHG emissions reduction to achieve carbon neutral using the carbon dioxide removal pathways. Here, the objective of this study is to examine the opportunity to achieve a carbon neutral oil palm sector based on production process that can lead to the achievement of the SDG 13 (climate action).

2 Methodology

The methodology of this study is to explore the mitigation pathway to reduce GHG emissions from oil palm in its current state based on the RSPO study. RSPO is widely recognized as the credible palm oil certification system and has the largest reach of all certification systems. As of 2018, the RSPO certification already covers 2.55 million hectares of oil palm and 315 Certified Palm Oil Mills, which producing 11.86-million-tons of certified sustainable palm oil which is approximately 19% of the world's total palm oil production (Gan et al., 2018). The study from Gan and Cai (2017) became the baseline for the GHG emissions value from oil palm. This study using the input data from Gan and Cai (2016) which compare the difference of certifications system in Oil Palm industry, e.g.: ISCC, ISPO and RSPO. The Gan and Cai (2017) study using RSPO Palm GHG Calculator as tool that was developed by Chase et al. (2012).

The Palm GHG Calculator was using life cycle analysis to which calculates the GHG from seed till final products: Crude Palm Oil (CPO), Palm Kernel Oil (PKO), and Palm Kernel Expeller (PKE). In this study the final product is focused only CPO. The boundary of the comparative analysis is crude palm oil production to the palm oil mill exit gate was depicted in Fig. 2. The GHG emission in reference to the functional unit of each production step per ton of fresh fruit bunches (FFB), per ton of crude palm oil (CPO), etc. We refer to the study from Gan and Cai (2017) since it considered the land use changes which occurred in Indonesia due to rapid oil palm development during the period 1980–2005. It also considered technology development such as methane capture (MC) which could convert Palm Oil Mill Effluent (POME) into biogas.

While Gan and Cai study has three scenarios study with two variations: with methane capture (MC) and without methane capture (non-MC) were developed to test the Palm GHG calculator. The first scenario is assuming no peat in the concession, hence zero planting on peat. No set-aside areas. The second scenario is assuming the concession is peatland, hence 100% planting on peat. No set-aside areas. The third scenario is assuming no peat in concession, hence zero planting on peat. In this scenario an extra 2000 ha of conservation area is set-aside within the concession. Since RSPO members is not allowed to be planting on the peat soil and not all RSPO members has 2000 ha conservation area, we only use scenario 1 that widely applied to all RSPO member as the reference as depicted in Table 1.

3 Results and Discussion

Table 1 shows that the GHG emissions of oil palm is highly varied; it ranges from −0.29 tonCO_2eq./t CPO to 8.8 tonCO_2eq./t CPO. The largest contributions of GHG emissions in Table 1. In absolute numbers (above 0.5 tonCO_2eq./t CPO) are coming from peat, oil palm sequestration, land conversion, followed by POME. The medium impact GHG emission sources (0.2 tonCO_2eq./t CPO to 0.5 tonCO_2eq./t CPO) are from conservation area sequestration, and the combination of chemical and organic fertilizers. Hence, we will focus on the possibility to reduce GHG emissions from those six sources (4 high impact and 2 medium impact) and from new planting materials.

3.1 Reducing Land Use Change Impact Via Avoided Peat Development and Degraded Land Utilization

A. Avoided peat development

Peat emissions is one of the largest GHG components of oil palm production process. It was found that approximately 84% of peat carbon in Southeast Asia was located in Indonesia, whereas there are extensive deforestation and degradation of peat swamp forests has been occurred since the 1990s (Novita et al., 2021). The reference study from Gan and Cai shows that oil palm based on peat land contributes 8.88 tonCO_2eq./ton CPO compared to mineral soils-based oil palm 0.6 tonCO_2eq./ton CPO (Gan & Cai, 2017). Given that tropical peat swamp having exceptionally high carbon stocks coupled with rapid rates of deforestation in the past, it is envisaged to avoid the oil palm development on peat.

Forest conversion would create GHG emissions from land use change since the carbon stock from forest would be

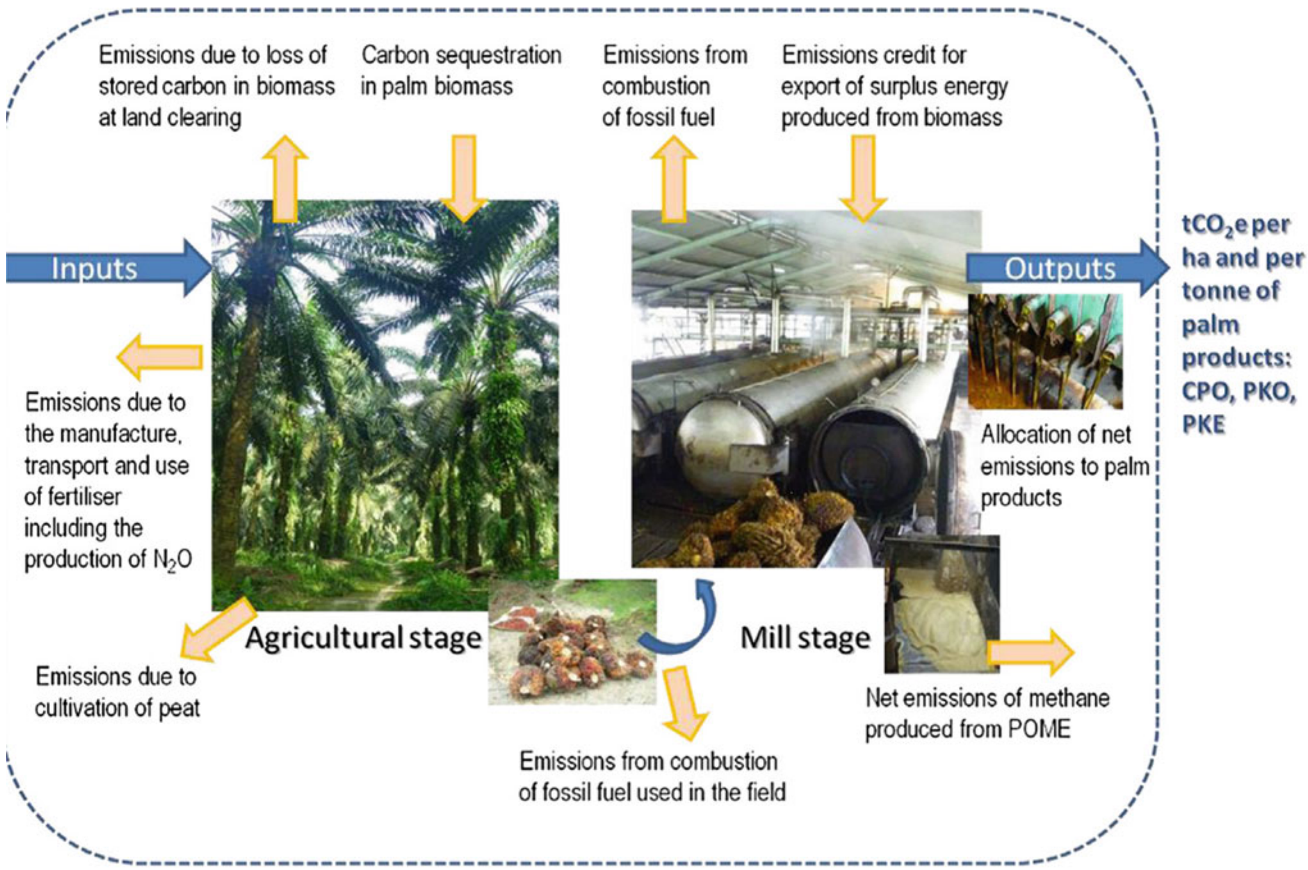

Fig. 2 Boundary of palm oil GHG calculator (Bessou et al., 2014)

Table 1 The GHG emissions from oil palm (tonCO_2eq./ton CPO) (Gan and Cai, 2017)

	Scenario 1	
	With MC	Without MC
Estate		
Land conversion	0.96	0.96
Fertilizer	**0.12**	0.12
N_2O	**0.14**	0.14
Fuel	0.01	0.01
Peat	0	0
Oil palm sequestration	**−1.28**	−1.28
Conservation area sequestration	0	0
Mill		
POME	0.07	**0.65**
Fuel	0.001	0.001
Electricity	0	0
Chemicals	0	0
Credit from electricity sale	−0.04	0
Credit from shell sale	−0.14	0
Credit from EFB sale	0	0
Total (Estate + Mill)	**−0.16**	**0.6**

higher than the carbon stock from oil palm, in peat soils. The study conducted by Novita et al. (2021) at Tanjung Putting in Central part of Kalimantan Island, shows that the carbon stock of primary peat swamp forest was 1,770 Mg C/ha compared to carbon stock of oil palm 759 Mg C/ha: land use changes 1,011 Mg C/ha. The study conducted by Guillaume et al. at Jambi in Sumatra Island shows the carbon stock in mineral soils from rain forest was 284 Mg C/ha compared to carbon stock of oil palm 110.76 Mg C/ha; land use changes 173.24 Mg C/ha (Guillaume et al., 2018). Since peat soil has higher carbon stock either as forest or oil palm plantation, conserving peat forests with their high carbon density would be one of the most cost-efficient tools for climate change mitigation at both global and local levels. Land use is particularly important in relation to the GHG emissions of oil palm, as land conversion from peatland to oil palm will lead to increased GHG emissions. The latest Nationally Determined Contribution (NDC) report for Indonesia mentioned that 1.7 million ha of peat land already allocated for oil palm development (Ministry of Environment and Forestry, 2021). Yet only 0.9 million ha has been planted. Peatland protection has been one of the most urgent issues facing palm oil producing countries and it has been a key area of focus and discussion for RSPO and its stakeholders over the last few

Table 2 Carbon stock value reference in RSPO Palm GHG (Bessou et al., 2014)[1]

No.	Land use	C stocks (t C/ha)
1	Primary forest	225
2	Logged forest	87
3	Coconut	75
4	Rubber	62
5	Cocoa under shade	70
6	Oil palm	≥ 50
7	Secondary regrowth	48
8	Shrub	26
9	Food crops	9
10	Grassland	5

years, and particularly with the recent Principle and Criteria (P&C) (Oil Palm Magazine, 2018).

B. Land conversion from less carbon stock

In 2018, to response with the international criticism on the deforestation was caused by palm oil, a 3-year moratorium was signed by the Indonesian president covering oil palm licensing. During the period time, no peat development or land use conversion for oil palm development occurred (Mongabay, 2018). The latest study from Gaveau et al. (2020) shown that despite of moratorium, the deforestation still occurs between 2018 to 2019 in slower rate than the previous years. Once the moratorium expires, in order to reduce the GHG emissions for the oil palm, the land use conversion should be from lower carbon stock than the oil palm. This degraded land might facilitate the GHG sink instead of GHG emissions. The value of carbon stock for each type of land was depicted on Table 2 based on RSPO study.

In Table 2 it is showed that oil palm has carbon stock 50 ton C/ha, while other land types such as: secondary growth, shrub, food crops, and grassland or so-called abandoned land have lower carbon stock than oil palm. Hence, the land use change from those abandoned land into oil palm could lead to negative carbon emissions. There is an estimated 4.4 million ha of abandoned land in Indonesia that could be potentially converted to oil palm. By doing this, the GHG emissions will be reduced due to carbon sequestration from oil palm is higher than the abandoned land (shrub and seasonal crops).

[1] PalmGHG is an open access software that belongs to RSPO that is used to measure the GHG emissions of oil palm from seed into final product crude palm oil (CPO)

C. Conservation area sequestration

In oil palm concessions, some of the areas which contain high carbon stock and high carbon value remain intact. In the RSPO report 2018, 265,000 ha are designated high conservation value (HCV). The latest data shows that there are potentially 1.4 million ha of natural forest located in the 16.4 million ha concession area for oil palm. The permit referred to the Ministry of Agriculture Decree No. 833 in 2019. More than half of the 1.4 million ha contains areas of rich biodiversity and carbon stock. Without conservation of the natural forest in the oil palm concession area, it is difficult to achieve the carbon neutral target.

3.2 Palm Oil Methane Effluent (POME)

Apart from Land Use Changes (LUC), Palm Oil Mill Effluent (POME) is the second largest source of GHG emissions in palm oil production.[2] POME is the wastewater that was produced during crude palm oil production process (Lim and Biswas, 2019). Raw POME has low pH (4–5), biochemical oxygen demand (BOD) of −32,000 mg/L, total nitrogen of 600–1000 mg/L, chemical oxygen demand (COD) of ~62,000 mg/L, suspended solids of 5000–54,000 mg/L, with temperature 60–70 °C. The raw POME was obtained 0.7–1.0 m^3 from 1 ton fresh fruit bunches (FFB). This study assumed two parameters: yield of 0.8 m^3 of raw POME for each ton of FFB and POME density is 0.876 ton/m^3. Hence, about 200,000 m^3 POME waste per year for a typical 40 MT of FFB/hour palm oil mill, resulting in annual GHG emissions of 24,000–36,000 tons of CO_2eq. A biogas plant could use methane capture and convert all the methane release to atmosphere into biogas. In this way, biogas could reduce the GHG emissions from 0.814 tonCO_2eq./ton CPO into 0.196 tonCO_2eq./ton CPO (Lim & Biswas, 2019).

3.3 Nutrient Management

Given that 48.7% of the emissions from the plantation come from nitrogen alone (*N* fertilizer), careful nutrient management could help reduce GHG emissions (Pardon et al., 2016). The current *N* fertilizer widely used is inefficient and has the potential to be mitigated by using a better fertilizer and utilization of the oil palm residues [POME and empty fruit bunches (EFB)] as organic fertilizer. The sources of nutrient are the chemical and organic (residue of Oil Palm such as EFB and mixture of POME with EFB).

[2] The current GHG emissions for POME refer to ISCC emissions factor: 510 kgCO_2eq./ton CPO.

A. Chemical Fertilizer Management

Fertilizer management varies greatly between plantations and through the age of oil palm (Pardon et al., 2016). The RSPO study shows fertilizer contributes 43% of total GHG emission (see Table 1 for scenario 1). Hence, urea fertilizer management is particularly important to reduce GHG emissions. One study mentioned that soil erosion will decrease the nitrogen level from 6.97% N to 0.75–2.44% N (Bah et al., 2014). The other study on the technical and structural mitigation options in agriculture found that smart fertilizer such as nitrification inhibitor could reduce between 2% till 23% GHG emissions (Frank et al., 2018). In this study we use midpoint 13% GHG emissions reduction due to smart fertilizer.

B. Organic Fertilizer Management

The utilization of organic residue from the oil palm production process can also contribute to GHG emissions reduction. To reduce the environmental impact of chemical fertilizers, the residues utilization from oil palm production process such as using empty fruit bunches (EFB) as organic fertilizer could reduce GHG emissions significantly from 123.6 kgCO_2eq./1270 kg Crude palm oil + Palm Kernel Oil + Palm Kernel Cake to become 81.7 kgCO_2eq./1270 kg CPO + PKO + PKC (Wiloso et al., 2015). Beside application of EFB as compost, the mixture of EFB and POME is also commonly used in oil palm plantations. The combination of EFB and POME could reduce GHG emissions 89% from 1150 kg CO_2eq./ton CPO to become 126.5 kgCO_2eq./ton CPO based on the study conducted by Baron et al. (2019).

3.4 New Planting Materials

Introducing new planting materials with higher yield might bring a positive impact to reducing GHG emissions. The new planting materials such as Eka 1 seeds and Eka 2 seeds could produce yields 10-ton CPO/ha (Eka 1) and 13-ton CPO/ha (Eka 2) compared to the current average yield between 4 to 6-ton of CPO/ha (Benih Perkebunan, 2020). In this study by shifting the old seed into new planting materials, the GHG emissions could be halved due to the change of the yield from 6.25-ton CPO/ha (Gan and Cai, 2017) to become double; 12.5-ton CPO/ha.

3.5 Overall Summary

Figure 3 summarizes all four scenarios for GHG emission reduction. The highest GHG emissions reduction are from land use conversion: avoided peat land impacts (zero peatland development), high carbon stock forest conversion (zero deforestation) and degraded land utilization. The other significant contribution for the GHG emissions reductions is from methane capture which converts POME into biogas. The third most significant is from new planting materials followed by better fertilizer management (e.g.: smart fertilizer and/or organic fertilizer utilization).

The BAU scenario RSPO referred to is the study of Gan and Cai (2017) where no MC applied and the GHG emissions value is 0.6-tonCO_2eq./ton CPO. The scenario 1 so-called Land Use,—where there is no land use conversion anymore in case oil palm was established before 2005 adheres to RSPO Principles and Criteria (P&C). Scenario 1 suggest the ability to reduce from 0.6-tonCO_2eq./ton CPO become negative GHG emissions −0.36 tonCO_2eq./ton CPO. Scenario 2 is the so-called POME Utilization—where all oil palm plantations implement methane capture to produce biogas and sell the excess residue into the grid. Scenario 2 could reduce GHG emissions from BAU 0.6 tonCO_2eq./ton CPO to become GHG emissions 0.15 tonCO_2eq./ton CPO.

Scenario 3 is the so-called fertilizer management,—where fertilizer management (smart fertilizer utilization, residue utilization, and biochar utilization) contributes to 13% reduction of N_2O emissions. The smart fertilizer urease inhibitor could reduce the GHG emissions from BAU 0.14 tonCO_2eq./ton CPO to become 0.12 tonCO_2eq./ton CPO. Further, composting POME and EFB could reduce GHG emissions from 0.65 tonCO_2eq./ton CPO to become 0.13-tonCO_2eq./ton CPO. In total, scenario 3 shows that combined smart fertilizer and POME + EFB could reduce GHG emissions from 0.13 tonCO_2eq./ton CPO to become 0.06 tonCO_2eq./ton CPO.

Scenario 4 is the so-called new planting,—which relies on the utilization of the 12.5 ton CPO/ha hence this double yield could reduce half of the entire GHG emissions from 0.6 tonCO_2eq./ton CPO to become 0.3 tonCO_2eq./ton CPO. Combining all scenarios; the total GHG emissions could reduce from BAU 0.6-tonCO_2eq./ton CPO to become negative GHG emissions −0.37-tonCO_2eq./ton CPO. In this case POME utilization is prioritized for co-composting instead of POME to biogas since the GHG emissions reduction value is better (0.13 tonCO_2eq./t CPO instead of 0.2 tonCO_2eq./t CPO). Since 47.4 million-ton CPO was produced in 2018 (Katadata, 2019) hence the potential GHG emissions reduction from 6 tonCO_2eq./ton CPO to -0.37 tonCO_2eq./ton CPO is 301.94 million tonCO_2eq. This GHG amount is equivalent to 20.7% of the entire Indonesian GHG emissions in 2016 (1457 million tonCO_2eq.). The details of the GHG emissions reduction potential from oil palm is available on Appendix.

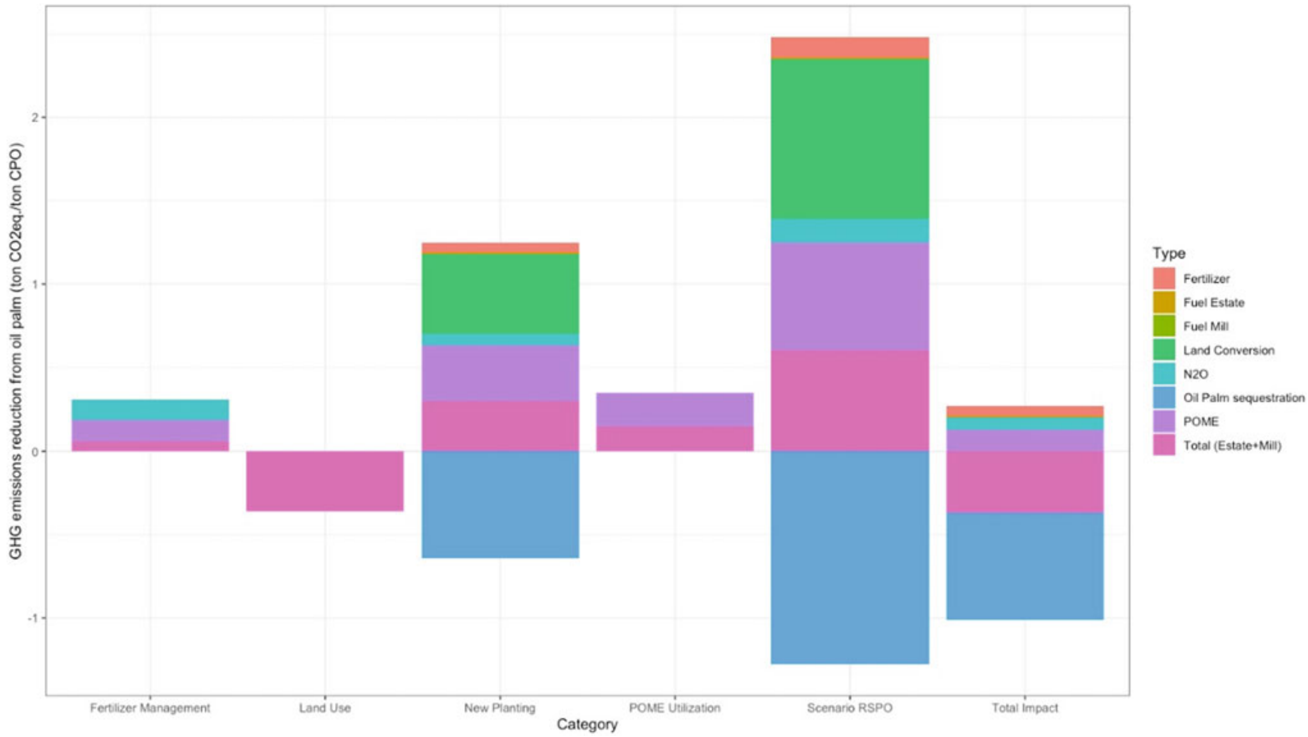

Fig. 3 The potential for GHG emissions reduction from oil palm (tonCO_2eq./ton CPO)

3.6 Unexplored Pathway: Biochar

The carbon dioxide removal pathway has been explained in previous sections. It covers all natural pathway: soil carbon sequestration, peatland restoration, and improved forest management. Other pathway that are feasible to be implemented is biochar from oil palm residue. The biochar is considered as one of the most affordable negative emissions technologies (NETs) for the large-scale deployment of carbon dioxide removal (CDR) in the future (Tisserant & Cherubini, 2019). Biochar system interacts with climate system in complex and highly case specific. In term of GHG emissions, biochar aims to mitigate climate change by capturing and storing atmospheric carbon in recalcitrant form, while the combined effort of increased soil organic carbon (SOC) stability and biomass yield after biochar application may also lead to an increase in stock of carbon soil in agroecosystems. The best feedstock for biochar is carbon rich feedstock such as lignocellulosic biomass (i.e.: EFB/trunk) since they contain less sugars/metabolites, and more lignin compared to leaf materials. Most of the biochar are aim on the carbon sequestration and soil conditioning which required yield of biochar. The most common process is slow pyrolysis while the fast pyrolysis and gasification process are less fit for the climate change mitigation and applications to soil due to produce lower yield and lower carbon content, as well as higher energy costs during pretreatment and higher risk of contamination (Tisserant & Cherubini, 2019).

4 Conclusions

Among all four possibilities for GHG emission reduction, the highest probability for GHG emission reduction was related to the land use conversion: avoided peat land impacts (zero peatland development), avoided forest conversion (maintain high conservation value forest). The second most significant contribution for the GHG emissions reductions is using methane capture technology which converts POME into biogas. The third largest contribution is from better nutrient management (e.g., smart fertilizer and organic fertilizer utilization). The BAU of the GHG emissions from palm oil is 0.6 tonCO_2eq./ton CPO. Four scenarios have been built to examine the GHG emissions reduction potential according to the significant contribution from land, POME utilization technology, new planting materials and nutrient (fertilizer) management which contributes to −0.36 tonCO_2eq./ton CPO, 0.15 tonCO_2eq./ton CPO, 0.3 tonCO_2eq./ton CPO, and 0.06 tonCO_2eq./ton CPO, respectively. Altogether, those four scenarios contribute negative GHG emissions with value −0.37 tonCO_2eq./ton CPO. In the future the biochar from oil palm residue could be explore as part of carbon dioxide removal pathways. It is expected that these results will become reference guidelines to accelerate the carbon neutral goal for final consumer goods products. Since palm oil is the material products for multiple consumers goods products, carbon neutral from palm oil will lead to the reduction on the carbon footprint from its derivative: biofuels, foods, and oleochemical industries.

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Appendix

See Table 3.

Table 3 The potential for GHG emissions reduction from oil palm (tonCO_2eq./ton CPO)

	Scenario RSPO	Impact				Total Impact
		Land Use	POME utilization	Fertilizer management	New Planting	
Estate						
Land conversion	0.96	0			0.48	0.00
Fertilizer	0.12				0.06	0.06
N_2O	0.14			0.12	0.07	0.07
Fuel	0.01				0.01	0.01
Peat	0				0.00	0.00
Oil palm sequestration	−1.28				−0.64	−0.64
Conservation area sequestration	0				0.00	0.00
Mill						
POME	0.65		0.20	0.13	0.33	0.13
Fuel	0.001				0.00	0.00
Electricity	0				0.00	0.00
Chemicals	0				0.00	0.00
Credit from electricity sale	0				0.00	0.00
Credit from shell sale	0				0.00	0.00
Credit from EFB sale	0				0.00	0.00
Total (Estate + Mill)	0.6	−0.36	0.15	0.06	0.30	−0.37

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Climate Change Mitigation and Adaptation in Urban Planning and Design

Impact of Urban Overheating on Critical Infrastructure

Simei Wu, Xiaojun Liu, and Bao-Jie He

Abstract

Affected by urban overheating (UO), urban areas are suffering more frequent thermal threats. This problem has severe environmental, economic, social and health consequences, where UO damages critical infrastructure (CIE) such as blackout, roads melting, and others. The disorder of the CIE under UO conditions can further aggravate the threats to public health. There is a need to take mitigation approach for an environmentally sustainable interpretation of CIE for in the planning, design, construction, operation and maintenance processes. However, whilst there are some reports on the impact of UO on CIE, there is a lack of systematic understanding, particularly associated with the CIE development and management. Therefore, this study fills this research gap by analysing such impacts in transport, energy, water and emergency or healthcare services. This study further provides recommendations for future management of CIE, including the high-temperature-resistant design, the use of high-temperature-resistant materials and targeted follow-up maintenance and management based on CIs characteristics across studies. This paper provides a comprehensive review of the effect of UO on CIE, the suitability of various technologies to reduce the impacts and future perspectives. This review can be a start for researchers and practitioners to optimise CIE management, and in turn, improve urban wellbeing.

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Keywords

Urban overheating • Critical infrastructure • Sustainability • Climate change

1 Introduction

It is undeniable that urban overheating (UO) will be a common problem for many cities around the world due to the heat wave and urban heat island (UHI) phenomenon, along with global climate change and urbanisation. Under such circumstances, not only the urban inhabitants will suffer more heat stresses with an increase in health risks and mortality but also the urban systems and environments (e.g. air pollution, biodiversity loss) will be under severe threats (Manoli et al., 2019; Pyrgou et al., 2017). Critical infrastructure (CIE) is a system which provides critical support service to the lives and health of the population. Even a disruption of CIE will bring great damages to the societal functions (Hawchar et al., 2020; Rehak, 2020). Energy supply is one of the several types of the CIE, and existing studies have reported that an elevated temperature in summer results in the increase of electricity demand and leads to economic loss (Li et al., 2020; Manoli et al., 2019). If no further mitigation and adaptation measure is taken, UO will exert severer impacts on urban life and environments (Santamouris & Kolokotsa, 2015).

Though there is no universal agreement of the scope of CIE, the impact of UO on CIE is far beyond the energy or electricity. However, there is limited discussion on the impacts of UO on the CIE. Regardless of a systematic scope of the CIE, to the research gap of lack of systematic understanding of UO-induced impacts on CIE, this study will investigate the CIE which is possibly affected by the ever-increasing temperature, in four aspects of transport, energy, water supplies and emergency or healthcare services. A good understanding of the UO-induced impacts can

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support the maintenance of CIE function through sound management approaches (Eldosouky et al., 2021). There are interactions, interconnections and interdependencies amongst CIE, and the destruction of one type of the CIE may transfer associated impacts onto another type of CIE amongst different stages (Fig. 1). Although CIE is designed for a long service lives, the reliability and resilience of CIE can be potentially reduced.

2 Threats and Mitigations of Urban Overheating on Critical Infrastructure

This section analyses the possible UO-induced impacts on CIE in aspects of transport, energy system, water supplies and emergency or healthcare services through literature review.

2.1 Transport

2.1.1 Threats of Urban Overheating on Transport

A historical climatic data are always adopted to support the engineering design of CIE. However, the occurrence of UO indicates the dynamic trend of temperature and implies the inaccuracy of using previous climatic data. The CIE may be not robust enough to resist heat-induced disasters and results in structural failure or quality degradation (Underwood et al., 2017). The mechanical properties of susceptible materials in flexible pavement, for example, can be affected by the working temperature (e.g. melting asphalt), with the disorder of whole structure, workability and service life (Viola & Celauro, 2015). A rigid pavement may undergo increasing heat stresses, slab bulking and thermal crack due to the excessive expansion (i.e. in the concrete), whilst a composite pavement may suffer the problems (e.g. waves, shifts, ruts and crowds) underwent by the flexible pavement.

Under the cycle of cold-hot temperatures, the pavement could suffer thermal crack and stiffness reduction (Pereira & Pais, 2017). Moreover, the increasing temperatures potentially result in an increase in permanent deformation, potholes and rutting, which leads to the significant increase in the maintenance costs (Chapman et al., 2013; Stoner et al., 2019; Underwood et al., 2017). It is estimated that the reliability and resilience of pavement infrastructure may be significantly damaged, and by 2040 (under the RCP 4.5 scenario), the United States will see an annual budget of $19.0 billion in the pavement costs (Underwood et al., 2017). Whilst the operation and maintenance cost grows fast in the of road, the one in the railway industry grows the fastest, particularly in Europe (Mulholland & Feyen, 2021).

With the growing temperature, the disaster susceptibility and economic losses of railway infrastructure are increasing (Liu et al., 2021). Chinowsky et al. (2019) figured out that delay-minute costs of railway industry ranged between $25 and $45 billion cumulatively through 2100 under a low greenhouse gas emissions future. The growing temperature may exceed the operating conditions of railway and damage the support performance of steel rails. Accordingly, the rail tracks may buckle and offset causing derailment, train delays and derailments under high temperature (Chinowsky et al., 2019; Mulholland & Feyen, 2021). The interactions amongst different types of the CIE can also bring thermal threats to the railway. For instance, the overheating can influence energy network, leading to failures of traffic signal and air conditioner (Chapman et al., 2013). The damage of urban overheating on the transport are showed in Table 1.

2.1.2 Mitigations of Urban Overheating on Transport

Selection of materials and mix design should be considered to address UO-induced impacts (Pereira & Pais, 2017; Viola & Celauro, 2015). Changing the asphalt mix design can remedy the thermal crack, permanent deformation, potholes and rutting. The improvement in thermal properties and emissivity may help mitigation urban heat challenges. Moreover, the rail sector can adjust stress-free temperature, use high-temperature-resistant asphalt binder and adjust

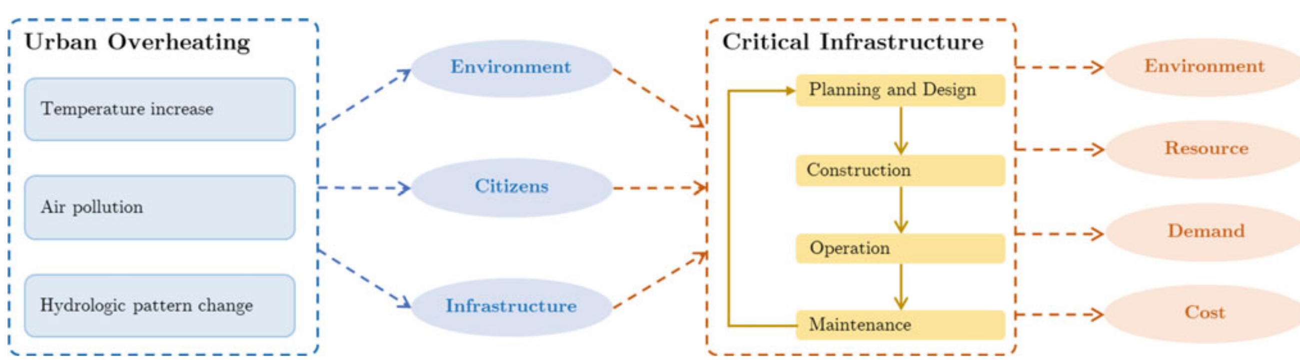

Fig. 1 Framework of the impacts of urban overheating on urban infrastructure in different stages and associated components

Table 1 Threats of urban overheating on the pavement

Section	Sub-section	Threats	Results
Pavement	Flexible pavement	Melt of susceptible materials	Failure of whole structure, the reduction of workability and service life
	Composite pavement	Waves, shifts, ruts and crowds	Failure of whole structure, the reduction of workability and service life
	Rigid pavement	Stresses in the concrete, slab bulking and thermal crack	Thermal crack and stiffness reduction, permanent deformation, potholes, rutting, operation and maintenance costs
Railway	Railway	Delay, impact of operation and maintenance	Operation and maintenance costs, delay-minute costs
	Steel rails	Buckle and offset	Derailment, train delays, derailments
	Energy network	Traffic signal, air conditioner	Accident, dissatisfaction

alternative aggregate structure and pavement structure (Mulholland & Feyen, 2021). To mitigate thermal threats, rail companies should upgrade track materials, new technologies and management pattern. The sensor technology may be coupled with refinements to speed reduction procedures, in which way the rail companies can leverage temperature monitoring capabilities and adjust train speed appropriately. Though the mitigation measures may bring extra pressure to the finance, it underperforms the economic losses caused by a system-wide train delay (Chinowsky et al., 2019).

2.2 Energy

2.2.1 Threats of Urban Overheating on Energy

Demand for reliance of energy (e.g. electricity, oil and gas) network is also increasing under high temperature conditions (Chapman et al., 2013). Electricity infrastructure is the most sensitive energy-related CIE to extreme hot weather, such as the electric grid system failures and blackouts. The air-conditioning system is the commonest way to overcome extreme thermal stresses (He et al., 2021), whilst the increase in cooling demand puts large pressure on grid reliability (Stone et al., 2021), especially the peak and the total electricity demand (Santamouris et al., 2015).

The ways that high temperature bring damages to electricity infrastructure are diverse (Table 2). First, the high temperature leads to an increasing electricity demand and disturbs generation efficiency (Varianou Mikellidou et al., 2018), since the turbines of thermal power plants are driven by steam which requires water cooling. As water temperature elevates, cooling efficiency decreases, so as the capacity of electricity generation (Rübbelke & Vögele, 2013; Varianou Mikellidou et al., 2018). Second, the electricity transmission efficiency decreases with temperature increase (Varianou Mikellidou et al., 2018), as high temperature can significantly impact operation efficiency. In addition, the operational life of transformer can be affected (Chapman et al., 2013). It is reported that the heat damage accounted for 9% of European hazard-related impacts in the energy sector (Forzieri et al., 2018). Moreover, the rising temperature can impact the performance and reliability of electricity infrastructure, resulting in a significantly increase in the annual costs (Fant et al., 2020). The threats of urban overheating on the energy are presented in Table 2.

Apart from affecting electricity production, warming temperature can also bring damage to both oil and natural gas infrastructure. Rising temperature can lead to permafrost melting, threatening oil and gas extraction, and the melting permafrost may lead to geological disaster, severely affecting the CIE built on it and pipeline built in it (Cruz & Krausmann, 2013). High temperature can enhance cooling requirements, bringing damage to the transportation systems of oil and natural gas industry and the increase in the maintenance costs. The mitigation and adaptation measures will require initial costs as well (Cruz & Krausmann, 2013).

2.2.2 Mitigations of Urban Overheating on Energy

First, the electricity production of power plants should be guaranteed under elevated temperatures, in which its cooling techniques should be adjusted for higher cooling efficiency which is important for the operation of power plants (Förster & Lilliestam, 2010). Nevertheless, there is a need of the change in power generation from the fossil fuel to renewable energies in the long run in order to realise decarbonisation. Second, the energy sector should introduce wide-area monitoring systems in the design of energy system. The smart-grid technologies such as power line temperature, sag monitoring systems and dynamic ampacity systems can enhance the safety and reliability of energy system. The monitoring systems can combine with advanced actuator and routing infrastructure to direct electricity. The dynamic

Table 2 Threats of urban overheating on the energy

Section	Sub-section	Threats	Results
Electricity infrastructure	Electricity infrastructure	Operation and maintenance	Operation and maintenance costs
	Electric grid system	Failures	Blackouts, lack of mechanical cooling systems, heat exposure
	Generation	Cooling of thermal power plants	Capacity of generation
	Transmission	Increase of resistance	Transmission efficiency
	Transformer	Operation	Operation efficiency and operational life
	Electricity demand of buildings	Total electricity demand	Pressure on the grid reliability
Oil and natural gas infrastructure	Oil and natural gas infrastructure	Transportation systems	Hence costs
	Permafrost	Melt permafrost	Threaten oil and gas extraction, affect the infrastructure building upon it and pipeline

ampacity systems can provide real-time electrical and environmental data. Heat-resistant technologies can be used to increase the reliability of energy system under warming temperatures. Renewable power generation technologies, distributed deployment of energy storage technologies and dynamic electricity pricing schemes can further offset the impact of UOs on energy sector (Bartos et al., 2016). Third, the energy sector should prepare plans and programmes to maintain the operation of energy systems. Redundancy design and substitution facilities need to be introduced to improve the robustness of systems. The operators of systems need to optimise management strategies and to ensure the resilience of real-time operations (Duan et al., 2019; Varianou Mikellidou et al., 2018). Besides, to enhance the reliability and resilience, reducing the increasing energy demand is another way to protect systems from extreme heat.

2.3 Water

2.3.1 Threats of Urban Overheating on Water

Extreme heat has a deep impact on water resource and brings about associated impacts on human society. Under warmer temperatures, the pattern of rainfall, flows and precipitation volumes change and result in lower flows (Table 3). Elevated temperatures result in an increase in water demand amongst the population and industries. Such a problem further increases the vulnerability of water supply (Leveque et al., 2021). In the coming decades, if the temperatures and population keep growing, the public water supply may face water shortage (Guo & Shen, 2016).

Rising temperature can increase evapotranspiration so that the frequency and intensity of surface drying and water storage can be enhanced. The elevated temperatures may further threaten urban water supply systems by accelerating evaporation and causing water shortages in reservoirs (Nam et al., 2015; Sisto et al., 2016). Moreover, warmer temperatures can also change the structure of phytoplankton community and increase the intensity of anoxia, release of nutrients from sediment and the growth of harmful algae in reservoir (Mi et al., 2020). The threats of urban overheating on the water are presented in Table 3.

2.3.2 Mitigations of Urban Overheating on Water

Under UO challenges, it is essential to improve water supply efficiency, where the design and operations of urban water

Table 3 Threats of urban overheating on the water

Section	Sub-section	Threats	Results
Water sector	Water consuming	Change pattern of rainfall, flows and precipitation volumes	Critical low flows
		Evapotranspiration	Surface drying and water storage
	Reservoirs	Accelerating the evaporation in reservoirs	Water shortages
		Structure of phytoplankton community	Anoxia, release of nutrients from sediment and the growth of harmful algae

systems should be adjusted. Both green and decentralised infrastructures should be incorporated to enhance the reliability and resilience of cities (Duan et al., 2019; Leveque et al., 2021). There is also a demand to make emergency water rationing plan. This plan protects the operation of key sectors play important roles in the society. Besides, the water supply system should integrate new water sources. New water sources have less correlations with existing sources for avoiding systematic risks (Sisto et al., 2016). Under warming temperatures, another way to reduce water stress is to enhance water connectivity amongst watersheds. In this way, the sensitivity of water stress can have a significantly decrease (Duan et al., 2019). Moreover, it is essential to adjust the withdrawal strategy of reservoir to avoid the deep water warming.

2.4 Emergency or Healthcare Services

2.4.1 Threats of Urban Overheating on Emergency or Healthcare Services

Extreme heat can directly threaten human health (Chapman et al., 2013), where deteriorating thermal comfort and aggravating thermal stress lead to increasing heat-related health issues and mortalities. Urban overheating is a driver to the elevation of air pollution which may further affect the respiratory system (Su et al., 2021). The intensity of high temperature has stronger influences on mortality than duration, resulting in increasing pressure on emergency departments and healthcare services (Pyrgou et al., 2017). The threats of urban overheating on the emergency or healthcare services are showed in Table 4.

The electric grid failure may devastatingly affect the efficiency of emergency departments and healthcare services. Moreover, the failure of mechanical cooling systems could further aggravate the situation of heat-related mortality and morbidity (Stone et al., 2021). For the low-income population, the extreme heat may cause a further deterioration of thermal risks (Santamouris & Kolokotsa, 2015) so that the reliability of emergency departments and healthcare services is likely to be further burdened.

2.4.2 Mitigations of Urban Overheating on Emergency or Healthcare Services

In the emergency and healthcare services sector, not only it needs to make adaptation plans for additional patients, but also it needs to relieve heat stress and reduce patients at the source, which can be achieved by cool materials, green and blue infrastructure and proper urban planning and design. For instance, the use of cool materials that have a high solar reflectance and emissivity, in construction industry, can effectively reduce air temperature and peak cooling demand of dwellings (Carnielo & Zinzi, 2013). Moreover, greenery and evapotranspiration can lead to a substantial reduction in UOs (Santamouris et al., 2020). For instance, nebulization was an effective solution to urban heat in Italian urban contexts (Ulpiani et al., 2019). Water stretch may be another key mitigation strategies to against extreme heat by reducing air temperature peak and thermal response by evaporation phenomena. Green infrastructures which include trees, parks and rooftop gardens have significant impacts on ameliorating urban heat (Battista et al., 2019). In addition, the GIs can provide shading, increase evapotranspiration and windshielding to decrease thermal response and solar reflectance.

3 Conclusions

CIE plays a vital role in modernised and urbanised societies, whilst it is under the severe influences of warming temperature. The possible failure of CIE can result in significant challenges to societal functions and operation. It is critical to maintain the lives and health under extreme hot weathers. Therefore, the CIE development should include the resilience to extreme heat. This study supports this by analysing UO-induced impacts on CIE (transport, energy, water and healthcare services) and providing proper recommendations to overcome such impacts. Overall, this study help scholars and practitioners to optimise CIE management and, in turn, improve citizens' satisfaction. This study can further support a wide-area heat monitoring system which can support the local government and industries to take mitigation and adaptation measures.

Table 4 Threats of urban overheating on the emergency or healthcare services

Section	Sub-section	Threats	Results
Emergency departments and healthcare services	Emergency departments and healthcare services	Thermal comfort and exerted thermal stress	Heat-related health issues and mortalities
		Air pollution levels	Respiratory system
		Electric grid failures	Efficiency
		Failures of mechanical cooling systems	Heat-related mortality and morbidity

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Tree Canopy Characteristics Affect Street Canyon's Microclimate Conditions and Human Thermal Comfort in Hot-Humid Climate

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Abstract

Tree species concerning key canopy and leaf characteristics play important role in mitigating microclimate on pedestrian walkways. In this study, we investigated the impact of leaf area index (LAI) and tree crown width on microclimate conditions and human thermal comfort characterized by physiological equivalent temperature (PET) through field measurements from 07:00 to 19:00 local standard time (LST) in summer in a street canyon of Wuhan, China. Results showed that LAI is the most critical factor in determining microclimate and PET benefits between different tree species. The mean radiant temperature and PET were reduced by up to 5.4 and 12.1 °C at 15:00 LST under the high-LAI (value: 3.03) canopy compared with the canopy with low-LAI (value: 1.83) with the same tree species and crown width. Tree canopy and leaf characteristics could not determine the microclimatic and PET benefits with the similar LAI. These findings may help landscape designers and decision makers to achieve optimal tree planting and management in street canyons in regard to outdoor thermal comfort regulation.

Keywords

Leaf area index • Tree crown width • Human thermal comfort • Street canyon • Field measurement

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1 Introduction

Street canyon has become an important component of enhancing urban quality because of closely related to urban residents (Levin, 2015). The synergy between urban heat islands and heatwaves directly affects the quality of people's life, and good outdoor thermal comfort has become a critical indicator to measure street walkability with the frequent high-temperature and the weakening wind events. Most studies have shown that outdoor thermal comfort of street canyon is affected mainly by street geometry (Ali-Toudert & Mayer, 2007; Krüger et al., 2011; Rodríguez-Algeciras et al., 2018), surface materials (Carnielo & Zinzi, 2013; Santamouris, 2013), and greening (Armson et al., 2013; Lee et al., 2016). Urban morphology and spatial structure are usually difficult to change in the urban renewal process, so adjusting street greening is the most effective approach to improve outdoor thermal comfort of street canyon.

Tree affects outdoor thermal comfort from two aspects. On the one hand, tree canopy can block and reflect solar radiation and surroundings radiation in street canyon; on the other hand, latent heat of transpiration and convective heat transfer are formed to regulate heat and moisture inside street canyon through transpiration and photosynthesis (Smith and Johnson, 2004; Tanaka & Hashimoto, 2006). It can be seen that tree canopy is the major component of tree to modify microclimate conditions and outdoor thermal comfort. Armson et al. (2012) investigated that the dense and tall tree canopies reduced the surface temperature and the average radiation temperature by 12 °C and 4 °C, respectively, at 13:30 through field measurement in Manchester, England. Zhao et al. (2016) concluded that Acer saccharum Marsh with the largest crown width reduced the PET by 11.7 °C at 11:00–14:00 LST. In addition, Morakinyo et al. (2018) reported that human thermal comfort was influenced by crown width, clear length, and tree height. To describe canopy characteristics more comprehensively, many researchers used leaf area index (LAI) which determines

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ecological characteristics of trees including solar penetration rate, water transpiration capacity, and airflow rate to describe tree canopy features, the indicator that was proved to be more suitable for analyzing the relationship between tree and microclimate condition (Morakinyo et al., 2018). Shahidan et al. (2010) revealed that there was a strong positive correlation between LAI and solar penetration rate through field measurement at 10:00, 12:00, and 14:00 in Kuala Lumpur, Malaysia. The *Mesua ferrea* L. with high-LAI (value: 6.1) can reduce solar radiation by nearly 93%, while the *Hura crepitans* L. with low-LAI (value: 1.5) can only reduce solar radiation by 79%. In general, tree canopy affects outdoor thermal environment by tree crown width, LAI, and other features in the street canyon. However, some studies have shown that there are time differences in the influence of tree canopy on thermal environment. Park et al. (2012) reported that tree canopy would hinder airflow and reduce wind speed after sunset. Charalampopoulos et al. (2013) noted that air temperature under tree canopy may be slightly higher than those in nearly open areas after sunset, while trees in the street canyons may provide benefits during the daytime. Therefore, the influence of tree canopy on outdoor thermal environment needs to be further studied from the perspective of temporary development.

In this study, we investigated the microclimate and PET benefits from trees with different canopy characteristics using field measurements and the Rayman model in a shallow street canyon in Wuhan, China. The influence of tree crown width and LAI on microclimate and PET conditions was explored in different time periods. This study hopes to provide a decision-making basis for microclimate adaptive design of street greening. This study hopes to provide landscape designers and greening professionals with scientific guidelines on how to plant trees in street canyons to mitigate outdoor thermal comfort.

2 Methods

2.1 Study Area

This study was conducted in Wuhan city (29°58′–31°22′N, 113°41′–115°05′E). Wuhan experiences high-temperature and humidity climatic conditions. The mean air temperature is 29.8 °C, and the relative humidity is over 75% in summer (Yu et al., 2008; Zhang et al., 2018). The investigation site is located in Yejin 1st Street, Qingshan District, Wuhan City. The street is a 300-m-long shallow valley (height/width: 1.18) with east–west orientation. The street is located in a typical urban residential area with multi-story buildings in surrounding areas. The height/width of the street is the same, the underlying surface is similar, and the traffic flow is small, which is suitable as the research site. There are *Platanus orientalis* Linn and *Cinnamomum camphora* (Linn) Presl in the selected street canyon, which are the two most planted street trees in Wuhan.

2.2 Microclimate Measurement

Field measurements were conducted at a pedestrian sidewalk in August 20th and 21st, 2019. Table 1 shows the air temperature, wind speed, and relative humidity condition of two days from the Wuhan meteorological station. As is shown in Table 1, the climate conditions of the two days were similar. The air temperature ranged from 26.6 to 38.2 °C, the relative humidity was from 40 to 96%, and the wind speed was from 0 to 2.7 m/s.

Eight portable climate stations were used for measuring microclimate parameters from 07:00 to 19:00 LST. Four observation stations were under tree canopies of *C. camphora* (Linn) Presl, three under tree canopies of *P. orientalis* Linn, and one outside of all tree canopies (Fig. 1).

The microclimate parameters were investigated through field measurement, which comprised air temperature (T_a), wind speed (WS), relative humidity (RH), and globe temperature (T_g). Mean radiation temperature (T_{mrt}) was calculated by T_a, T_g according to Eq. (1). Data was acquired and stored each minute. The instrument settings comply with standard ISO7726 (Table 2).

$$T_{mrt} = \left[(T_g + 273.15)^4 + \frac{(1.1 \times 10^8 \times V^{0.6})}{\varepsilon D^{0.4}} \times (T_g - T_a) \right]^{0.25} - 273.15, \quad (1)$$

Note: D—globe diameter (150 mm); ε—globe emissivity (0.95)

2.3 Tree Canopy Parameters Measurement

Using Hemi View to take hemispherical photographs for LAI estimation, which comprises a self-leveling mount and a Canon EOS 60D with Sigma EX DC 4.5 mm F2.8 fisheye lens. We obtained hemispherical photos at 0.8 m height of each measuring point (Fig. 2). The images were processed by Hemi View 2.1 hemispheric image analysis software to obtain LAI (Feng et al., 2011). Tree crown widths were measured using Leica Disto handheld laser rangefinder by taking the average of horizontal crown diameters in north–south and east-south directions (Gering & May, 1995). Tree canopy characteristic parameters of each measuring point are shown in Table 3.

Table 1 General climate conditions on measurement periods from the Wuhan meteorological station

Date	T_a (°C)			RH (%)			WS (m/s)		
	Mean	Max	Min	Mean	Max	Min	Mean	Max	Min
20st-08-2019	32.2	38.2	27.3	63.5	90	40	1.6	2.6	0
21st-08-2019	31.1	38.1	26.6	66.7	96	42	1.1	2.7	0.4

Fig. 1 Aerial view of the measured street canyon and the distribution of measured points

Table 2 Sensor specifications of the portable observation stations applied in the measurement

Microclimate factor	Instrument	Specification
Air temperature	Richter thermal comfort test system ISO7730	±0.5 °C
Relative humidity		±2%
Globe temperature		±0.5 °C
Wind speed		0–0.5 m/s: ±5 cm; 0.5–1.5 m/s: ±10 cm; >1.5 m/s: 4%

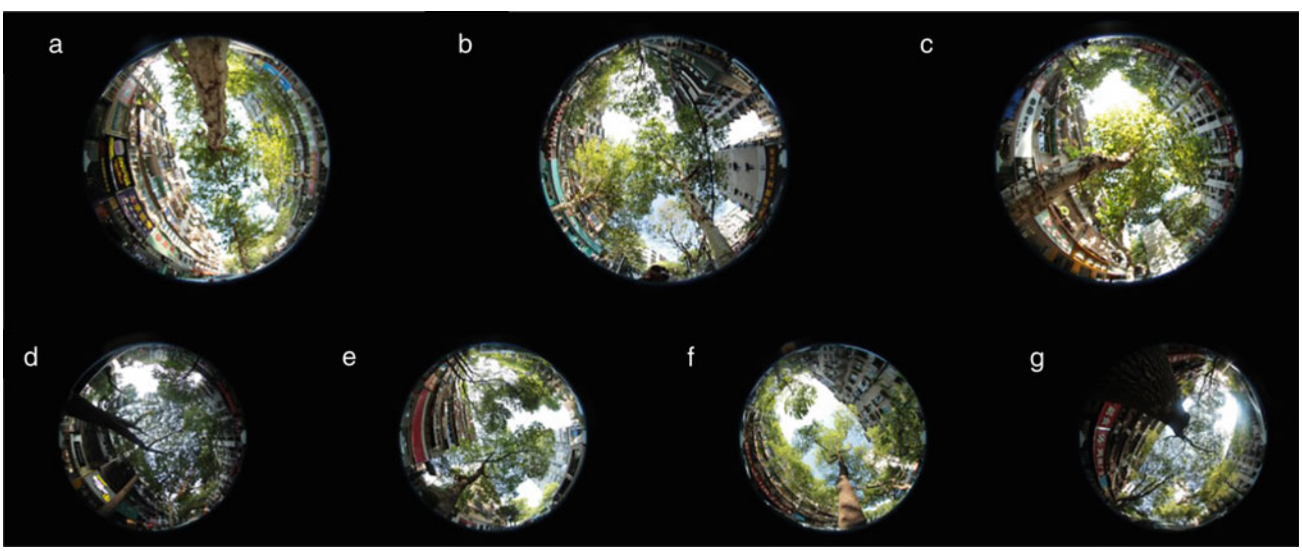


Fig. 2 Hemispherical photographs of measured trees

Table 3 Description of tree species, leaf type, LAI, and crown width corresponding to each measuring point

Measuring point	Tree species	Leaf type	LAI (m^2/m^2)	CW (m)
A	*P. orientalis* Linn	Deciduous	2.49	8.90
B			2.10	13.10
C			2.92	10.76
D	*C. camphora* (Linn) Presl	Evergreen	2.75	10.40
E			3.03	13.55
F			1.83	7.65
G			2.24	9.20
H	/	/	/	/

LAI Leaf area index; *CW* Crown diameter width

2.4 Human Thermal Comfort Characterization

Physiological equivalent temperature (PET) that is used to estimate human thermal comfort is calculated by microclimate parameters including T_a, RH, WS, and T_{mrt}. PET is calculated through the Rayman software, of which the basic human metabolism is 80 W (light activity), and the clothing value is 0.9 (Mayer & Höppe, 1987).

3 Results and Discussion

3.1 Microclimate and PET Benefits from Trees with Different Canopy Characteristics

As shown in Fig. 3, From 07:00 to 10:30 LST, the air temperature, T_{mrt}, and PET of all the measuring points (A-G) under tree canopies are lower than those of point H outside tree canopy. However, the PET value of point H was lower than other measuring points under tree canopies because point H began to be shaded by buildings after 10:30 LST. The difference of PET and T_{mrt} reached the highest of 5.4 °C and 12.09 °C at 15:00 LST between the point E with the highest LAI and highest crown width and the F point with the lowest LAI and lowest crown width. The PET and T_{mrt} of point E (LAI value: 3.03) were significantly larger than that of point B (LAI value: 2.1) with different tree species and similar crown widths. However, the microclimate and PET benefits of points E and C were nearly no difference with different tree species and similar LAI, regardless of the obvious variance of leaf type and crown type. To sum up, there was no noticeable difference in air temperature between trees that possessed different canopy features. The wind speed, globe temperature, T_{mrt}, and PET conditions differed greatly.

It is obvious that trees can promote microclimate and outdoor thermal comfort mitigation under tree canopies compared to areas outside the tree canopy. Building shading has a greater impact on PET benefits than tree shading, the finding is consistent with Lee et al. (2018) who revealed that the cooling intensity of building shading was greater than that of tree and umbrella shading. In addition, Ali-Toudert and Mayer pointed that trees improve thermal comfort more strongly in east–west orientation street (Ali-Toudert & Mayer, 2006).

The wind speeds at points E, F, and G were higher than that of other points owing to the more open spatial environment, especially for point H outside tree canopy. Park et al. (2012) reported that tree canopy would block airflow and reduce wind speed.

Trees have lower average radiation temperature and PET value with higher LAI and higher crown width than those with lower LAI and lower crown width, because the attenuation degree of solar radiation increased with LAI increasing. Morakinyo and Lam (2016) reported that average solar attenuation increased with LAI rising. Armson et al. (2013) pointed that tree species with higher LAI, Crataegus laevigata, and Pyrus calleryana, reduced T_{mrt} by 2 °C than the other species. Morakinyo et al. (2018) pointed that LAI is the main driving factor to regulate air temperature and improve outdoor thermal comfort followed by trunk height, tree height, and crown diameter.

3.2 Influence of Leaf Area Index, Crown Width on Street Microclimate and PET Conditions in Different Time Periods

Pearson correlation analysis was used to study the influence of LAI, crown width on microclimate factors and PET in different time periods (early morning 7:00–9:00, noon 12:00–14:00, late afternoon 17:00–19:00). LAI had a significant negative correlation with globe temperature and PET only at noon (Table 4), with no correlation in the early morning and late afternoon. Figure 4 shows the relationship between PET and LAI at noon, which reflected that LAI affects PET by influencing solar radiation at noon. The crown width did not show a significant correlation with microclimate factors and PET in the whole period.

LAI had the most significant correlation with globe temperature and PET at noon (12:00–14:00), however, it

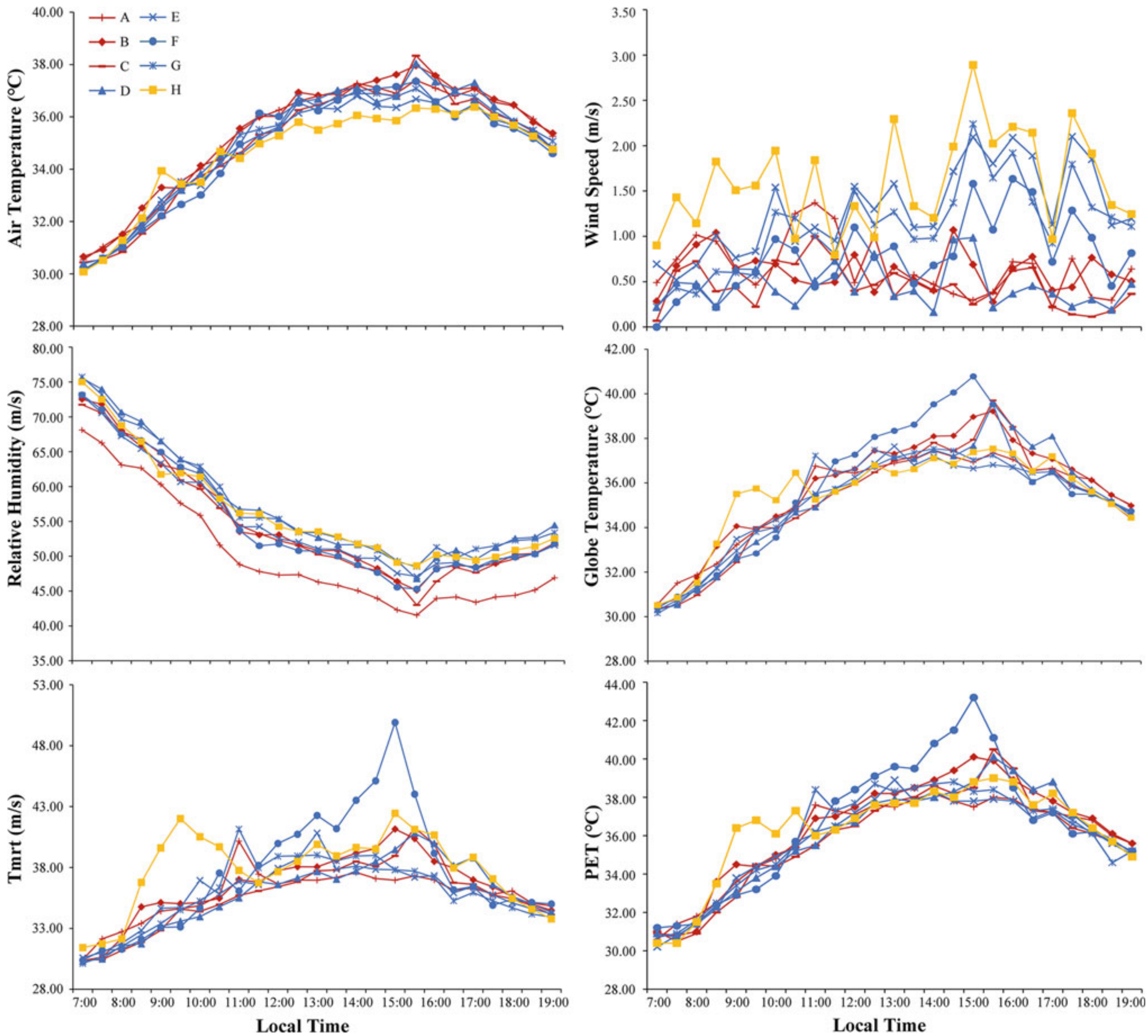


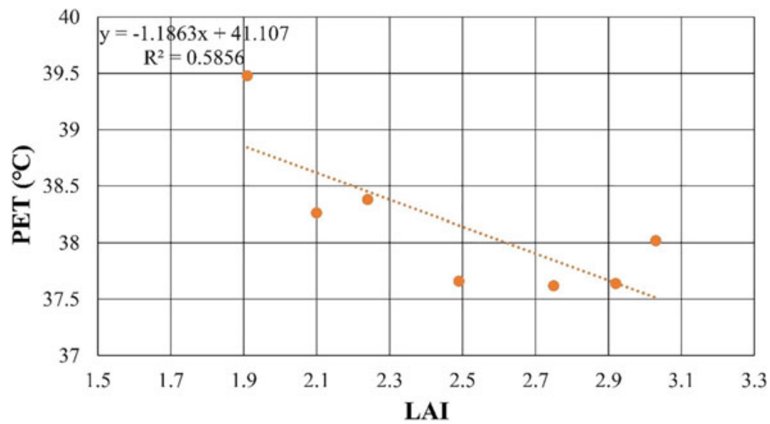
Fig. 3 Air temperature, relative humidity, wind speed, globe temperature, mean radiant temperature, and PET from 07:00 to 19:00 LST at measuring points

Table 4 Correlation analysis between tree crown width, LAI, and microclimate factors and PET at noon (12:00–14:00)

		Air temperature	Relative humidity	Wind speed	Globe temperature	T_{mrt}	PET
LAI	Pearson correlation	−0.431	−0.045	−0.649	−0.800*	−0.649	−0.789*
	Sig (2-tailed)	0.334	0.923	0.115	0.031	0.115	0.039
	N	7	7	7	7	7	7
CW	Pearson correlation	−0.156	0.231	0.150	−0.415	−0.334	−0.383
	Sig (2-tailed)	0.739	0.618	0.748	0.354	0.465	0.397
	N	7	7	7	7	7	7

*Correlation is significant at the 0.05 level (2-tailed)

Fig. 4 Linear relationship between LAI and PET at noon (12:00–14:00)



was not significant in the early morning (7:00–9:00) and late afternoon (17:00–19:00). The finding is consistent with Souchsouch (1993) who reported that the impact of trees on air temperature was light between 07:00 and 09:00 LST, however, the cooling effect became significant of decreasing air temperatures by 0.7–1.3 °C between 12:00 and 14:00 LST. Trees have the greatest impact on pedestrians' microclimate and thermal comfort from noon to afternoon in summer when solar radiation is strongest (Sanusi et al., 2016). LAI is an important parameter in radiation filtering to reduce more ground radiation, which may also be the reason why LAI is significantly correlated with globe temperature at noon.

4 Conclusions

In this study, we investigated the impact of tree canopy characteristics on street microclimate and outdoor thermal comfort through field measurements. Results showed that street canyon provided greater benefits to microclimate and PET conditions with *C. camphora* (Linn) Presl and *P. orientalis* Linn than no trees. Trees with high-LAI and high-crown width can improve microclimate and thermal comfort better than those with low-LAI and low-crown width when tree species are the same. Differences in leaf type and crown width could not determine the microclimate and PET conditions with the same LAI. LAI is significantly correlated with globe temperature and PET at noon in summer, with no correlation in the early morning and late afternoon. Our research provides evidence for landscape designers and greening professionals in tree species selection and street greening design. In the selection of street tree species, trees with high LAI could be preferred to maximize the value of trees in improving thermal comfort.

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Research on Space Resilience Assessment and Space Optimization of Old Community in City

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Abstract

The community as the smallest unit of the city, in the context of urban renewal, urban disaster prevention and mitigation, and ecological construction, it is of great significance to study the space resilience assessment and space optimization of old community in city. Based on this, this paper first constructed a space resilience assessment indicator system of old community from multiple dimensions such as existing buildings, infrastructure, and public space. The unascertained measure theory and combination weighting method were introduced to establish the space resilience assessment model of old community. Then, the space optimization strategy was proposed, such as the isolation of existing building disaster, the improvement of infrastructure function and the beautification of redundant public space. Finally, a community was taken as an example to conduct space resilience assessment and space optimization, hoping that the disaster resilience, safety, ecology, and livability of old community can be improved.

Keywords

Old community • Resilience assessment • Space optimization • Unascertained measure theory

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1 Introduction

As the smallest unit of a city, the community is a large collective of interconnected life formed by a number of social people in a certain area, it is a microcosm of the macro-society. The community is such a "social life community composed of people living in a certain geographical area" (Ma et al., 2020; Marion et al., 2017). With the development and changes of society, residents' lives have undergone more and more changes, and residents' living standards have been significantly improved. Therefore, residents have higher and higher requirements for quality of life and living environment (Dong et al., 2020). Due to the narrow space and chaotic environment, those old communities can no longer keep up with the changes of the times and can no longer adapt to the requirements of residents' lives at present (Li et al., 2021). When encountering sudden natural disasters or social events, they cannot quickly adapt to such changes and react quickly (He, 2019; Zhang et al., 2020).

Resilience comes from the Latin "resilio", which means "restore or return to the original state" (Chai et al., 2018). It was first used to describe the stability of materials and the ability of "deformation-recovery" under the action of external forces. As all sectors of society pay attention to complex issues such as global environmental changes and the depletion of natural resources, resilience is gradually being introduced into the field of social sciences. Community resilience is an important part of urban resilience (Pike et al., 2010; Fan et al., 2021). Domestic and foreign experts have increasingly in-depth research on "community resilience" and "old community resilience". Ma et al. took a community as an example to carry out a resilience assessment and proposed the key improvement directions for the community to respond to major disaster risks (Ma et al., 2021). Imperiale et al. used social impact assessment to strengthen community resilience in the mountainous rural areas (Imperiale et al., 2016). Rędzińska et al. established

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procedures for community to resist climate threats, and then put forward suggestions to enhance the community's ability to adapt to climate change (Rędzińska et al., 2020). Antwi et al. proposed a community-based resilience assessment model, which can provide feasible assessment criteria and key indicators for community level resilience assessment (Antwi et al., 2014). Lai et al. conducted an resilience assessment of rural community, and revealed the link of rural community resilience and social-ecological sustainability (Lai et al., 2021). Through combing, it is found that the current research on community resilience is relatively broad and not highly targeted.

In short, the old community is a weak link in a resilient city, and the shortcomings must be made up as soon as possible. The old community resilience includes many aspects, such as space, society, economy, organization, and management. Space is the material carrier of the community, including existing buildings, infrastructure, and public space. Therefore, this paper takes the old community space as the research object, and conducts the related research on space resilience assessment and space optimization.

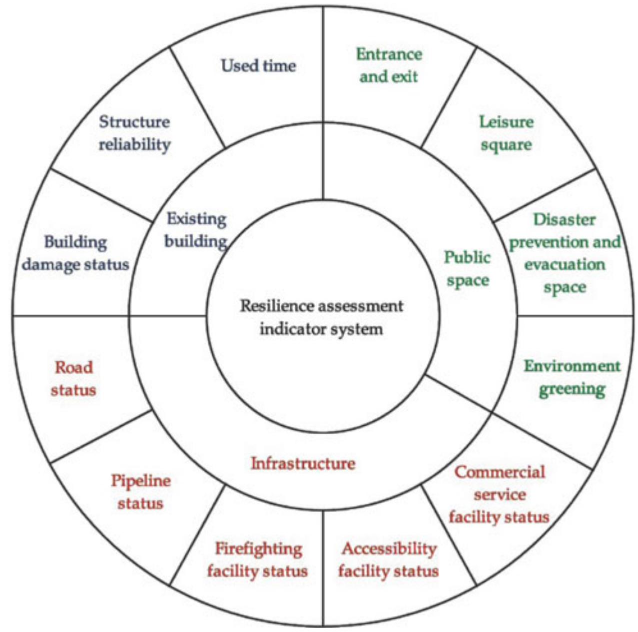


Fig. 1 Assessment indicator system of space resilience for old community

2 Space Resilience Assessment Model of Old Community

2.1 Construction of Resilience Assessment Indicator

On the basis of literature review and project investigation analysis, the main factors that affect the space resilience of old community are analyzed and identified. According to the principles of objectivity, representativeness and operability, the space resilience assessment indicator system of old community is established, as shown in Fig. 1.

It can be seen from Fig. 1 that the space resilience assessment indicator system of old community mainly include three aspects: existing buildings, infrastructure, and public space. By using the grading standardization method, each indicator is divided into 4 assessment grades, namely, Grade I (high resilience), Grade II (relatively high resilience), Grade III (moderate resilience), and Grade IV (low resilience). In order to facilitate the indicator value, the unified indicator quantification standard is shown in Table 1.

2.2 Selection of Resilience Assessment Method

At present, there are many methods for assessment, and each has its advantages and disadvantages (Jiang et al., 2018; Li et al., 2018, 2021). Considering that there are still many uncertainties in the assessment indicator and assessment process of space resilience for old community. Therefore, it is necessary to choose a reasonable mathematical method to carry out the space resilience assessment.

The unascertained information and its mathematical processing theory were first proposed by Wang Guangyuan in 1990 (Wang, 1990). Liu Kaidi et al. continued to study the method in-depth and developed an assessment model for unascertained measure theory in 1999 (Liu et al., 1999). Thereafter, the mathematical model has been widely applied in many fields, such as risk assessment (Li et al., 2017), development assessment (Li et al., 2017), planning evaluation (Wang et al., 2020), bidding quotation (An et al., 2018), scheme optimization (Zheng et al., 2020a, 2020b), project delivery (Li et al., 2015), and sustainability assessment (Chang et al., 2018). This paper applies unascertained measure theory to the space resilience assessment.

2.3 Establishment of Resilience Assessment Model

2.3.1 Determining the Single-Indicator Unascertained Measure

Suppose that the research object $X = \{X_1, X_2, \ldots, X_n\}$ and the indicator set $R = \{R_1, R_2, \ldots, R_m\}$. If x_{ij} denotes the measured value of the ith object X_i with respect to the jth indicator R_j, then X_i can be expressed as an m-dimensional vector $\{x_{i1}, x_{i2}, \ldots, x_{im}\}$. Suppose that the grade space $G = \{G_1, G_2, \ldots, G_p\}$, where $G_k(k = 1, 2, \ldots, p)$ is the kth grade set. Furthermore, suppose that the kth grade is higher than the $k+1$ th grade that is, $G_k > G_{k+1}$. If

Table 1 The indicator quantification standard

Indicator	Code	Quantification standard		
		Grades	Value range	Description
Used time	R11	Grade I (G1)	[90, 100]	This indicator value can be determined according to the building use time. The used time is less than 10 years
		Grade II (G2)	[75, 90)	The used time is 10–20 years
		Grade III (G3)	[60, 75)	The used time is 20–30 years
		Grade IV (G4)	[0, 60)	The used time is more than 30 years
Structure reliability	R12	Grade I (G1)	[90, 100]	The structure reliability levels of more than 90% buildings in old community are Grade II
		Grade II (G2)	[75, 90)	The structure reliability levels of 60–90% buildings in old community are Grade II
		Grade III (G3)	[60, 75)	The structure reliability levels of 20–60% buildings in old community are Grade II
		Grade IV (G4)	[0,60)	The structure reliability levels of less than 20% buildings in old community are Grade II
Building damage status	R13	Grade I (G1)	[90, 100]	The building structure is basically not damaged
		Grade II (G2)	[75, 90)	The building structure is slightly damaged
		Grade III (G3)	[60, 75)	The building structure is damaged
		Grade IV (G4)	[0, 60)	The building structure is seriously damaged
Road status	R21	Grade I (G1)	[90, 100]	The road is in good condition, and the road is basically undamaged
		Grade II (G2)	[75, 90)	The road is in moderate condition, and the road is slightly damaged
		Grade III (G3)	[60, 75)	The road is in bad condition, and the road is partially damaged
		Grade IV (G4)	[0, 60)	The road is in very bad condition, and the road is severely damaged
Pipeline status	R22	Grade I (G1)	[90, 100]	The pipeline is in good condition, and the pipeline is basically undamaged
		Grade II (G2)	[75, 90)	The pipeline is in moderate condition, and the pipeline is slightly damaged
		Grade III (G3)	[60, 75)	The pipeline is in bad condition, and the pipeline is partially damaged
		Grade IV (G4)	[0, 60)	The pipeline is in very bad condition, and the pipeline is severely damaged
Firefighting facility status	R23	Grade I (G1)	[90, 100]	The firefighting facility is complete, and the firefighting facility is basically undamaged
		Grade II (G2)	[75, 90)	The firefighting facility is relatively complete, and the firefighting facility is slightly damaged
		Grade III (G3)	[60, 75)	The firefighting facility is incomplete, and the firefighting facility is partially damaged
		Grade IV (G4)	[0, 60)	The firefighting facility is seriously missing, and the firefighting facility is severely damaged
Accessibility facility status	R25	Grade I (G1)	[90,100]	The accessibility facility is complete, and the accessibility facility is basically undamaged
		Grade II (G2)	[75, 90)	The accessibility facility is relatively complete, and the accessibility facility is slightly damaged
		Grade III (G3)	[60, 75)	The accessibility facility is incomplete, and the accessibility facility is partially damaged
		Grade IV (G4)	[0, 60)	The accessibility facility is seriously missing, and the accessibility facility is severely damaged

(continued)

Table 1 (continued)

Indicator	Code	Quantification standard		
		Grades	Value range	Description
Commercial service facility status	R25	Grade I (G1)	[90, 100]	The scale and business configuration of commercial service facility are reasonable, and the material reserves are sufficient
		Grade II (G2)	[75, 90)	The scale and business configuration of commercial service facility are relatively reasonable, and the material reserves are relatively sufficient
		Grade III (G3)	[60,75)	The scale and business configuration of commercial service facility are unreasonable, and the material reserves are insufficient
		Grade IV (G4)	[0, 60)	The scale and business configuration of commercial service facility are extremely unreasonable, and the material reserves are severely insufficient
Entrance and exit	R31	Grade I (G1)	[90, 100]	The location of entrances and exits is reasonable and the number is large
		Grade II (G2)	[75, 90)	The location of entrances and exits is relatively reasonable and the number is moderate
		Grade III (G3)	[60, 75)	The location of entrances and exits is unreasonable and the number is small
		Grade IV (G4)	[0, 60)	The location of entrances and exits is severely unreasonable and the number is very small
Leisure square	R32	Grade I (G1)	[90, 100]	The distribution of leisure squares is reasonable and the area is large
		Grade II (G2)	[75, 90)	The distribution of leisure squares is relatively reasonable and the area is moderate
		Grade III (G3)	[60, 75)	The distribution of leisure squares is unreasonable and the area is small
		Grade IV (G4)	[0, 60)	The distribution of leisure squares is severely unreasonable and the area is very small
Disaster prevention and evacuation space	R33	Grade I (G1)	[90, 100]	The service radius of disaster prevention and evacuation space is less than 500 m
		Grade II (G2)	[75, 90)	The service radius of disaster prevention and evacuation space is 500–1000 m
		Grade III (G3)	[60, 75)	The service radius of disaster prevention and evacuation space is 1000–1500 m
		Grade IV (G4)	[0, 60)	The service radius of disaster prevention and evacuation space is greater than 1500 m
Environment greening	R34	Grade I (G1)	[90, 100]	The environment is good and the green area is large
		Grade II (G2)	[75, 90)	The environment is general and the green area is moderate
		Grade III (G3)	[60, 75)	The environment is poor and the green area is small
		Grade IV (G4)	[0, 60)	The environment is extremely poor, and the green area is very small

$G_1 > G_2 > \cdots > G_p$ or $G_1 < G_2 < \cdots < G_p$ is satisfied, $\{G_1, G_2, \cdots, G_p\}$ is called an ordered segmentation class of grade space G (Li et al., 2020).

If $\mu_{ijk} = \mu(x_{ij} \in G_k)$ denotes the degree to which the measured value x_{ij} belongs to the kth grade G_k. When μ satisfies Eqs. (1)–(3), μ is an unascertained measure.

$$0 \le \mu(x_{ij} \in G_k) \le 1 (i = 1, 2, \ldots, n; j = 1, 2, \ldots, m; k = 1, 2, \ldots, p) \quad (1)$$

$$\mu(x_{ij} \in G) = 1 (i = 1, 2, \ldots, n; j = 1, 2, \ldots, m) \quad (2)$$

$$\mu\left| x_{ij} \in \bigcup_{l=1}^{k} G_l \right| = \sum_{l=1}^{k} \mu(x_{ij} \in G_l)(k = 1, 2, \ldots, p) \quad (3)$$

For every research object $X_i (i = 1, 2, \ldots, n)$, the matrix $(\mu_{ijk})_{m \times p}$ is the single-indicator measure matrix of X_i, as shown in Eq. (4).

$$(\mu_{ijk})_{m \times p} = \begin{bmatrix} \mu_{i11} & \mu_{i12} & \cdots & \mu_{i1p} \\ \mu_{i21} & \mu_{i22} & \cdots & \mu_{i2p} \\ \vdots & \vdots & \ddots & \vdots \\ \mu_{im1} & \mu_{im2} & \cdots & \mu_{imp} \end{bmatrix} \quad (4)$$

For simplicity, this paper adopts the linear function to determine the single-indicator measure matrix, and the corresponding function expression is as follows:

$$\mu_{ij1} = \begin{cases} 0 & x_{ij} \le a_2 \\ \frac{a_2 - x_{ij}}{a_2 - a_1} & a_2 < x_{ij} \le a_1 \\ 1 & x_{ij} > a_2 \end{cases} \tag{5}$$

$$\mu_{ijk} = \begin{cases} 0 & x_{ij} \le a_{k+1} \text{ or } x_{ij} > a_{k-1} \\ \frac{x_{ij} - a_{k+1}}{a_{k+1} - a_{k-1}} & a_{k+1} < x_{ij} \le a_k \\ \frac{a_{k-1} - x_{ij}}{a_{k+1} - a_{k-1}} & a_k < x_{ij} \le a_{k-1} \end{cases} \tag{6}$$

$$\mu_{ijk} = \begin{cases} 1 & x_{ij} \le a_p \\ \frac{a_{P-1} - x_{ij}}{a_{P-1} - a_p} & a_p < x_{ij} \le a_{P-1} \\ 0 & x_{ij} > a_{p-1} \end{cases} \tag{7}$$

where $a_1, a_2, \ldots, a_{k-1}, a_k, a_{k+1}, \ldots, a_{p-1}, a_p$ generally takes the average of the value range of each grade.

2.3.2 Determining the Indicator Weight Based on the Combination Weighting Method

1. The subjective weight is calculated using the analytic hierarchy process (AHP), and the steps are as follows:

(1) Establishing the hierarchical structure mode and constructing the judgment matrix C. Where c_{ij} is the ratio of the relative weight between the indicator i and j.

$$A = \begin{bmatrix} 1 & \frac{w_1}{w_2} & \cdots & \frac{w_1}{w_n} \\ \frac{w_2}{w_1} & 1 & \cdots & \frac{w_2}{w_n} \\ \vdots & \vdots & \ddots & \vdots \\ \frac{w_n}{w_1} & \frac{w_n}{w_1} & \cdots & 1 \end{bmatrix} = \begin{bmatrix} c_{11} & c_{12} & \cdots & c_{1n} \\ c_{21} & c_{22} & \cdots & c_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ c_{n1} & c_{n2} & \cdots & c_{nn} \end{bmatrix} \tag{8}$$

(2) Calculating the weight using the arithmetic average method.

$$w_j' = \sum_{i=1}^{n} \overline{c_{ij}} (j = 1, 2, \ldots, n) \tag{9}$$

2. The objective weight is calculated using the improved entropy weight method, and the steps are as follows:

(1) Determining the entropy of the jth indicator.

$$E_j = -t \sum_{k=1}^{p} f_{ijk} \ln f_{ijk} \tag{10}$$

where $E_j > 0$; $f_{ijk} = (\mu_{ijk} + 0.1) / \sum_{k=1}^{p} (\mu_{ijk} + 0.1)$; $t = 1/\ln p$.

(2) Calculating the entropy weight of the jth indicator.

$$w_j'' = \frac{D_j}{\sum_{j=1}^{m} D_j} = \frac{1 - E_j}{m - \sum_{j=1}^{m} E_j} \tag{11}$$

3. Combination weight

According to the w_j' and w_j'', and the combination weight is w_j.

$$w_j = \alpha \times w_j' + \beta \times w_j'' \tag{12}$$

where $\alpha + \beta = 1$; $\alpha = 0.5$ and $\beta = 0.5$.

2.3.3 Determining the Multi-indicator Comprehensive Unascertained Measure

Given that $\mu_{ik} = \mu(X_i \in G_k)$ denotes the degree to which the research object X_i belongs to the kth grade G_k. The vector $\{\mu_{i1}, \mu_{i2}, \ldots, \mu_{ip}\}$ is called the multi-indicator comprehensive measure vector of X_i.

$$\mu_{ik} = \sum_{j=1}^{m} w_j \cdot \mu_{ijk} (i = 1, 2, \ldots, n; k = 1, 2, \ldots, p) \tag{13}$$

2.3.4 Credibility Degree Recognition and Determining the Assessment Grade

Suppose that λ ($\lambda \ge 0.5$, and usually, $\lambda = 0.6$ or 0.7) is the credibility degree. If $G_1 > G_2 > \cdots > G_p$ is satisfied and p_0 is satisfied by Eq. (14), the research object X_i belongs to the grade G_{p_0}.

$$p_0 = \min \left| p : \sum_{k=1}^{p} \mu_{ik} > \lambda, i = 1, 2, \ldots, n \right| \tag{14}$$

3 Space Optimization Strategy of Old Community

The space in old community is the material carrier for the construction of resilient community. Only in this space can it be convenient to carry out behaviors such as risk prevention, emergency avoidance, and adaptive evolution (Han, 2021; Zhu et al., 2020). However, most of old communities are unable to adapt to the needs of today's resilient community due to their age and backward facilities. Therefore, this paper takes the existing buildings, infrastructure and public space in the space resilience assessment of old community as the starting point for optimization, specifically proposes three optimization strategies for the isolation of existing

Fig. 2 Space optimization framework system for old community

building disaster, the improvement of infrastructure function and the beautification of redundant public space (Fig. 2). From the building body to the external space, and then to the corresponding service facilities, the space resilience of old community is comprehensively improved (Dong, 2020; Mei et al., 2015).

3.1 Isolation of Existing Building Disaster

Due to the disrepair of buildings in old community, existing buildings cannot better resist various risks. The building space is the main place for the community residents to live, and it is also the last line of defense for safe avoidance in community. The optimization of existing buildings should be mainly considered in terms of structural safety and ease of evacuation.

3.1.1 Dividing the Building Group Unit

The buildings in old community are mostly low-rise and multi-story buildings, and there is no elevator facility. At the initial stage of optimization, the number and age structure of the actual resident population in the building can be counted, and the building groups can be divided according to the population density and age structure. In addition, add outdoor escape corridors and roof safety rescue spaces for each building group.

3.1.2 Strengthening the Building Safety Performance

On the one hand, it is necessary to entrust professional institutions to conduct building structure inspection and appraisal, to clarify the structural safety status, and to strengthen and repair the building structure with structural safety hazards. On the other hand, for buildings with tiled facades, it is necessary to regularly check and reinforce the adhesiveness of the tiles, or replace them with facade decorations with strong adhesiveness to prevent the risk of falling objects from height.

3.2 Improvement of Infrastructure Function

The infrastructure of old community is in line with the material needs of the people at the time when the construction was completed. However, the lives of residents have undergone earth-shaking changes. The tense public space in old community has led to inadequate facilities such as disaster relief, medical care, fire rescue, and necessary convenience services. At the same time, there is a lack of necessary evacuation and escape routes. The lack of space resources requires the same space to accommodate different functions at different time nodes. Therefore, the multifunctional conversion of space has become a necessary trend for the optimization of space resilience in old community.

3.2.1 Improving the Service Supply During Disasters

When a disaster strikes, the basic material supply is related to the lifeline project of the residents. After investigation and research, there is a general lack of necessary convenience service facility in old community, and the disaster relief medical and firefighting facility are relatively shabby, making it difficult to cope with the occurrence of disasters. Among them, convenient service facility are the main infrastructure that supplies basic living materials to the residents in old community when disasters occur, and they are particularly important when facing external traffic interruptions.

Therefore, the corner space in old community should be fully developed, such as the space between the boundary of the community and the buildings, the garden between the buildings. Considering the convenience of internal and external transportation links, set up convenient facilities to make it a hub for contacting the inside and outside of the community and distributing materials to community residents. In addition, these spaces can also be used to disperse facilities such as first aid kits and fire extinguishers for temporary use in disasters.

3.2.2 Adding the Risk Avoidance Path During Disasters

Due to the lack of underground space in old community, random parking and stacking of debris on the ground are very common, which will cause the problem of unclear evacuation roads. Therefore, when optimizing the space, the interests of the owner, the property and other parties can be coordinated first, and the evacuation route must be set up to the greatest extent, and the route must be unobstructed. In addition, the age structure of residents in old community tends to be aging, and the demand for barrier-free facilities is also very large. Therefore, it is necessary to add barrier-free ramps, barrier-free handrails and other facilities to meet the needs of residents for travel and safe evacuation.

3.3 Beautification of Redundant Public Space

The shortage of land and public space has always been the shortcomings of old community. The extensive use and single function of space when the space itself is tight is a manifestation of a waste of space. Resilient cities emphasize redundancy and versatility. Redundant public space and public greening can be built in old community. While taking on the activities of residents on weekdays, it can also carry out space conversion during disasters, so as to achieve the purpose of resilience and disaster reduction.

3.3.1 Creating the Redundant Space Structure

The redundant space structure should be completed in two steps: The first step is to formulate different disaster prevention space layout plans for different types of community space structures. For example: the centralized community should set up a large disaster prevention space inside the community, and determine a main evacuation road horizontally and vertically; the belt-shaped community should set up disaster prevention space at the intersection of the vertical road and the horizontal main road, and set the community boundary evacuation road parallel to the vertical main road; the free and decentralized community should set up disaster prevention spaces at road intersections and determine a main circular evacuation road.

The second step is to build a disaster prevention space that combines disaster relief. After the disaster prevention space is selected, the site must be refurbished to meet the needs of residents' daily activities. At the same time, set up refuge facilities that meet the relevant national standards, and reserve corresponding space. During a disaster, it can quickly organize resource allocation and safe transfer of people, and in peacetime, it can be used as a place for residents' daily activities.

3.3.2 Strengthening the Landscape Healing Property

The beautiful green environment helps to soothe and relax people's nerves, but due to the lack of space in old community, many green spaces are occupied by private individuals. Therefore, in terms of strategy, it is necessary to repair the damaged landscape first, and then use the corner space in old community to plant dotted landscapes, such as under the windowsills and the foot of the building walls, to highlight the landscape atmosphere of the entire community. At the same time, a "shared garden" can be built to guide residents to actively participate in planting, which will not only make residents feel comfortable but also beautify the environment.

4 Case Study

4.1 Project Introduction

This paper takes the TNS community project as an example for empirical analysis. The TNS community is located in Xicheng District, Beijing, with a total area of 11.1 ha. The TNS community scene is shown in Figs. 3 and 4. Through on-site investigation, it is found that the community has the following characteristics: ① The residential buildings in the TNS community have been in disrepair for a long time. Although most of them have been reinforced with earthquake resistance, there are still phenomena such as very closed buildings and balconies, messy pipelines, and damaged walls. ② There are a number of shops in the TNS community for residents to purchase daily necessities, but there are no convenient service facilities in the community. ③ The distance between buildings is small, and the evacuation route is insufficient and unclear. Based on this, this paper uses the established model to assess the space resilience and optimize the corresponding space to create a resilient and livable community space that is multifunctional, adaptable, and improves quality and quantity.

Fig. 3 The scene 1 of TNS community

Fig. 4 The scene 2 of TNS community

4.2 Space Resilience Assessment

(1) Determining the indicator value

This paper invited 9 experts in related fields to inspect the TNS community, and scored the indicators according to the indicators quantification standard in Table 1. The final indicator value are shown in Table 2.

(2) Calculating the single-indicator measure matrix

According to the above-mentioned theoretical methods and indicator quantification standard, the single-indicator measure function is constructed, as shown in Fig. 5.

Then, the single-indicator measure matrix of the TNS community space resilience assessment can be obtained.

$$\mu_{12\times4} = \begin{pmatrix} 0.000 & 0.000 & 0.914 & 0.086 \\ 0.000 & 0.910 & 0.090 & 0.000 \\ 0.000 & 0.871 & 0.129 & 0.000 \\ 0.000 & 0.405 & 0.595 & 0.000 \\ 0.000 & 0.119 & 0.881 & 0.000 \\ 0.000 & 0.000 & 0.861 & 0.139 \\ 0.000 & 0.300 & 0.700 & 0.000 \\ 0.000 & 0.000 & 0.042 & 0.528 \\ 0.000 & 0.186 & 0.814 & 0.000 \\ 0.000 & 0.500 & 0.500 & 0.000 \\ 0.000 & 0.000 & 0.823 & 0.177 \\ 0.000 & 0.000 & 0.971 & 0.029 \end{pmatrix} \tag{15}$$

(3) Calculating the multi-indicator comprehensive measure vector

According to combination weighting method, the indicator weights is calculated, as shown in Table 2. And then, the multi-indicator comprehensive measure vector can be obtained.

$$\mu_{1\times4} = (\,0.000 \quad 0.338 \quad 0.586 \quad 0.076\,) \tag{16}$$

(4) Determining the assessment grades

Suppose that $\lambda = 0.6$, when $p_0 = 3$, $0.338 + 0.586 = 0.924 > 0.6$, $0.076 + 0.586 = 0.662 > 0.6$, so the space resilience assessment grade is Grade III. By combining the two results, the space resilience assessment grade of the TNS community is Grade III.

4.3 Space Optimization Suggestions

(1) Isolation of existing building disaster

After field investigation, it was found that most of the buildings in this community were built in the 1980s and 1990s. These buildings have been seismically strengthened around 2015 and are in good structural condition. However, due to closed balconies, exposed pipelines, and piled up debris in stairwells, disaster risks have greater hidden dangers when they come. Especially the stairwell, which is the only evacuation exit of the building, is very narrow and dark, with single function and poor guidance. Therefore, the focus of this optimization is on the stairwell. The fluorescent trail system is introduced to the steps of the stairwell, and two colors of yellow and green are used to distinguish the steps and the stairs, which solves the problem of difficult identification of the steps at night (Fig. 6).

Table 2 Indicator values and weights

Indicator code	Scoring by nine experts									Indicator value	Weight
R11	70	63	70	61	61	63	65	63	65	64.29	0.073
R12	78	78	76	89	88	85	79	75	84	81.14	0.159
R13	85	81	75	81	84	80	79	77	82	80.57	0.097
R21	72	75	78	71	74	71	76	70	76	73.57	0.084
R22	68	68	72	65	71	69	71	68	70	69.29	0.076
R23	57	60	56	66	65	65	66	61	62	62.29	0.089
R24	64	65	78	74	73	64	78	74	76	72.00	0.065
R25	43	45	47	55	46	53	60	45	42	47.71	0.077
R31	64	75	78	69	70	70	63	66	79	70.29	0.071
R32	79	77	71	71	74	73	79	79	72	75.00	0.067
R33	58	65	61	53	62	59	64	66	57	60.86	0.083
R34	66	68	65	69	68	70	64	63	65	66.43	0.059

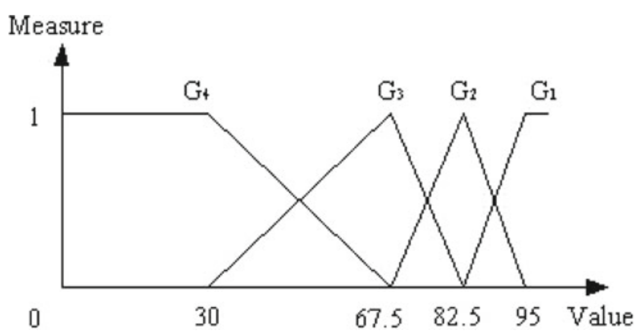


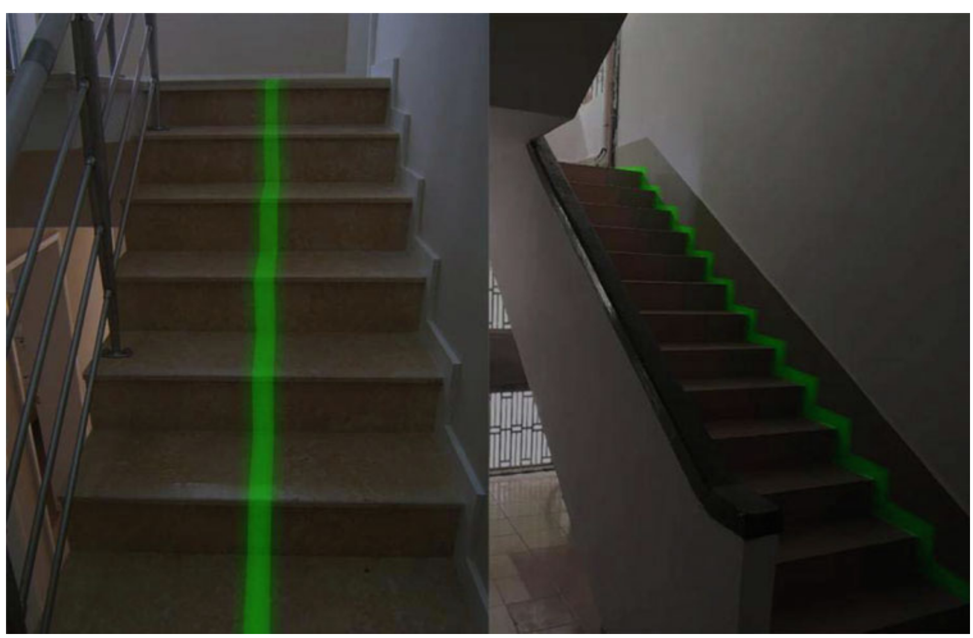
Fig. 5 The single-indicator measure function

(2) Improvement of infrastructure function

The community originally had a large fruit and vegetable market, which was the main place for residents to purchase daily supplies, but the market was forced to close due to the epidemic. After investigation, there are no convenient service facilities in the community. Residents say that it is very inconvenient to buy daily necessities.

Therefore, when optimizing the space, we choose to hollow out the garden between the buildings as a sunken plaza, and arrange the side of the sunken plaza as shops. The sunken plaza can be used as a place for community residents

Fig. 6 Fluorescent trail system



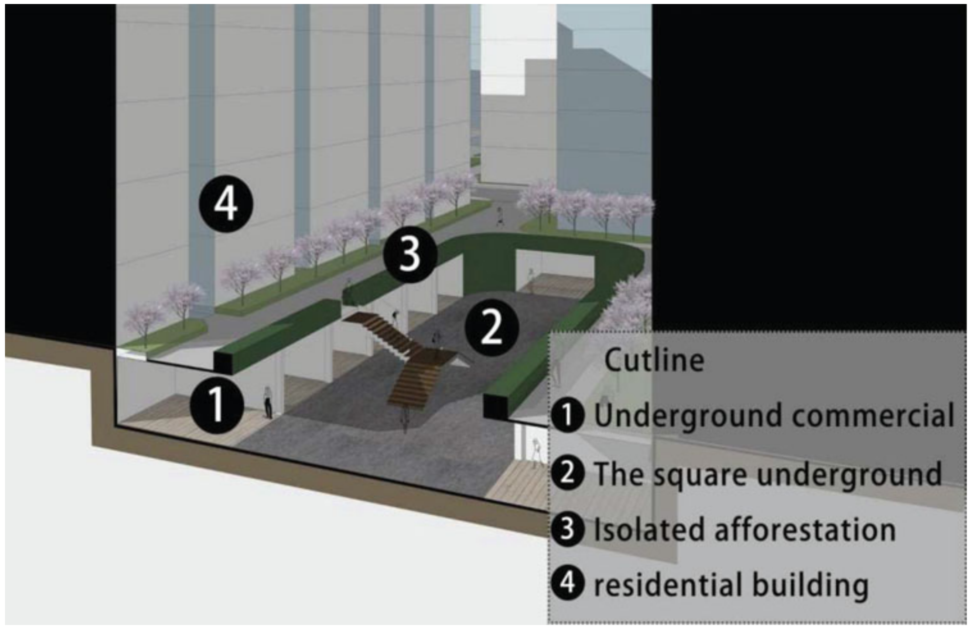


Fig. 7 Multifunctional underground plaza

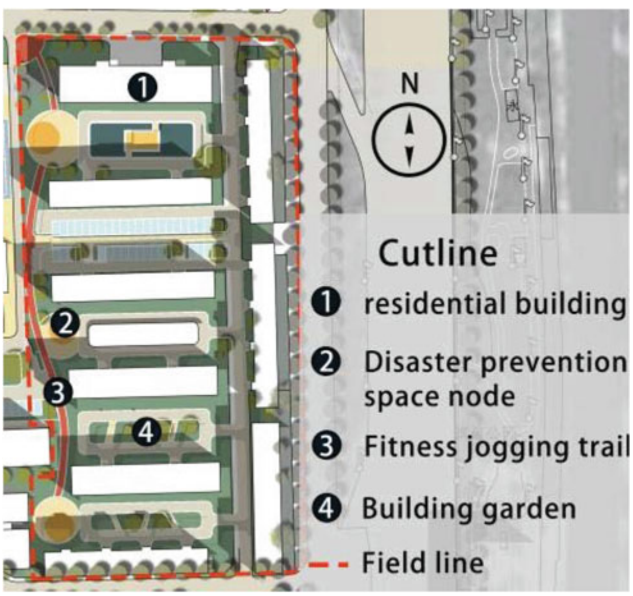


Fig. 8 Fitness jogging trail plan

to purchase living materials and provide convenient services on weekdays. When disaster strikes, it can also be used as a space for residents to gather and distribute materials and distribute materials (Fig. 7).

(3) Beautification of redundant public space

Through the map observation method, it is found that the buildings in the community are distributed in a strip shape from north to south. There is only one vertical road connection in each building group. This arrangement is likely to cause the evacuation path to be too long and the connection between the buildings is not close. By using the idle space between the building and the boundary wall of the community, an evacuation walkway parallel to the main longitudinal road can be set up. The connection between the walkway and the garden between the buildings can be enlarged and treated as an evacuation site. In weekdays, the evacuation path can be used as a fitness trail, and can be used as an escape route during disasters to increase the life safety of residents (Figs. 8 and 9).

5 Conclusions

To improve the space resilience of old community, create a good living environment. This paper assessed the space resilience and proposed the space optimization strategy of old community. First, an assessment model for space resilience of old community was established. Among them, a space resilience assessment indicator system for old community including three main aspects: existing buildings, infrastructure and public space is constructed, and unascertained measure theory is applied to the space resilience assessment process. Second, from the above three aspects, three space optimization strategies are proposed for the isolation of existing building disaster, the improvement of infrastructure function and the beautification of redundant public space. Finally, an empirical study was carried out with a TNS community as an example, which not only verified the feasibility of the space resilience assessment model established in this paper, but also proposed three aspects of space optimization suggestions based on the

Fig. 9 Fitness jogging trail renderings

assessment results. It shows that this paper can provide new ideas for space resilience assessment and space optimization of old community in the future.

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Trends in Incentive Policies of Green Roof: An Overview

Gaochuan Zhang, Hexian Jin, Jiang Lu, and Bao-Jie He

Abstract

Green roof has been widely recognized as the solution to many urban environmental problems, while the implementation of green roof is not extensive. Accordingly, many cities around the world have released relevant policies and regulations to promote green roof implementation. To understand international policy and regulatory landscapes, this study analyzed 20 policies and regulations on green roof in six countcries to compare the main contents and motivations of green roof policies in advanced countries/cities, classify the measures of incentive policies, and guide the trendency of incentive policies of green roofs. The results indicate that previous green roof policies have been mainly focused on controlling UHI, water runoff, and atmospheric hygiene, and so on. There are four aspects of incentive policies of green roof implementation: information and advocacy, unenforced intervention, enforced intervention, and economic subsidies. The "5I" trends were proposed to explore direction for making incentive policies of green roof and to cope with future popularization and construction.

Keywords

Green roof • Policies • Motivations • Barriers

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1 Introduction

With the rapid upward trend of urbanization, cities are under the challenges of many environmental problems, such as air pollution, water pollution, and urban heat island (UHI) effects. In particular, UHI effects have been a critical problem for many cities, due to its associated impacts such as the increase in energy and water consumption, thermal comfort reduction and the increase in mortality and morbidity. Furthermore, because of the variability of health condition, education level, urban construction, and economic situation, UHIs cause climate injustice, especially among vulnerable groups and economic-disadvantaged families. Nevertheless, UHIs will be further aggravated particularly in Asian and African cities along with population increase and urbanization. Existing studies have been widely conducted to reveal the causes of UHIs (Fig. 1) and develop effective mitigation and adaptation strategies. The mitigation strategies include the use of cool materials (e.g., reflective and permeable materials), green and blue infrastructure, and the proper urban morphology for shades and ventilation.

Among several strategies, the importance of green infrastructure has been widely recognized in promoting urban sustainable development because of its versatile benefits such as energy efficiency, UHI mitigation, roof longevity prolongation, air purification, runoff control, water purification, urban infrastructure improvement, sound insulation and noise reduction, biodiversity increase, recreation and esthetics, property value enhancement, and employment

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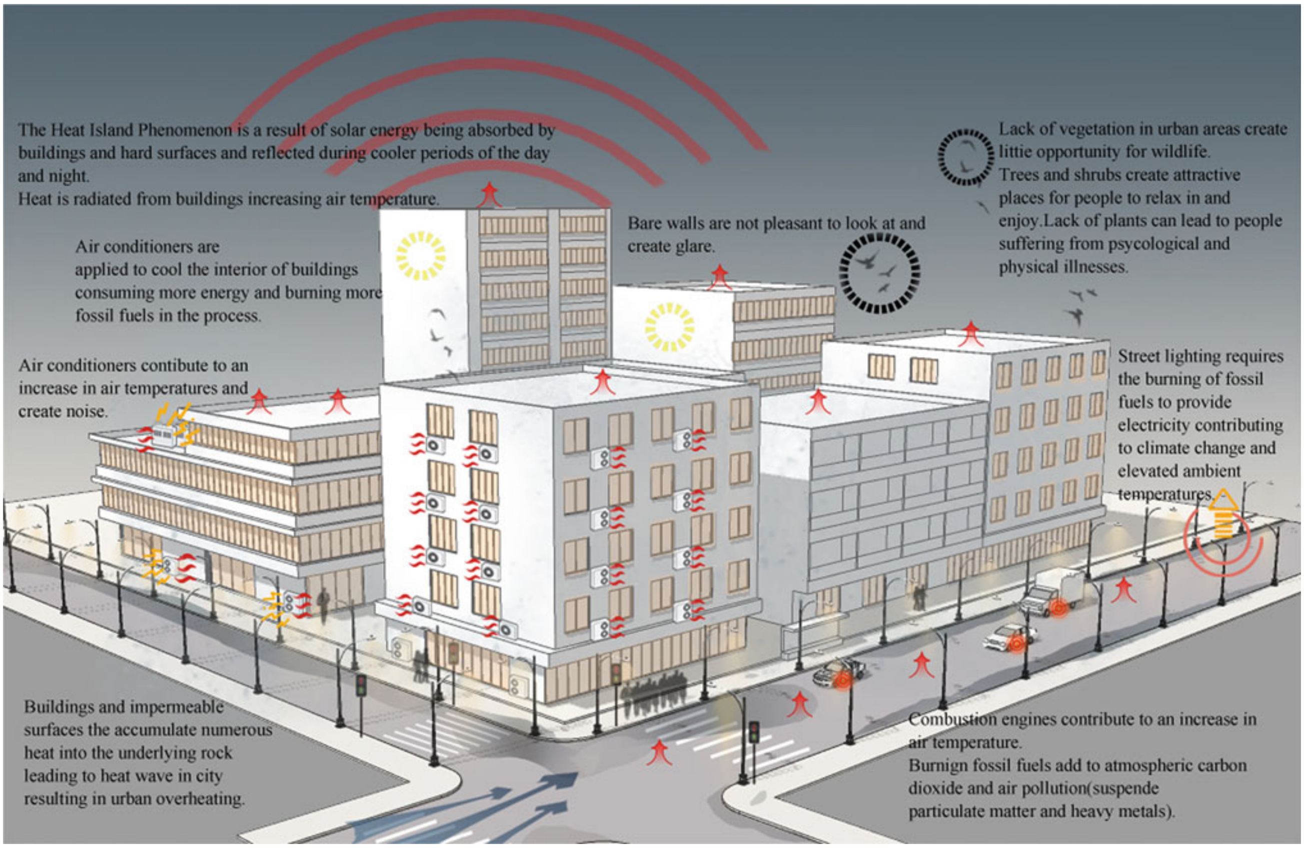


Fig. 1 Formation of thermal issues in cities

improvement. Green roofing, one of several types of green infrastructure, has gained increasing attention for the development of roof spaces (Popescu et al., 2012; Shafique et al., 2018; Zhang et al., 2020). By 2020, it is estimated that green roof market all over the world reached 1.1 billion USD, and there will be an annually economic growth rate of 17% from 2020 to 2027 (GVR, 2020).

Nevertheless, green roof installation and application are in dilemmas because green roofs are of national interest, but they are not efficiently intervened by policies, regulations, advocacies, and legislation (Carter & Fowler, 2008). To improve the efficiency of existing proposals and policies, it is essential to analyze them and then draw experience from different cities, which is because such proposals and policies generally focus on multifaceted of incentives or potential benefits. For instance, an investigation suggests that fiscal subsidy is the most direct stimulus to control UHI effect so that there is a need to pour money into feasible scope (Zhang et al., 2019). Similarly, a study demonstrates that both tax incentives and financial subsidies are socially receptive and demanded to convince possible groups to implement green roofs (Claus & Rousseau, 2010). Moreover, a mandatory instrument in Tokyo, Japan, describes policies to popularize green roofs in buildings with a ratio of 50–70% for the whole building coverage (Brenneisen, 2004). In Quebec, Canada, a financial incentive is put forward for installing green roofs (Berardi et al., 2014; Carter & Fowler, 2008). In some states of the U.S, green roofs have been successfully promoted with the incentives and policies. For example, in Oregon, more than 70% of the roofs are implemented with green roofs (Berardi et al., 2014). Meanwhile, the way to grant sustainable labels for buildings which are installed with green roofs is also regarded as a chance, such as LEED (American standards) or BREEAM (England standards) which originates from the assessment movement for building sustainability (Berardi, 2012; GhaffarianHoseini et al., 2012). Therefore, a sound policy and regulatory landscape for green roof installation can potentially speed up its implemenation; otherwise, the implementation of green roof is difficult to move forward (Brudermann & Sangkakool, 2017).

However, it should be noted that incentive policy of green roof design, installation, and maintain is not a one-size-fits-all solution for each area but a comprehensive consideration. There are many different types of existing policies and regulations that can be implemented in individual or public area to combine with regional economic, social, cultural needs. Therefore, this study aims to analyze the commonality and differences of existing green roof policies and regulations all over the world. This study can present how similar incentives could be accepted regionally in accordance with what has been suggested in other areas even in the world that can be used to improve the popularity of green roofs. In particularly, this paper introduces a detailed list of considerations by (i) investigating the main contents and motivations of green roof policies in pioneering countries/cities, (ii) classifying the measures of incentive policies, and (iii) guiding the trendency of incentive policies of green roofs.

2 Materials and Methods

2.1 Green Roof Policy in Six Countries and Main Regions

Green roof policies of six countries including Germany, U.S., Canada, China, Japan, and Singapore will be selected for analysis because of the positive development and studies of green roof in such countries (Berardi et al., 2014; GVR, 2020; Zhang et al., 2020). In particular, Germany is the first country to standardize green roof. The landscape research development & construction society was founded in 1975 with the main mission to study, establish, popularize and promote the principles, guidelines, and norms of green roof implementation. Meanwhile, the United States, China, Canada, and Japan are global economic powers and leading forces in green roof implementation. Although Singapore's gross domestic product is relatively low by comparison with the other five countries, its green roof implementation is developed as well. The policies and regulations relevant to green roofs are obtained and provided in Tables 1, 2, 3, 4, 5 and 6.

2.2 Classification of Incentive Measures

Overall, 20 policies or regulations have been obtained. Such policies and regulations were released between 1996 and 2020. These policies and regulations suggested the benefits of green roofs in alleviating heat island and air quality. Moreover, incentive policies are versatile in the form of law (BAF), encouragement (CBUGs, GAR, GRNC), guides (CBUGs, GRNC, SRG, QRIERGCMB, DGs, LUSH 3.0). Among the 20 policies of these six countries (capitals), nevertheless, the most popular are government guidance and subsidies, which potentially indicates that the current implementation of green roof still lacks of the public's active participation and common sense. In short, it preliminarily ideates that the current green roofs have four measures of policy landscape to incent green roofs implementation as shown in Fig. 2. Based on such 20 policies and regulations, this study further analyzes the trend of green roof policies and regulations in "5I" pattern.

3 "5I" Trends for Incentive Policies of Green Roof

3.1 Improve Target Groups of Attention and Participation

Stakeholders should focus on benefits and merits of green roofs from both a natural and an anthropogenic perspective. The attention could be instilled by the workshops, information offices, and visits to green roof projects (Getter & Rowe, 2006). Government can strengthen attention to rooftop planting through demonstration projects, competitions, mass media, and special events. For instance, the World Green Roof Photography Competition was held in Nanjing (China) in 2013, presenting many novelties from a wide array of firms, video record of new development and creation of green roof as a show. Due to competition belonging to voluntary initiatives, it received more actively focus among building owners than regulators, which many look upon as a burden. Mass media and competitions can enable those green roofs to be seen and appreciated, which is key for roofs that are not physically visible and accessible to the public. Special events that government or nongovernmental organizations can be involved in, from launching new projects and products to meeting attendance, providing chances to popularize green roofs. New products by an open-garden event can be shown for the public and thereby regional application.

3.2 Intensify the Reform of Government Guide and Support

In the initial stage, the promotion of green roof cannot be separated from the government promotion (Brudermann & Sangkakool, 2017). The governments of continents and countries should consciously reform the policy requirements for the implementation of green roof, break down the tasks from different perspectives (such as water conservation and energy conservation, etc.), define the development goals of all regions, and ensure the overall goal of green roof. Moreover, government should strengthen the administration and inspection sessions of the development indicators of green roof and urge the local enterprises to accelerate. There is a call that can promote local governments to speed up the progress of legislation and reform the original outdated system to form a new performance assessment to weigh implementation. In terms of collaborative incentives, it is

Table 1 Policy collection of green roof in Berlin, Germany

City	Policy name	Year	Main content	Motivations
Berlin	Biotope Area Factor (BAF) (Climate ADAPT, 2014)	2014	BAF can be set up primarily in landscape plans for an environmental plan including green roof parameter, which is utilized to the areas of which legally binding landscape plans are present	Improve and safeguard urban atmospheric hygiene and microclimate, including urban heat waves and urban heat island; safeguard and develop soil function and water balance, including water-related extremes; create and enhance the habitat quality for plant and animal, including ecosystem and residential environment
	Green Roof Guidelines (GRGs) (FLL, 2018)	2018	GRGs were firstly published in 1982 and it has been revised some times since 1990 which was treated as a criterion of guidelines for green roof implementation in Germany	Present common criterions and demands for maintenance, execution, and planning that ensure the state-of-the-art condition of knowledge and reflect current technology; improve the living and working environment
	Charter for Berlin Urban Green Spaces (CBUGs) (BDLA, 2021)	2020	CBUGs inform within a free consulting about the chances and advantages of green roofs as well as further activities on properties rainwater management, which allocated €2.7 million in funding to encourage green roof implementation	Relief for the climate, animals, and humans

Incentive measures Law (BAF), Codes (GRGs), Encouragement (CBUGs), Guides (CBUGs)

Table 2 Policy collection of green roof in Washington, America

City	Policy name	Year	Main content	Motivations
Washington	Green Factor (GF) (FIFE, 2009)	2007	GF regulates new buildings and reconstructions must have a landscape plan, which is calculated by multiplying the square feet of a landscape factors by its score. Green roofs need beyond 2 inches of growing substrate and get a higher score if it have over 4 inches of growing substrate that will get a project permit	Calculate green area factor by lot area and promote green roof popularization
	Green Area Ratio (GAR) (DC.Gov, 2017)	2017	GAR demonstrates that all new buildings should provide a certificate of occupancy need accord with the appropriate GAR in light of the zoning district, while it displays the ratio of the weighted value through both land area and landscape elements which is included: substrate and amendment, bioretention, plant types, vegetated walls and roofs, and so on	Encourage target groups to plant and expand urban green area
	Green Roofs for New Construction (GRNC) (Climate ADAPT, 2019)	2019	GRNC defined new development and existing buildings suffering much renovations in specific occupancy groups which regulated to own a 100% of the available roof space as a sustainable zone	Promote a sustainability in roofing zone by green roofs and/or wind turbines and/or solar panels

Incentive measures Regulations (GF), Encouragement(GAR, GRNC), Guides (GRNC)

coordinated with the ecological area as policy demonstration. The energy conservation by green roof could financially support and demonstrate in project models by incentive policy to promote the green roof work and upgrade the development quality for new cities or districts.

3.3 Induce an Example of Regulations and Laws

Both independent institutional and evaluation systems for green roof standards and laws are important. Although the perception is admitted that dry plant could lead to fires being

Table 3 Policy collection of green roof in Beijing, China

City	Policy name	Year	Main content	Motivations
Beijing	Clean Air Action (CAA) (Chinadaily, 2011)	2011	CAA makes regulations to improve the ratio of green area	Control air pollutions
	Beijing Urban Plan (BUP) (PGBM, 2017)	2016–2035	BUP drafts an urban development plan including population, traffic, green area, and so on	Promote the education building to be sustainable to cover green roof
	Specification for Roof Greening (SRG) (JBK, 2019)	2019	SRG strengthens green roof construction	Make a specification for green roof
	Quality Requirements and Investment Estimation of Roof Greening Construction and Maintenance in Beijing (QRIERGCMB) (BMFPB, 2020)	2020	QRIERGCMB defines guidelines of green roof construction to improve the construction and management standards of urban green roof	Promote the healthy and sustainable development of green roof in city

Incentive measures Regulations (CAA), Advertisements (BUP), Guides (SRG, QRIERGCMB)

Table 4 Policy collection of green roof in Toronto, Canada

City	Policy name	Year	Main content	Motivations
Toronto	Toronto Green Roof Bylaw Brochure (TGRBB) (TORONTO, 2009a)	2009	TGRBB establishes a graded requirement of green roof for new buildings or extension part that beyond 2000 m^2 in gross floor area that the covering ranges between 20 and 60% for the available roof space of a building, satisfying with construction standard	Manage storm water, heat wave in city, and saving energy
	Eco-Roof Incentive Program(ERIP) (TORONTO, 2009b)	2009	ERIP describes reward tax credit for intuitions, such as real estate, which covers green roofs	Improve green roof implementation by indirectly financial means
	Design Guideline (DGs) (TORONTO, 2013)	2013	DGs creates a sustainable development and infrastructure of cities	Guidelines for biodiverse green roofs

Incentive measures Regulations (TGRBB), Tax (ERIP), Credit (ERIP); Guides (DGs)

Table 5 Policy collection of green roof in Tokyo, Japan

City	Policy name	Year	Main content	Motivations
Tokyo	Neo-Green Space Design (NGSD)	1996	Policies make sure green layout in city through long-term green planning and utilize financial means to upgrade green area (Grant, 2006)	Solve urban heat island and instruct green roof construction
	Guide to Roof and Wall Green Technologies (GGWGT)	1999		
	Green Roof Q&A (GR Q&A)	2000		
	Green Roof Law (GRL) (IATP, 2002)	2001	GRL stipulates new development with a roof area of more than 1,000 m2 must plant greenery beyond 20% of the surface that provides a part of subsidies	Solve urban heat island

Incentive measures Subsidy (NGSD, GGWGT, GR Q&A, GRL)

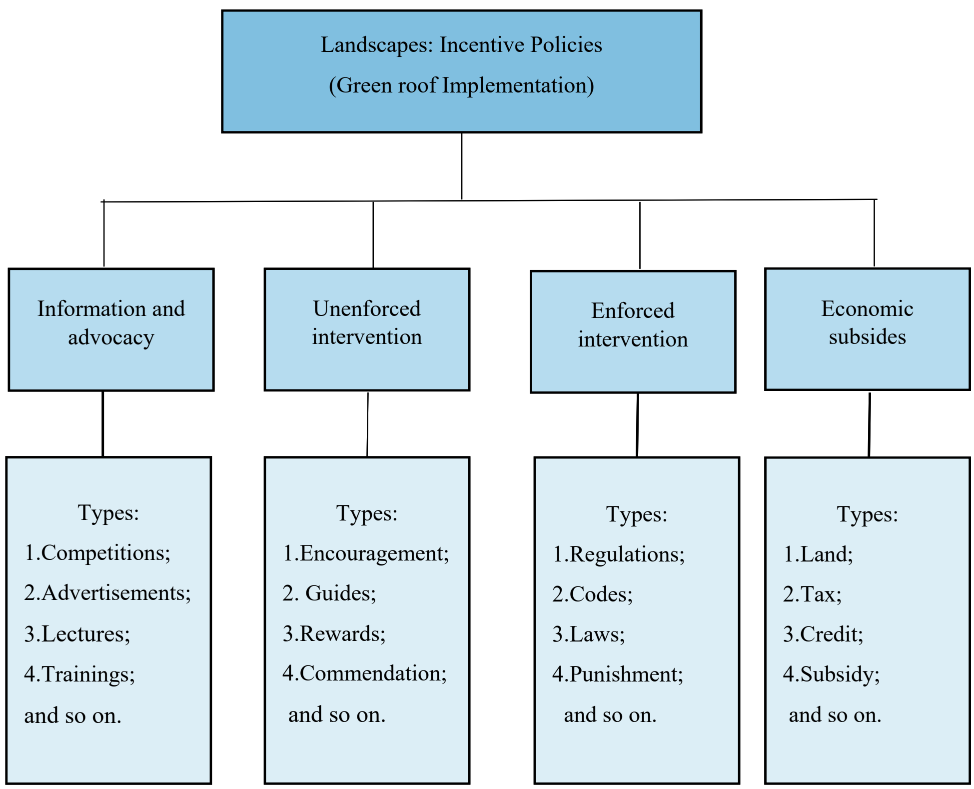
occurred on green roofs during the summer days, related standards to avoid the accident are indistinct and lack of example on this issue. In detail, a comprehensive consideration of fire resistance for membranes and firewall settings is needed. Strict laws should be set to control the use of firebreaks and the amount of combustible material adopted in green roof soils. Furthermore, a management organization with a clear purpose will also inform how the example should be evaluated and how green roof will be formulated in new policy or item under considerations. An example of green roof project may satisfy up-to-date style to lead by installing green roofs on all existing and future new public

Table 6 Policy collection of green roof in Singapore

City	Policy name	Year	Main content	Motivations
Singapore	Green Mark Certification and Incentive Scheme (GMCIS) (BCA, 2005)	2005	An initiative to manage urban construction industry and bonus points in the scoring to be achieved by implementing green roofs	In order to be much more environmentally friendly buildings
	Skyrise Greenery Incentive Scheme (SGIS) (BCA, 2005)	2009–2015	SGIS supports the existing buildings to install skyrise green, creates a distinctive status of the city, which financed up to 50% for installation fees of green roofs, encourage and upgrade more green area in building facade to construct comfortable city	Improve environmental benefits such as alleviate the urban heat island effect and improve air quality
	LUSH 3.0 (URA, 2017)	2017	LUSH 3.0 is a new version to add up vertical area and roof area for greenery to complement the previous plan of landscape replacement area, such as rooftop urban farming, to suggest roof area could be used for sustainable features, to make green plot ratio guidelines for private constructions and to upgrade sufficient density of greenery	Put forward softscape concept and green plot ratio standards; provide a quality living environment; strengthen city in a garden identity

Incentive measures Rewards (GMCIS), Subsidy (SGIS), Guides (LUSH 3.0)

Fig. 2 Conceptual framework



buildings, such as a minimum depth of substrate, minimum maintenance agreements, and minimum green coverage. Especially, public welfare houses which are covered with green roof will primarily play an exemplary role to realize the objectives policy for green roof popularization.

3.4 Increase Analysis of Incremental Cost

Before analyzing the incremental cost, it is necessary to make clear the composition materials and construction ways. Green roof materials mainly include eight layers that are vegetation layer, substrate layer, water storage, filter layer, root barrier, drainage layer, waterproofing layer, and roof construction from up to bottom, and every layer should utilize environment-friendly and sustainable materials (Zhang & He, 2021). The utilization of organic fertilizer can effectively control the cost and compacted soil. Furthermore, fruit trees and vegetables plant in rooftop area can stimulate the interest and income of residents. The current construction for green roof is on-site; however, if the process is greatly improved and centralized assembly production are adopted, the initial investment in green roof can be reduced. In the aspect of returning to the capital, green roof should be considered about the long-life cycle in multi-dimensions and be focused on improving individuals' living standards and infrastructure needs. In dry and hot areas, not only do energy saving consideration but also consider urban environment. For example, green roof can effectively alleviate storm flood arrival time of one hour by calculation and reduce runoff to form a sponge city (Tang et al., 2018).

3.5 Intend on Potential Subdivisions

More details should be specifically addressed in the planning schemes so that green roof would be widely used in the world. Related to subdivisions, it would encourage stakeholder to incorporate green roof into a part of green infrastructure and make a detailed plan to guide planners that which procedure or application would be utilized including permit for instance pruning and planting. Besides, green roof projects need more details to take considerations of permission, construction, and implement buildings and works, including for structures such as pergola, handrail or the supporting structure for watering and planting. Subdivision would provide an accessible and convenient way, for example, if the roof area needs an overlay which should consider structural type and work requirement. Details of rooftop greenery as accessible open space may also raise some planning issues instead of mandatory controls. Therefore, several elements of supplementing planning that could be renovated green roof to fill stubborn area, and clarify blank situations on promoting the theoretical system of green roof. These incentive sides could include the way to get preferential treatment for developments that incorporate the process of green roof.

4 Conclusions and Prospects

This paper combs and analyzes the main contents and motivations regarding economic, environmental, and social benefits of green roof, through the analysis of twenty policies in six countries. The results indicate that previous green roof policies mainly focus on controlling UHI, water runoff, and atmospheric hygiene and so on. There are four aspects of incentive policies of green roof implementation: information and advocacy, unenforced intervention, enforced intervention, and economic subsidies. The "5I" trends are proposed to explore direction for making incentive policies of green roof and to cope with future popularization and construction.

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Natural Wetland Evolution in China: A Review

Lingyan Wang, Liang Ma, Lianxi Sheng, Shuying Zang, and Hanxi Wang

Abstract

Wetlands are vulnerable and sensitive to climate change and human activities. Based on literature research, this paper analyzes the characteristics of wetland evolution in China. The results show that the current researches mainly focus on the wetlands of East China and North China, especially key river valleys and protected areas have attracted extensive attention. The main research methods include remote sensing, GIS, landscape index and mathematical model etc., which are still relatively simple. The area of China's natural wetland reduced by a mean of 0.19–1.67% per year, and some wetlands reach 5.56%. The constructed wetland area increased by a mean of 1.80–5.95% per year, with the increase of paddy field area. Meanwhile, the degree of fragmentation of natural wetlands in China increased by human factors. This paper analyzes China's natural wetlands generally show a trend of obvious degradation, and the relevant research results provide an important basis for wetland protection, and at the same time to provide reference for relevant policy making.

Keywords

Wetland • Evolution • GIS • Model

1 Introduction

The types of climates in China are complex and diverse, which across the plateau climate zones, cold temperate, temperate, subtropical and tropical. The annual precipitation decreased gradually from the southeast coast to the Northwest inland, wetland has obvious regional characteristics. According to the Ramsar Convention on Wetlands, wetlands in China could be divided into five types, including constructed wetlands (CWs), marsh wetlands, offshore and coastal wetlands, lake wetlands and river wetlands.

The total area of wetland in China is 5360.26 $\times$ 10^2 km^2, and the wetland rate is about 5.58%. The natural wetland area is 4667.47 $\times$ 10^2 km^2 which accounts for 87.37% of the global wetland area. Marsh wetlands and CW were 2173.29 $\times$ 10^2 km^2 and 674.59 $\times$ 10^2 km^2 which respectively accounts for 40.68% and 12.63% of the global wetland area, and the proportion of marsh wetland area was the largest (The state forestry administration of the People's Republic of China 2015). The wetland plant resources are abundant in China with rich plant species and complex elements of flora. The angiosperm is the main part of the wetland plant, accounting for about 92% of the total number of wetland plants.

Wetlands are one of the most biodiverse ecological landscapes, and wetland ecosystem is also one of the most threatened ecosystems (Gao et al., 2010; Lemly et al., 2000). Due to the large scale of wetlands in space, the study of wetland is carried out by remote sensing and meteorological data, at the same time to carry out field investigation, isotope measurement, analysis of wetland area, ecological factors, and function change etc. (Barbieri et al., 2013; Goldhaber et al., 2011; Li et al., 2016). The evolution of wetlands is

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affected by the external factors (natural and social factors) in addition to its internal factors, especially human factors (Medjani et al., 2015; Puy et al., 2014; Zhang et al., 2015a). At present, the study of wetland in developed countries focuses on the change of biology and sediment, especially changes in wetland species and changes in biodiversity (Caraballo et al., 2012; Jasper et al., 2010; Kearsey et al., 2016; Reuter et al., 2010; Sullivan et al., 2016). Wetland hydrological change is the main factor causing wetland change, it is necessary to study the change of groundwater level and the relationship between groundwater and surface water for better protection of wetlands (Liu et al., 2012; Twilley et al., 2016; You et al., 2015). Affected by social factors, wetland research shows that the natural wetland area is decreasing, while the area of CW is increasing (Liao et al., 2014a). The change of wetland policy has experienced 3 stages: wetland development, policy transformation and wetland protection in developed countries, and gradually reduced the rate of wetland degradation (Kim, 2010).

The wetland has important carbon fixation and carbon storage function, which has important impacts on global climate change. The global climate change has changed the function of natural wetland, and affected the evolution of wetlands, therefore, studying wetland evolution is of great significance for addressing global climate change (Bernal et al., 2016; Garris et al., 2015; Helbig et al., 2017; Lewis & Feit, 2015; Osland et al., 2016). This paper analyzes the northeast (Including Liaoning, Jilin and Heilongjiang), North China (Including Beijing, Tianjin, Hebei, Shanxi, Inner Mongolia, and Hebei), East China branch (Including Shandong, Jiangsu, Anhui, Zhejiang, Fujian, Jiangxi, Hubei, Hunan, and Shanghai), Southern China (Including Guangdong, Guangxi and Hainan), northwest (Including Ningxia, Xinjiang, Qinghai, Shaanxi, and Gansu) and southwest (Including Sichuan, Yunnan, Guizhou, Tibet and Chongqing) of the 6 regions for the study of China wetland evolution, the relevant research results provide an important basis for wetland protection, and at the same time to provide reference for relevant policy making.

2 Materials and Methods

2.1 Literature Retrieval and Analysis

The authors searched respectively journal article, dissertations and conference papers by "wetland" and"evolution" as the key words on CNKI. 1764 articles were retrieved, there are 531 articles from 2000 to 2020, and accounting for about 90.69% of the total number of articles, the mean annual published articles are stable at about 88 during the last 20 years (Fig. 1), the annual publication of the articles are below 10 before 2002. The related dissertations retrieved are 921, and there were about 858 dissertations in the last 20 years, accounting for about 93.16% of the total number of dissertations, the number of dissertations retrieved every year is about 40 in the past 20 years. The research articles including Northeast China, North China, East China, Central China, Southern China, Northwest, and Southwest regions within the past 5 years. The basins focused on the Yangtze River, the Yellow River and Songhua River. The proportion of the articles in East China accounted for more than 50% among them, which is the hot spot in the past 6 years (Fig. 2).

Searched on the web of science website with "wetland" and "navigation" as keywords, and retrieved 233 SCI (E) papers from 2000 to 2020. There are more than 10

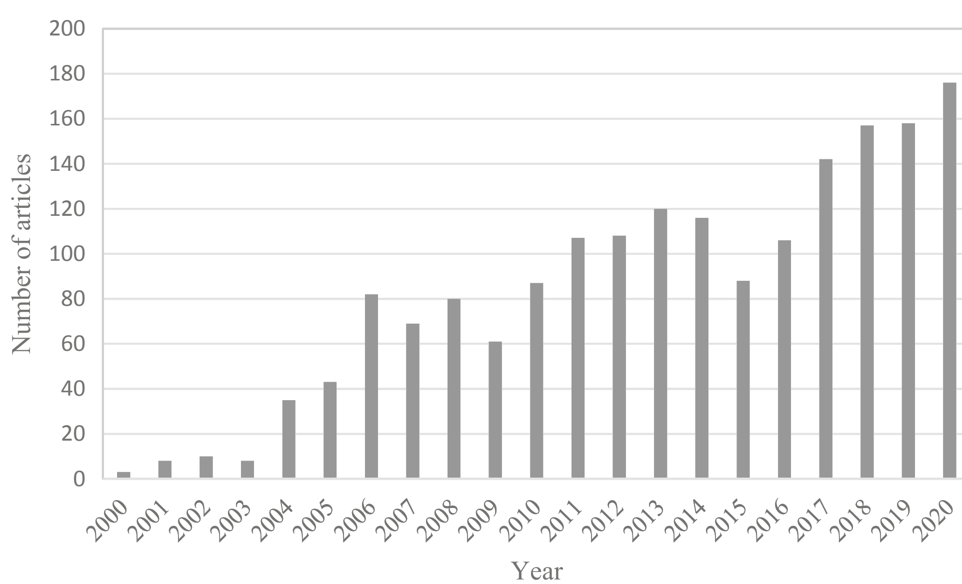

Fig. 1 The number of articles published from 2000 to 2020

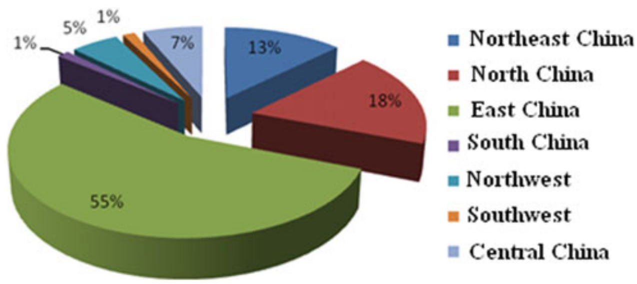

Fig. 2 Regional distribution of articles published from 2000 to 2020

papers at 2005, 2010, 2016, 2017, 2018, 2019, and 2020, and the number of papers showed an increasing trend in the past 5 years (Fig. 3).

The largest number of papers published in the United States on wetland research retrieved by SCI in the past 6 years, mainland China is in second, which shows that mainland China has carried out more wetland research in the world (Table 1).

2.2 Literature Content Analysis

The problems and shortcomings can find out in the research process by analyzing the searching literatures of data, the research methods, the analysis process, and the main research results etc. The authors carried out in-depth research on the problems of single research method, too concentrated research field, insufficient analysis depth, etc. The research results will point out the direction for the evolution of wetlands in China.

3 Results and Discussion

3.1 Wetlands of Northeast

3.1.1 Results

At present, the area of wetlands in Northeast China is 753.57×10^2 km^2, of which the proportion of CW is about 8.51%. The study found that the total area of wetlands is decreasing year by year, and most of the disappeared wetlands converted to cultivated land. The natural wetlands in the Sanjiang Plain, the CWs in the Songnen Plain and the marsh areas in the northeast all change over time (Table 2) (Mao et al., 2016). The change of landscape pattern is characterized by landscape pattern index. The coastal wetland in Zhuanghe City is rapidly deteriorating and experiencing landscape fragmentation (Li et al., 2013a, 2013b). By analyzing the changes of the main landscape elements and landscape structure of Zhalong Wetland, it was found that the swamp landscape, water area landscape, cropland landscape and grassland landscape had higher protection rates, and the transition and swamp between grassland is the main process of landscape type transfer (Gong et al., 2010).

Analysis of the temporal and spatial changes of marsh wetlands and their driving forces from 1975 to 2007. The center of Raoyang River wetland moved, and the temporal and spatial changes of paddy fields were the direct driving force. The area of marshes and wetlands was positively correlated with the river area (Sun et al., 2010). Analyzing the landscape changes of the Liaohe Estuary wetland in the past 30 years, the landscape types not changed, but the landscape pattern changed (Huang & He, 2011). Analyzing the characteristics of the water environment evolution of the

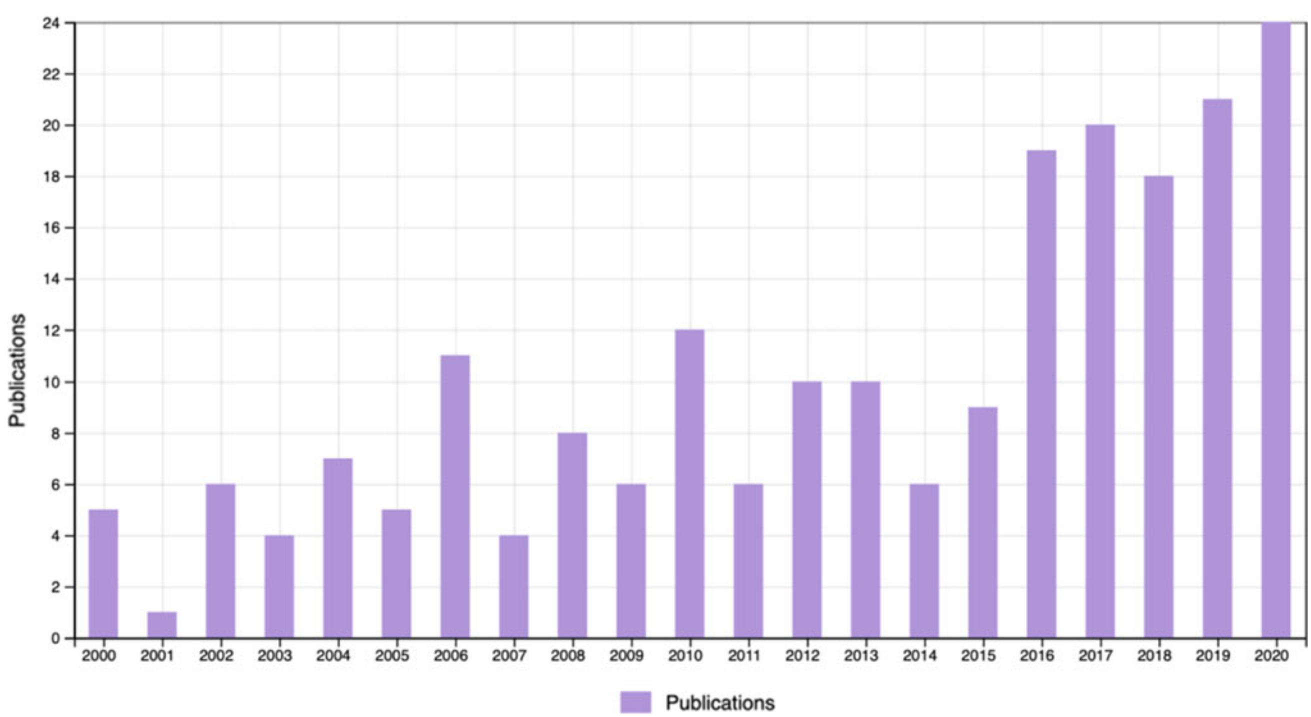

Fig. 3 The number of articles retrieved by SCI (E) from 2000 to 2020

Table 1 List of published papers on wetland research in major countries by SCI (E) in the past 6 years

Sequence number	Country	Article number	Proportion (%)	Column shape
1	USA	32	49.23	
2	PRC	13	20.00	
3	Australia	5	7.69	
4	Hong Kong, Macao and Taiwan of China	5	7.69	
5	Canada	3	4.62	
6	France	3	4.62	
7	Brazil	2	3.08	
8	Germany	2	3.08	

Table 2 List of wetland changes in different regions

Distribution area	Wetland type	Loss area (km^2)	Reason
Sanjiang plain	Natural wetland	− 9935.2	Transition to farmland
Songnen plain	CW	+ 1141.9	Opened wasteland
Northeast China	Marsh wetland	− 16,091.4	Climate change and human activity

Note "+" for the increase, "−" for the reduction

Chagan Lake wetland, the trends of alkalization and organic pollution have been serious since 2006, and the water quality has changed from Class III to Class IV. The water quality of Chagan Lake is cross-affected by discharge, endogenous release and hydrological conditions, and show significant phosphorus-restricted mesotrophic (Li et al., 2014). By the dynamic model of land, patch area, patch number and patch density and so on, it is clear in fragmentation of the landscape in the year 1988 and it will be continued in fragmentation (Cheng et al., 2012). In 1983, 1995 and 2007, the study on the changing laws of wetlands in the Yalu-river Estuary found that the reduction of wetland area led to the reduction of wetland biological living space and the corresponding degradation of ecological functions (Table 3) (Zhang et al., 2014).

3.1.2 Discussion

At present, the research data of the wetland in the northeast China are mainly from remote sensing, hydrological data and meteorological data etc., interval of data collection is mostly between 5 and 10 years, the longest up to 13 years., it affects the accuracy of the analysis results on account of the lack of field investigation and experimental data. The main research methods include RS technology, GIS technology, landscape feature index method and comprehensive evaluation method etc. The annual loss rate of wetland in Northeast China was 0.88–1.00%, and the maximum amount of the Yalu-river estuary wetland was 4.86% (Table 4). The main driving factors are human activities for decrease of natural wetland and increase of CW in northeast China, the main types of increase of paddy field area for CW area increased, and farmland reclamation, engineering construction, intensified human activity disturbance is the main reason for the wetland reduction. The change of landscape pattern is influenced by human activities, especially agricultural development, oil field development and urbanization. The reduction of marsh area in natural wetland is not only related to the hydro logical factors caused by climate change, but also closely related to human activities including water conservancy construction and land use.

3.2 Wetlands of North China

3.2.1 Results

The total area of wetland in North China is 744.81×10^2 km^2, the CW area accounted for 6.34%. Beijing, Tianjin, Hebei and Shanxi area of CW accounts for a larger

Table 3 Changes of wetland pattern in the Yalu-river Estuary from 1983 to 2007

Item	Wetland change (km^2/a)	Increase or decrease	Types of changes	Reason
Natural wetland	4.16	Decrease	Beach and reed	Industrial and agricultural production activities
CW	23.43	Increase	Rice fields and farms	

Table 4 Changes of wetland area in Northeast China

Loss area (km^2)	Various cycles (a)	Mean annual loss rate (%)	Geographical location
1.18×10^4	1990 → 2000	1.00	Wetlands of northeast (Mao et al., 2016)
1.34×10^4	2000 → 2013	0.88	
97.64	2000 → 2010	0.74	Zhuanghe coastal wetlands (Li et al., 2013a)
99.10	1975 → 2007	3.01	Raoyanghe marsh wetland (Sun et al., 2010)
90.85	1983 → 1995	4.86	Yalu-river estuary wetland (Zhang et al., 2014)
13.60	1995 → 2007	1.74	

proportion, respectively 49.75%, 48.87%, 26.26%, and 28.78%, the Inner Mongolia area of CW area accounted for a smaller proportion of about 2.19%. Affected by the economy, scholars have carried out a lot of research on North China at present, which has accumulated rich experience in the protection of wetland. Affected by the economy, lots of research were carried out on North China and accumulated rich experience in wetland protection. For example, the area of the Baiyangdian Wetland (Hebei Province) decreased, and its landscape diversity showed a downward trend. The landscape index changed greatly during 1979–1991, and minor changes were observed after 1991 (Bai et al., 2013; Zhang et al., 2016). According to the hydrological data of the Baiyangdian Wetland, during the period 1960–2003, all inflows into the wetland, precipitation in the basin, and potential evapotranspiration all showed a downward trend, and were affected by climate change, artificial water intake, and evaporative seepage processes on the changes in the wetland water intake. It is 25.1%, 57.53% and 17.4%, and the integration of all human activities has an impact on the wetland water intake of 74.9%. In addition, the Baiyangdian Lake Basin has reduced precipitation, increased temperature, reduced water surfaces and depressions, and made the ecosystem more fragile (Fang et al., 2012; Yuan et al., 2014).

Through the analysis of changes of urban Reservoir Wetland in Beijing, the driving factors in different periods are different in the past 30 years. The fractal dimension of total patch area, average patch area and landscape pattern index is selected to analyze the evolution characteristics of Beijing wetland landscape pattern. The total area of wetlands increases first, then decreases sharply, and then slightly increases. The offset of the wetland space centroid is constructed as the main form of wetlands in Beijing, and the total area of wetlands leads the trend change (Table 5) (Gong et al., 2012, 2013; Li et al., 2012). By analyzing the dynamic evolution of Beijing wetlands, it is found that the wetland patches are irregular and the degree of fragmentation is increasing. The transition probability matrix of the two main states is established (Gu et al., 2010). Six driving factors, annual rainfall, evaporation, inflow, available groundwater, urbanization rate and average daily sewage discharge, are the main factors affecting the change of wetland area in Beijing. Rainfall and evaporation affect changes in wetland area, with a contribution rate of 36.54%, and urbanization rate and average daily sewage volume affect 19.52% (Jiang et al., 2012).

Analyzed the landscape changes of TBNA wetlands in 1984–2008, the area of wetland was continuously declining during 2004 to 2008, about 13.4% of TBNA total land area was transferred from wetland into construction land, which was the main component of land use change.

By analyzing the changes of wetland landscape in TBNA from 1984 to 2008, it is found that the wetland area continued to decrease from 2004 to 2008, and about 13.4% of the total land area of TBNA was converted from wetland to construction land, which is the main component of land use change (Li et al., 2011). Since 1960s, the total quantity of water resource and water entry decreased in Tianjin City, low-lying pond and marsh wetland area were reduced (Qin, 2012). Remote sensing data from Tangshan City show that the dynamic changes and landscape pattern evolution from 2000 to 2010 show that the total area of wetlands has decreased, and the wetland morphology has become complex and fragmented (Hu & Ye, 2014).

3.2.2 Discussion

At present, the main data for wetland research in North China mainly comes from remote sensing images, hydrological data and aerial photos, mainly through GIS, RS and mathematical model analysis. Some researchers collected longer data, the longest being 13 years. In addition, site surveys and field sampling experiments have less data, which brings difficulties to quantitative analysis and makes the research results deviate from the actual situation. The focus of current wetland research in North China is mainly in the Beijing-Tianjin-Hebei region. The types are mainly natural wetlands such as river wetlands, coastal wetlands, lake wetlands, swamp wetlands and some CWs. The annual loss rate of wetland in North China is 0.19–5.56%, mainly due to the natural wetland area reduction. The area of CWs has generally increased, and the mean annual increase of wetlands in Beijing reservoirs is about 4.8% (Table 6). Compared with other regions, there are more researches on

Table 5 The centroid deviation of wetland in Beijing

Date	Wetland type	Offset	Reason
1984–1998	River Wetland	Northeast offset 10.43 km	Adequate precipitation
1999–2006	River Wetland	Southwest offset 10.75 km	Continuous drought and many unreasonable exploitations
After 2006	Pond paddy wetland	Shifts southerly	Effect of "converting paddy drought" policy
2008	Park Wetland	To the north of Haidian District offset	The construction of the Olympic Forest Park

Table 6 The change of wetland area in North China

Loss area (km^2)	Various cycles (a)	Mean annual loss rate (%)	Geographical location
66.10	1979–2006	0.61	Baiyangdian wetland (Bai et al., 2013; Zhang et al., 2016)
34.35	1984–2013	0.47	
− 4.8	1984–2010	− 0.18	Beijing Reservoir Wetland (Li et al., 2012)
314.54	1996–2005	5.56	Beijing Wetland (Gu et al., 2010)
370.02	1984–2008	1.41	Tianjin Coastal New Area Wetland (Li, 2011)
24.11	2000–2010	0.19	Tangshan City wetland (Hu & Ye, 2014)

Note "−" for wetland area increase

CWs. From the research results, the level of socio-economic development, total population, agricultural development, and the change of climatic conditions are the main driving forces for the changes in the wetland landscape pattern in North China.

3.3 Wetlands of East China

3.3.1 Results

The total area of the wetland in East China is 804.78×10^2 km^2, which accounts for about 15% of the wetland area in China, and CW accounts for more than 31.29% of the wetland area, which is higher than that in other regions. The analysis of wetlands in Anhui section of the Yangtze River shows that after 2000, the area of floodplain wetlands and artificial aquaculture increased, the area of lakes, permanent rivers and herbaceous swamps decreased (Yang et al., 2011). It is predicted wetland area to biome area ratio was different in Chongming east beach, Nanhui side beach and Jiuduansha under three different scenarios (ecological protection, current situation trend and enhanced reclamation) in 2020 (Table 7) (Li et al., 2015a).

The changes of the mangrove wetland landscape pattern in Luoyang Estuary of Fujian Province were analyzed. It was found that the landscape indicators such as the number of patches, spacing, area-weighted average shape index, and fractal dimension of perimeter area first increased and then decreased; the average patch area showed an opposite trend (Cui et al., 2010). The change of landscape pattern of wulongjiang River Wetland in the last century are quantitatively studied. The total area is in a slight decline state, the degree of landscape heterogeneity reduced, and various changes can be observed (Li and Fan 2012).

The change and forecast trend of wetland in Pudong New Area are analyzed. It was found that the wetland area in Pudong New Area is decreasing. Through the analysis of wetland thematic information, the evolution of coastal wetlands in the southeast of Laizhou Bay in the past 30 years is characterized by the first increase and then the decrease of natural wetlands. Through the analysis of the geomorphic evolution of Chongming Dongtan wetland in the past 60 years, the wetland area increases year by year with human reclamation, but the intertidal structure of the wetland deviates from the natural state, and the proportion of high tide beach decreases (Sun et al., 2011; Zheng et al., 2013; Zhu et al., 2015).

The spatiotemporal characteristics and driving forces of wetlands in the eastern part of Pinghu from 1987 to 2009 are studied. The results showed that the natural wetlands are shrinking and the CWs are growing (Wang et al., 2014). The Nansi Lake wetland dynamic characteristics were analyzed, indicating a decreasing area of the natural wetland and a increasing area of CW from 1982 to 2012 (Fan et al., 2014). Wetland distribution changes were analyzed using landscape gradient and grid models. From 1987 to 2014, the Nansi wetland area gradually increased. The lake area decreased first and then increased, the coastal pond area gradually increased, and the marsh area continued to decrease during this period. From 1987 to 2014, the total area of Nansi wetland gradually

Table 7 Prediction of tidal flat wetland evolution in Changjiang Estuary

Estuarine wetland's location	Characteristic	Total area change (km^2)	Community area ratio
Chongming Dongtan, Nanhui Biantan and Jiuduansha	Ecological protection	+ 56	46:34:20
	Current trends	+ 44	38:38:24
	Intensified inning	− 7	38:37:25

Note "+" for the increase, "−" for the reduction

increased. The lake area first decreased and then increased, and the pond area along the riparian zone gradually increased, while the area of swamp continuously decreased during this period. From 1980 to 2012, the Nansi Lake wetland land use change was slow, but the ecosystem service value decreased. The increase of construction land area is mainly due to the urbanization effect and the decrease of tidal swamp and water area, which leads to the decline of ecological value in this area (Chen et al., 2016; Yang et al., 2014).

Wetlands decreased by 23.15%, and the land system faced the risks of low proportion of wetlands, scarce unused land and broken landscape. The regional sustainability has decreased to a poor level since 2010. In order to analyze wetland landscape changes in the middle reaches of the Huaihe River Basin, a great number of wetlands are transformed into paddy fields and non-wetlands, and some natural wetlands are transformed into CWs. The quantitative structure and spatial variation of Poyang Lake wetland area were analyzed. The results indicated that the fractal degree and dominance index of Poyang Lake wetland landscape pattern decreased, and the diversity index and fragmentation degree increased. This paper analyzes the evolution status of Poyang Lake Wetland affected by comprehensive physical and human factors, land desertification, intensified water pollution, sharp reduction of biological resources and serious degradation (Hu, 2011; Wu et al., 2013; Xiao et al., 2010; Yang et al., 2015).

By analyzing the evolution trend of the two coastal areas in Jiangsu Province, it has mainly changed from natural wetland to CW and non-wetland in the past 30 years (Hao et al., 2010). Through the change analysis of Yancheng Coastal Wetland National Nature Reserve and core area of Spartina alterniflora swamp, the area of Spartina alterniflora swamp increased from 2000 to 2011, and the mean size and aggregation index showed a downward trend (Table 8). Soil analysis results showed that the evolution of coastal wetland in Yancheng Nature Reserve is driven by the interaction of pattern and process, the expansion of reed swamp and rice grass swamp and the shrinkage of sedge swamp. Soil water content and salinity analysis of coastal wetlands showed a decreasing trend from straw marsh to salsa and reed (Zhang et al., 2011, 2012a, 2012b, 2013a, 2013b, 2013c).

Yancheng coastal wetland landscape changed significantly from 2002 to 2011, in which reed wetland increased by 3 times, Suaeda salsa wetland decreased by 15.29%, and rice grass wetland increased by more than 50% (Hou et al., 2013). Many original natural landscape types were transformed into artificial landscape types in erosion, transition and deposition areas from 1992 to 2010 (Fang et al., 2014). The research on the natural vegetation succession process of Yancheng coastal wetland and the evolution of soil quality after farmland reclamation showed that the physical, chemical and biological properties of wetland soil had been improved, which was reflected in the improvement of soil physical properties and the increase of soil nutrient content, microbial biomass and enzyme activity (Mao et al., 2010). The study of Yancheng coastal wetland shows that in recent 30 years, the wetland area has gradually decreased, and the CW construction land and cultivated land area has gradually increased. Wetland reclamation has become the most powerful reason for the evolution of Yancheng coastal wetland (Yan et al., 2012).

By analyzing the evolution of wetlands in the intertidal zone of northern Jiangsu in the past 30 years, the proportion of wetlands renovated is 38.39%, and the proportion of wetlands that have disappeared is 14.97%. Natural wetlands decreased by 354.1 km^2, while wetlands increased by 1061.45 km^2 (Liao et al., 2014a). In order to study the spatial dynamics of coastal wetlands and reclamation areas in central Jiangsu, the key ecological areas of coastal wetlands in Jiangsu decreased rapidly from 1977 to 2014, and the shrinkage of natural halophytes in southern Sheyang County and Dafeng County (Li et al., 2015b). To quantify the dynamic changes in wetland landscape patterns from 2002 to 2013, the results show that the wetland area in Yangzhou decreases, and the wetland landscape pattern in Yangzhou tends to be fragmented and more complex (Table 9) (Xu & Ye, 2015).

3.3.2 Discussion

Under the influence of regional economy, there are many studies on the distribution of wetlands in eastern China, especially inland wetlands and coastal wetlands such as the Yangtze River, the Yellow River, Shandong and Jiangsu. The main data comes from remote sensing, survey data, satellite data and sampling data. Remote sensing, RS and GIS technology, landscape index and mathematical model methods are mainly used. The time interval of collected data

Table 8 Spatial–temporal evolution characteristics of coastal wetland landscape in Yancheng

Item		Date (a)	Variety (%)
landscape structure	Natural wetland	1987–2007	42.45 → 21.44
	CW	1987–2007	18.19 → 58.88
Wetland transfer	Natural wetland → CW	1987–1997	45.40
	Natural wetland → CW and the non-wetland	1997–2007	37.91
Erosive coastal wetland	Mudflat	1987–2007	76.91 → 60.86
	Salsa wetlands	1987–2007	18.68 → 0
	Reed wetland	1987–2007	4.42 → 15.85

Table 9 Characteristics of wetland change in Yangzhou

Wetland type	Date	Area (km^2)	Rising and falling range (%)	Driving factors
Wetland	2002 → 2007	− 13.69	− 1.1	Economic development, increasing population, changes in the proportion of secondary industry and annual precipitation
	2007 → 2013	− 43.23	− 3.3	
River	2002 → 2013	− 9.64	− 5.6	
Beach	2002 → 2013	39.05	+ 73.2	
Pond	2002 → 2013	40.43	+ 6.2	
Lake	2002 → 2013	− 126.76	− 29.7	

Note "+" for the increase, "−" for the reduction

is long, mostly about 10 years, and the accuracy of analysis results is low. Statistics show that the annual loss of wetlands in eastern China is 0.26–1.67%, and the natural wetlands are gradually decreasing. Affected by economic benefits, the area of CW is increasing, with a mean annual growth rate of 1.8–5.95% (Table 10).

The current research on wetland types is mainly natural wetlands in coastal wetlands, river wetlands and lake wetlands. The results show that the landscape index, patch area, patch shape and land use pattern change dynamically, the wet geological center shifts, and coastal wetland landscape changes greatly. Compared with natural wetlands, there are fewer studies on CWs. According to the research results, the main driving factor for the decline of natural wetlands in eastern China is human activities.

3.4 Other Regions of China

3.4.1 Results

Except for the Northeast, North China and East China, the wetland area in other regions is 3038.90 × 102 km^2, and the CW area accounts for about 10.25% of the total wetland area. The wetland area in this region accounts for more than 50% of the China, and the natural wetland area accounts for 56.05% of the total area of natural wetlands in China.

By studying the evolution of coastal wetland landscape pattern in Zhuhai from 1988 to 2008, it is found that the total area of coastal wetland landscape has decreased significantly by 146.89 km^2 in the past 20 years, and the dynamic change of wetland landscape is very significant. Among them, the rice fields and shallow water areas are the most obvious and heterogeneity gradually increases (Liu et al., 2011). Through the dynamic analysis of wetland landscape in Shudu Lake Basin in the past 56 years, it is found that lakeside swamps and swamp meadows have decreased, and landscape diversity and uniformity have decreased (Li et al., 2013b). The total area of urban patch wetlands in Changsha City showed an increasing trend, the area of patch wetlands less than 32 ha increased, and the area of patch wetlands greater than 32 ha showed an opposite trend (Gong et al., 2012). The results indicating the health status of Dongting Lake wetland ecosystem showed a downward trend before 2003, and then gradually recovered (Liao et al., 2014c). The area of Futou Lake Wetland Lake and the area change most obviously, and the dynamic change characteristics of different wetland types are different. The two-way dynamic changes of CW types are more obvious, and they are greatly affected by human activities (Tang et al., 2011). The results show that the natural wetland in Yinchuan Plain shows a radiation attenuation trend from area to the whole, and the CW shows a gradual increase trend (He, 2016; Zhang et al., 2015b).

3.4.2 Discussion

There are few other wetland research fields, except Northeast China, East China and North China. The main data comes from remote sensing images, topographic maps and census data in the research literature, mainly using GIS, land use

Table 10 The change of wetland area in East China

Loss area (km^2)	various cycles (a)	Mean annual loss rate (%)	Geographical location
491.44	1982–2012	1.38	Nansihu Lake Wetland (Fan et al., 2014)
− 50.88	1987–2009	− 1.80	Dongping Lake Wetland (Wang et al., 2014)
120.25	1975–2007	− 0.26	Natural wetland in Anhui section of Yangtze River (Yang et al., 2011)
− 292.02	1975–2007	− 5.95	CW in Anhui section of Yangtze River (Yang et al., 2011)
303.2	1989–2013	0.68	Pudong New Area wetland (Zhu et al., 2015)
713.09	1987–2007	1.67	Jiangsu coastal wetland (Zhang et al., 2012a)
24.6	2000–2011	− 4.7	Yancheng Spartina marsh wetland (Zhang et al., 2013b)
354.1	1980–2008	0.91	Northern jiangsu coastal beach wetland (Liao et al., 2014b)

transfer matrix, landscape pattern index model and grey relational analysis methods. Some research documents are few, and the data collection interval is longer, about 10 years, and the longest can be up to 17 years.

According to the research literature, the wetland types in this area are mainly plateau wetlands, coastal wetlands and lake wetlands. From the research results, in addition to some wetlands that are greatly affected by natural factors, the main factors that cause the wetlands reduction and the CWs increase are the reclamation of lake bottoms, planting crops, and fish pond construction. Research on the evolution of natural wetlands has not been carried out regularly, resulting in a lack of data. In addition, research on wetlands in remote areas such as Xinjiang, Tibet and Qinghai are relatively small and needs to be strengthened.

4 Conclusions

Studies on the development of wetland in China, the main conclusions are as follows:

(1) The number of SCI(E) papers in China ranked second in the world according to the literature, behind the United States.
(2) The study sites are mainly in East China and North China, other regions especially in remote areas of Xinjiang, Tibet and Qinghai of research is less. The river basins focused on the Yangtze River, the Yellow River, Songhua River, and Huaihe River Basin. The national, provincial wetland protection areas and large coastal wetlands are the focus of attention.
(3) The main research methods include remote sensing, GIS, landscape index and mathematical model, etc., the study of some wetlands is based on field investigation, sampling analysis and isotope tracing analysis. In view of the overall situation, the current data collection is limited and the research method is single.
(4) The natural wetland area in China is decreasing in general, the mean annual reduction rate is between 0.19 and 1.67%, the overall natural wetland biodiversity is decreased, the decrease of water level is obvious, and there is a trend of degradation.
(5) The area of CW increased significantly in China, the mean annual increase is between 1.80 and 5.95%, the increase of CW area is mainly paddy field. Few researches on the CW function, which need strengthen.
(6) The total number of natural wetland patches showed an increasing trend because of human disturbance, but the mean patch area decreased significantly, the patch shape tends to be irregular, and the connectivity between plaques tends to be worse. The degree of wetland fragmentation is on an obviously increasing trend.

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Urban Morphology, Urban Ventilation and Urban Heat Island Mitigation: A Methodological Framework

Bao-Jie He

Abstract

Wind is a good regulator of urban temperature and outdoor thermal comfort. Urban ventilation, urban temperature and outdoor thermal comfort are affected by urban morphology. However, relationships among wind, temperature and outdoor thermal comfort have not been well documented, constraining urban planners and architects' capability of regulating urban morphology for enhancing urban ventilation and its associated potential for cooling. To address this challenge, therefore, this chapter aims to develop an analytical framework to reveal inter-relationships among urban morphology, urban ventilation performance, urban heat island (UHI) effects and outdoor thermal comfort. The framework consists of five components including physio-morphological characteristics, external meteorological conditions, precinct ventilation performance, UHI effects and outdoor thermal comfort. Through this framework, first, combined impacts of physio-morphological characteristics, external meteorological conditions on precinct ventilation performance were presented. Second, co-impacts of urban physio-morphological characteristics and precinct ventilation performance on UHI effects were explained. Third, associated impacts of urban ventilation performance and UHI effects on outdoor thermal comfort were analyzed. Overall, the analytical framework can inform of knowledge about future studies on urban morphology, local ventilation, UHI effects and outdoor thermal comfort. Meanwhile, the analytical framework can suggest urban planners and policy makers with rational decisions on urban modification for UHI mitigation.

Keywords

Methodological framework • Urban morphology • Urban ventilation • Urban heat island • Outdoor thermal comfort

1 Introduction

Along with the rapid but not sustainable urbanization, most cities all over the world are experiencing an iconic kind of urban climate: urban heat island (UHI), which poses significant challenges and threats to sustainable cities (He et al., 2022). Urban ventilation has potential to be a technique to mitigate UHI effects, since wind can significantly affect urban temperature. For example, Yow (2007) found when wind speed exceeded 5 m/s, UHI intensity decreased by 0.6–1.0 °C. Due to sea breeze, UHI effect of coastal cities was much lower than that of inland cities (He et al., 2020). Moreover, when wind in urban area reaches a wind threshold, UHI can be totally mitigated. The mechanism that the cool wind can weaken the strength of heat sources and dissipate excess urban heats should be therefore revealed.

Urban morphology alters wind direction and distribution in urban layout, density, building height and street canyon (Oke, 1988). The wind threshold for completely mitigating UHI effects is also dependent on urban morphology, such as urban scale and city population (Park, 1986). However, many cities are currently occupied by high-rise and dense buildings, resulting in wall effects, further obstructing

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natural ventilation and wind circulation, blocking peripheral cooler air flowing into built areas (Wong & Nichol, 2013). Urban heats, at the same time, are trapped in central cities, which is particularly evident for cities that are constructed with sea-view tall buildings. This indicates that urban morphology could influence urban ventilation and UHI effects simultaneously, at which time the wind potential for urban cooling is also weakened with urban ventilation performance reduction. How to practically adjust and modify urban morphology for the improvement of urban wind environment is still under exploration (Ng, 2009). Outdoor thermal comfort of human beings, indeed, is the consequence of the combination of urban morphology, urban ventilation corridor, wind and UHI phenomenon. During urban development, proper adjustments and modifications of urban morphology which will sequentially affect urban ventilation corridors, urban microclimate and outdoor thermal comfort, deserve great attention. There is a need of a guideline for the on-going development of cities, by providing instructions on how to modify urban morphology.

However, the analysis of urban morphology-ventilation performance, as well as their impacts on wind environment, UHI effects, and outdoor thermal comfort is quite complicated, which makes it difficult to use the wind to mitigate UHI effects in general, and assessment of urban ventilation cooling potential. Moreover, it is not easy to organize such high degrees of complexity among these aspects. To address such challenges, there is a need for a holistic and comprehensive methodological framework. To support this, therefore, this chapter aims to develop a methodological framework that can synthesize urban morphology, ventilation performance, UHI and outdoor thermal comfort. Through this methodological framework, the following questions will be addressed: (1) What are the relationships between urban morphology and urban ventilation performance, especially at the local scale? (2) What are the primary urban morphology parameters affecting the efficiency of urban ventilation? (3) What are the triple influences of urban morphology, urban ventilation and UHI effects on outdoor thermal comfort? Overall, the development of the methodological framework in this chapter is meant to inform urban planners with basic knowledge on modifying urban morphology to enhance urban ventilation for UHI mitigation in urban planning and design.

2 Development of a Methodological Framework

There have been many studies on wind flow and pollutant dispersion while existing generic models cannot effectively show how these factors influence wind environment, UHI effects and outdoor thermal comfort simultaneously (Athamena, 2022; Javanroodi et al., 2018; Rohinton & Erik, 2006). To address such a research gap, a methodological framework is developed to model relationships among urban morphology, urban ventilation, UHI effects and outdoor thermal comfort within the context of real precincts, with complex buildings, streets and other construction configurations. The synthesized methodological framework requires multidisciplinary knowledge for its real application. To explicitly show connections between every component encompassed, a diagram is developed to reveal interactions of all components.

The development of the framework follows three key principles. First, the framework should be contextualized at the precinct scale. Second, the framework should be capable of characterizing precinct ventilation (Part a in Fig. 13.1). Third, the framework should be capable of guiding the assessment of the impact of precinct ventilation performance on UHIs and outdoor thermal comfort (Part b in Fig. 13.1). Modification of section (a) leads to variations of wind, UHI effects and outdoor thermal comfort. The impact of Part (a) on Part (b) is the nature to explain causes and effects in the process of urban design for UHI mitigation. The framework is constituted by five elements: physio-morphological characteristics, external meteorological conditions, precinct ventilation performance, UHI effects and outdoor thermal comfort.

3 Dependence of Urban Ventilation Performance on External Wind Conditions and Urban Morphology at Different Scales

Urban ventilation, also titled city breathability, represents a process of air exchanges between inside and outside of urban areas, where ventilation efficiency assesses by its ability in providing urban areas with peripheral cooler air and removing airborne pollutants. Urban ventilation performance of a specific space is sensitive to both external wind and internal wind. The external wind at larger urban scales drives the internal wind, and the internal wind within a specific space is affected by the urban morphology. The behaviors of both external wind and internal wind vary with urban scale. The mesoscale and local scale winds are external wind conditions controlling urban ventilation performance at small scales. At the mesoscale scale, there are several types of wind such as seasonal prevailing wind, land-sea breeze, katabatic and anabatic wind. The prevailing wind of a city or region is controlled by the macro-scale wind and can vertically extend hundreds or thousands of meters relevant to atmospheric stability (Oke et al., 2017). The local scale covers a set of urban spatial scales including block, neighborhood, precinct and city. Beyond the penetration of mesoscale wind, some local scale wind (e.g., land-river

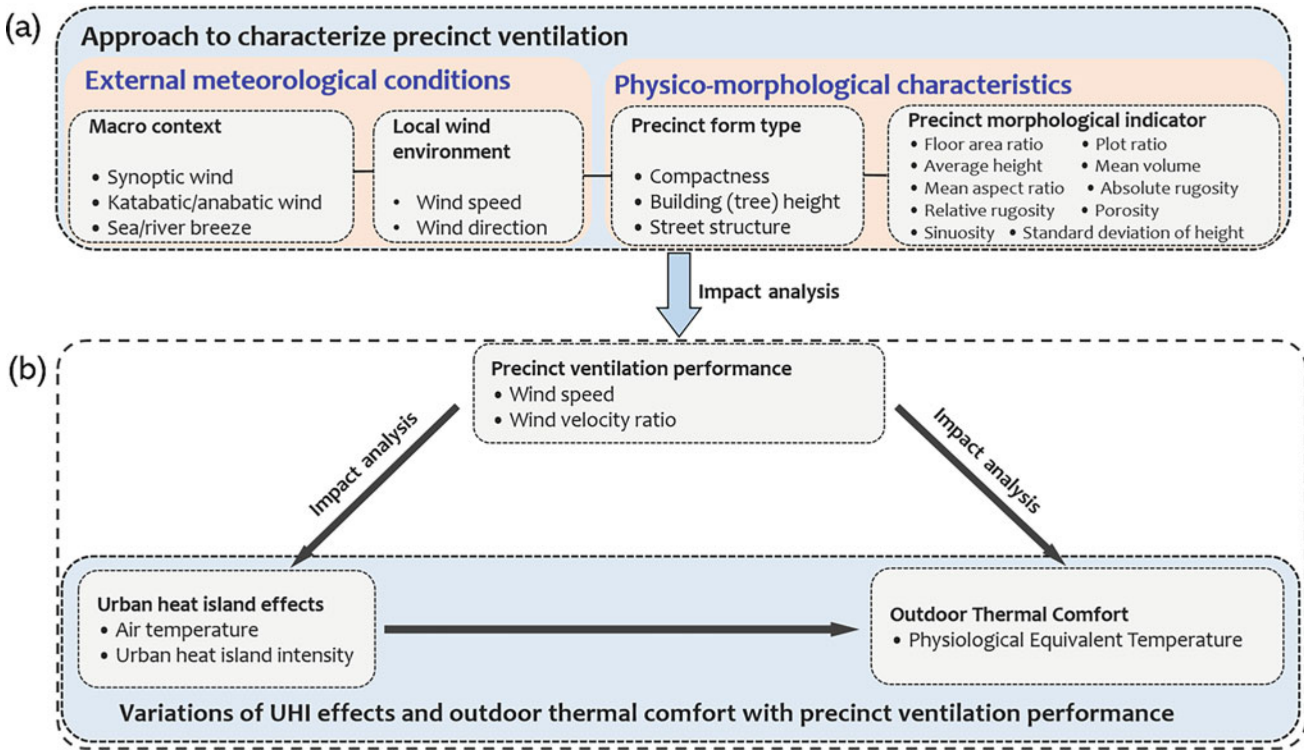

Fig. 13.1 A methodological framework of modeling relationships between urban morphology and local ventilation and their impacts on urban microclimates and outdoor thermal comfort

breeze, land-lake breeze, katabatic wind and anabatic wind) can be generated.

To guide the external wind into cities, it should be created based on major open ways, such as principal roads, interlinked open spaces, amenity areas, non-building areas, building setbacks and low-rise building corridors, through the high-density/high-rise urban morphology (Department, 2010). Urban ventilation corridors are robust to introduce wind derived from mountain, valley, seaside and rural areas into heated urban areas and provide them with cool sources. For example, Germany has successfully guide to hillsides wind down to central urban areas and Japanese government has launched a project to detect air paths that can bring sea breezes into downtown areas. Urban ventilation corridor can be conceptually deemed in functions of building and street, namely

$$\text{Ventilation corridor} = f(\text{building; street}) = (\text{building height}, \text{building number}, \text{building volume}, \text{building footprint}, \text{building frontal area}, \text{building array}, \text{street length}, \text{street width}, \text{street orientation})$$

The wind at the small scale focuses on the micro scale (e.g., building, street) and local scale (block, neighborhood, precinct). The mechanism of approaches that guide cool air derived from rural or seaside areas into urban areas lies in reserving sufficient voids and spaces. Urban canopy layers can be treated as porous media, according to a macroscopic model developed by Darcy. It demonstrates overall urban ventilation efficiency which is a function of interactions between clear-fluid region and porous regions, as well as porosity and permeability of porous medium, while air flow patterns around each building and street cannot be explicitly shown (Hang & Li, 2010). Urban morphology is critical to urban ventilation performance, primarily at the micro and local scales. Relationships between urban morphology and urban ventilation have been carried out extensively, from isolated buildings, two-dimensional street canyon, three-dimensional street canyon, a cluster of buildings, idealized cities with aligned several row column buildings and real built areas. Nevertheless, morphological characteristics at the neighborhood and precinct scales are too complex to fully quantify their ventilation performance. Therefore, studies of the ventilation performance of neighborhoods and precincts are mostly case-specific. For example, Blocken et al. (2012) studied the wind environment of an educational precinct in the Netherlands and Antoniou et al. (2017) numerically assessed the wind environment of a compact precinct in Nicosia, Cyprus. To understand the relationship between urban ventilation and urban morphology, the identification of key morphological characteristics is essential.

4 Impacts of Urban Morphology on Urban Heat Island Effects

Through local climate zone defined by Stewart and Oke (2012), it is found that surface structure, surface cover, building density and height affect UHI effects over precincts and cities. Compact building layouts undergo severer UHI effects, but with the increase in tree cover proportion, the UHI intensity reduces (Stewart & Oke, 2012). Land use type has profound influences on urban microclimate, especially its spatiotemporal patterns that can significantly affect UHI distribution and intensity (He et al., 2019). Humans use land in several ways, including residential, commercial, industrial, institutional, airport, park, agricultural, recreational, water and open space, etc. Typically, diurnal UHI intensity in Singapore decreased in the order of industrial, commercial, airport, residential and park, while the pattern of nocturnal UHI intensity varied, with decreasing UHI intensity in the sequence of commercial, residential, park, industrial and airport (Kardinal Jusuf et al., 2007). Artificial land use types including commercial, residential, industrial, transportation covered by concrete, cement and asphalt are contributable to UHI formation, while natural land use types such as water, park, agricultural and open spaces have strong cooling effects (Wong & Yu, 2005).

Physical composition and characteristics of land elements on the Earth's surface, such as vegetation, soil, concrete, asphalt, water, etc., playing a significant role in altering urban thermal balance, because of some possible variations in changes in evaporation, transpiration and heat flux on the ground surface. The diurnal UHI intensity decreases in the order of bare concrete cover, lawn, water areas, woods or the shade of trees, but nocturnal UHI intensity basically reverses where the lawn is the coolest cover (Huang et al., 2008). Impervious surface area (ISA) represents the surfaces that water cannot infiltrate and are mainly related to building roofs, and transportation, like streets, highways, parking lots and sidewalks. It is an important indicator of ground surface temperature, for most higher ISA percentage is responsible to intensifier UHI effects. For pervious surfaces, however, they are contributable to UHI mitigation, and their effectiveness is a function of vegetation types. Trees are more effective than grasses for the formation of tree shading and more moisture (Stone & Norman, 2006).

Solar radiations are mainly stored and re-radiated in urban areas due to massive construction material and canyon effect, which is more relevant with taller buildings (Arnfield, 1990). Sky obstruction (expressed by sky view factor, SVF, the ratio between radiation received by a planar surface and that from the entire hemispheric radiating) directly traps heats absorbed from the sun and consequently the net radiation (Oke, 1988). Urban morphology affects SVF and then UHI intensity, because of balances between optimized building space, optimized building form and SVF (Hu & Xue, 2016). But density layout (floor area ratio, FAR) is determined, the potential of using building form to adjust UHI effects is small and fixed. Among relationships between building density (FAR, BSC, Open space ratio and building layer), where 25% BSC is the most contributable factor to mitigate UHI effects (Wei et al., 2016). Apart from building density, building height is another indicator affecting ambient temperature. Comparatively, built-up areas with low-rise buildings suffer from a less severe UHI intensity (Stewart & Oke, 2012). When regulating ambient temperature, 10 m' building height increase can aggravate UHI by 1 °C (Perini & Magliocco, 2014).

Street canyon is the basic structural unit to study UHI effects in urban canopy layer for it controls net radiation. Origin of total heat that can disturb canyon thermal balance is solar radiation absorption generated by multiple reflection, reduction of turbulent sensible heat due to shelter effects and reduction of long-wave radiation loss (Oke, 1988). Canyon forms such as geometry and orientation are the main factors affecting its net radiation and then temperature. Concerning geometry, canyon width (W) and flanking building height (H) govern the amount of net solar radiation getting into the canyon, and the formation of shading area. This process depends on building heights, seasons, latitude and altitude. More importantly, during the nighttime, the aspect ratio (H/W) controls loss of long-wave radiation, which is generally characterized SVF. A lower SVF, the primary reason for nocturnal UHI effects, means smaller space opening to the sky, like a closed or semi-closed space, trapping heat in canyons (Oke, 1988). Canyon orientation also influences its thermal balance, for it determines whether vertical and horizontal surfaces are directly exposed to the sun (Oke, 1988), and then it determines potentials of adjusting H/W for UHI mitigation. In E–W direction, although canyon is deep enough, it is still hard to mitigate UHI effects because of limited shading, while in N–S direction, UHI effects can be reduced when H/W reaches two (Ali-Toudert & Mayer, 2006).

5 Impacts of Urban Microclimate on Outdoor Thermal Comfort

Outdoor thermal comfort that is the condition of the mind in which satisfaction is expressed with outdoor thermal environment should be further evaluated. This condition, an interaction result of physical, physiological, psychological and other factors, is determined by the level of activities people do and mostly the microclimate (Chen & Ng, 2012). The variation of urban morphology leads to the changes of wind environment, temperature as well as relative humidity in precincts. It is assessed by two indexes, including subjective thermal comfort and physiological equivalent temperature. Impacts of all urban morphology, wind environment and UHI effects are tested in various scenarios, e.g., tree shading area, solar exposure, street canyon, since, for instance, shading and no shading scenarios can generate direct influences on solar radiation absorbed by human bodies, and then affect outdoor thermal comfort (Lin et al., 2010). Windy and calm conditions are also considered since wind can enhance the water evaporation, possibly alter humidity conditions. In general, it is deemed that outdoor thermal comfort will undergo triple impacts of urban morphology, urban ventilation and UHI phenomenon, if urban morphology is modified. Through the scenario analysis and comparative analysis, the best situations that boost the most potential of wind can be obtained.

6 Conclusions and Implications

This chapter develops a methodological framework to facilitate the understanding of how urban ventilation influences UHI effects and outdoor thermal comfort, this study develops a framework for analyzing precinct ventilation and its impact on UHIs and outdoor thermal comfort. This framework is supposed to include five components including external meteorological conditions, precinct morphological characteristics, precinct ventilation performance, UHIs and outdoor thermal comfort. This framework is theoretically meaningful to reveal (1) the combined impacts of physio-morphological characteristics, external meteorological conditions on precinct ventilation performance, (2) the co-impacts of urban physio-morphological characteristics and precinct ventilation performance on UHI effects and (3) the associated impacts of urban ventilation performance and UHI effects on outdoor thermal comfort. This chapter provides a reference for precinct ventilation analysis and the analysis of the impact of precinct ventilation performance on UHIs and outdoor thermal comfort. Moreover, this chapter presents implications for urban planners and designers for using wind to cool cities:

1. External meteorological conditions include large-scale wind background and surrounding wind environment. Large-scale wind background includes seasonal prevailing wind, sea/river/lake breeze, katabatic/anabatic wind and the combination of these wind. Seasonal prevailing wind is a form of large-scale atmospheric circulation prevailing in a specific season. For areas near a sea/river/lake, sea/river/lake breeze can occur when there is a sufficiently large land-sea/river/lake temperature difference. Katabatic/anabatic wind forms on the fringe of mountainous areas when the hill-valley temperature difference is sufficiently large.
2. Surrounding wind environment consists of wind velocity and wind direction, forming the nearest boundary conditions of precincts. External meteorological conditions should not only include wind conditions, but also air temperature and relative humidity. Wind direction can potentially indicate the location from which the wind originates and reveals the temperature and relative humidity of the approaching wind.
3. Urban morphology identifies varieties of relationships among extremely complex objects or parts at different scales across building, street, block, neighborhood and city. Accordingly, urban ventilation performance varies with urban scale. Precinct ventilation performance refers to the wind or airflow motion within precincts. Precinct ventilation performance is the joint result of external meteorological conditions and precinct morphological characteristics. The wind direction helps in understanding the airflow regime within a precinct, while wind velocity and the wind velocity ratio quantify the ventilation performance within precincts.
4. UHI effects are mainly caused by the modification of land surfaces, where the modification of the land surfaces intervenes urban ventilation performance and solar radiation, representing the variation of convective and adventive heat transfer and solar heat incidence. Namely, urban morphology plays two-fold roles in UHI mitigation, namely, wind-induced UHI mitigation and urban morphology-induced UHI mitigation. Outdoor thermal comfort is the condition of mind that expresses satisfaction with the thermal environment to outdoor spaces, is assessed by subjective thermal perception and physiological equivalent temperature, where urban ventilation performance, temperature and mean radiant temperature are the drivers to outdoor thermal comfort variations.

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Istanbul; The Planning of Residential and Industrial Areas in the Process of Transformation into a Sustainable City

Hülya Coskun

Abstract

This research puts forward İstanbul's problematics as one of the largest Metropolitan in the world and the process of paradoxically the transformation from a historical city to a sustainable city. The aim of this study presents an updated dialogue about Istanbul's problems today which was changed to the mass agglomeration by the overpopulation and the examination of determination of "residential areas" and "industrial areas" in the context of sustainability. Even though recent public popularity of sustainability that initiated in the last quarter of the twentieth century but awareness of the people of Istanbul would take long years. Industrial zones that developed on the outskirts of the city for many years interwoven with slum areas, (gecekondu) where the worker's factories lived right next to it, and densely formed a wide hinterland that defined the borders of Istanbul today. Furthermore, Istanbul had to deal with inner problems in years such as natural hazards, earthquakes, and migrations which was triggered the housing problem. Even though many research on Istanbul city it was observed that the previous research did not involve the issue of sustainability in the context of "industrial areas" and "housing" was examined as separated matters lacked the integrative link within recent problematics and consequences. Recently in the new and innovative design, the discursive, and practical contexts in the climate change, some old urban planning techniques were came-back in urban planning dialectic as the new research object. These old discursive ideas and old zones (zoning) method based on separating "industrial", "residential", and "green" areas since the beginning of the twentieth century became major criteria again in the research for future planning of the cities. Establishing an updated historical connection between French architect-planner Henri Prost's Paris and Istanbul Master plans and his previous zoning planning principles which were used in these plans to determine "residential" and "industrial" and "green areas" was examined. Istanbul city re-examined in this study within a new perspective with a method based on multiple morphological and epistemological identifications also included old planning techniques and innovative methods.

Keywords

City planning • Industrial areas • Istanbul • Residential areas • Sustainable design • Zoning

1 Introduction

Recently in the new and innovative design planning, the discursive, and practical contexts in the climate change, some old urban planning tools and techniques were came-back in urban planning dialectic as a new research object. These old discursive ideas and old *zones* (zoning) methods used in this research based on separating "industrial", "residential", and "green" areas since the beginning of the twentieth century became major criteria again in the use of the research for future planning of the cities. Today's Istanbul city's hinterland was formed in long years with industrial areas that developed on the Haliç Heights (Golden Horn) and out of the antique city walls interwoven with slum areas, (gecekondu) the worker's houses built in practical way popped up next to factories they worked in.

This research focussed on sustainability, which has recently become more critical problematic for the cities development, and in this context, the planning of residential, and industrial areas in Istanbul city, in particular. In the twenty-first century, "sustainability" became a significant matter in the world, so the subject was updated and examined in order to create new awareness, focussed in the last

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twenty years with the problems of Istanbul in particular which was transformed into the mass agglomeration of people.

Sustainability has been identified with different labels since the 1990s, allowed us to think that environmental issues referred to such as green design and ecological design were determined as sustainable architecture today. Although, in 1996, Istanbul Conference had not created awareness so far about climate change for both the public and local governmental institutions as expected in Türkiye that echoed much more awareness in the world started with the Conference, in Rio, Brazil, 1992. After these series of conferences, the world encountered new, urban planning dynamics with the problematics based on human well-being, sustainability, and resilience. The problems of developing cities were still awaiting solutions in the world like Istanbul that now transformed into a mega-city with a 15 million population with increasing multiple problems. Changes in the urban and climatic effects which have been reflected in the present day were also intense and dramatic. Furthermore, some design paradigms needed change in the world at that time Istanbul were struggling with its problems such as massive inner migration due to industrialization. Finally, the process of producing more innovative solutions for cities found the opportunity to develop after the 1980s with the increasing of climate change concerns. The industrial-based cities became more problematic due to today's rapidly changing urban dynamics, especially the climate issues. The business, commercial, and industrial functions that were once seen in the central city have been dispersed in much more broad areas with entangled highway networks (Garreau, 1991; United Nations, 2007). In Istanbul, urban sprawl with "industrial areas" associated with inner and transnational migration, expansion of "residential areas" and highways continued to threaten green spaces and forests in the cities inducing the problematics.

1970s, was the milestone of the urbanization for İstanbul and the city continued to rapid development with newly developed factories and new housing areas for workers in the outer axis led to the extinction of green areas, creating a vicious living and working circle. Although the decentralization of industrial areas in Istanbul was foreseen at the beginning of the twentieth century, did not realize in practice and the city continued to develop uncontrollably, destroying green areas, forests for decades, especially after the 1970s, with the rapidly increasing factories and unplanned slum areas that emerged right next to them. Whilst Istanbul focussed on problems like in the other cities agenda with the recent climate change concerns such as planning sustainable, livable environment, and housing, the city had to involved inner problems in years such as natural hazards, earthquakes, and problems which depended on its location such as massive migration that was also triggered housing problem.

After the literature review regarding the previous studies on Istanbul, it was found that these researches were mostly based on a single discipline; the architecture, urbanism, planning residential areas, housing models, industrial areas, industrial buildings, sustainability, material choice, transportation, etc. However, they were not adopted multidisciplinary approaches as well as not updated the main problematic sustainability and climate change. It was observed that the previous research was not examined the issue of sustainability in the context of industrialization and residential areas considering as separated matters lacked the integrative link with the other disciplines within recent problematics and consequences. Due to significant deficiency observed in the research area, the "residential areas" and especially "industrial areas" were specified in the context of sustainability that was nearly no research was achieved on Istanbul. Thus, the subject of this research established on "industrial areas" and "residential areas" in the context of sustainability adopted a multidisciplinary method as well as the a research dialogue needed to reconcile mixed disciplines that brought them together.

The goal of this research determined to eliminate the deficiency in this research area and the idea of the subject was presented with a new and multidisciplinary discoursive approach as well as the recent problems of Istanbul were examined and updated. Although it was an old planning method based on traditional *l'Ecole*, (School) French School of Urbanism, to find solutions to the problems of the today's cities both in theoretical and in practical, Prost zoning plans might be use as the research object again also the other old planning tools to provide innovative solutions for today's cities. The zoning plannings used to establish the main axis of this research maintained a planning dialectic, on sustainability. This study aimed to centre the research subject the planning of "residential" and "industrial areas" and "green areas" in the context of the sustainability and future planning of the city. H. Prost's Paris, PARP, (*Le Plan d'Aménagement de la Region Parisienne*), (Development Plan of Paris Region) *zones* (zoning) plan based on the principles of separation of "residential" and "industrial" areas major criteria for specify zoning plans in Istanbul were examined. The previous zoning principles used to specify "residential areas" and "industrial areas" as well as "green areas" would contribute to the future development of Istanbul and other cities in the context of the sustainability.

Although climate change problems in Istanbul ignored for many years, today, the impact of densely urbanization in the city has started to emerge with uncontrolled developments and the residential areas and industrial facilities developed towards green areas, forest areas, and even water basins. The residential areas and industrial facilities previously located in the city centres in the historical past have started to decentralize towards the city's peripheries and outskirts creating a new problematic of threaten the green areas and deforestation.

The major concerns of climate change in the agenda of the recent Glasgow Summit, 2021: coal use, deforestation, and lower emission were highlighted issues once again (CNN, 2021). The need for the separation of new residential and industrial areas according to specifically prepared zoning plans by governments or local municipalities emerged once again. The major characteristics of the Mediterranean climatic zone were changed due to threats of intense urbanization, increasing housing, industrial areas, and the highways that induced carbon emission and some problems emerged as future life-threatening climatic issues of next years. Additionally, the recent Istanbul Mayor drew attention to the also drought and water scarcity after the Glasgow Summit as newly emerged issues.

Some suggestions and the measures were already taken, and the new laws and regulations were determined regarding agreements in the context of agenda 21 with the recent studies and increasing interests, more recently even though some steps of the state and Municipalities or private sector but these measurements did not address properly the problems far from producing real solutions in practice. Another trajectory of the issue was how these suggestions would be implemented, which was identified as another problem considered as an indicator of increasing interest.

2 Problem Statements

The research presented the following themes redefining the problematic: the city's current problems emerged from migration, and housing problem which was also related and accelerated by migration. Ironically, the increase in industrial areas intertwined to each other, also increasing population growth and housing shortage. Arranging new residential areas specifying the potential development axes of the city can be determined, and these can be brought under control. In this context, the following sub-headings have been determined as the main problems.

3 The Methodology

The research was focussed on a detailed analysis of the main problematic the planning of "industrial areas" and "residential areas" from the beginning of the twentieth century and the transformation of the city in years in the context of the climate change and sustainability. The need for a multidisciplinary research approach ranging from city planning to architecture the research axis was prepared as well as the recently updated studies on sustainability.

In order to examine the subject analyzes started to the concentration of H. Prost's Paris, PARP, *zones* (zoning) plans and the principles of separation of "residential", "industrial", and "green" areas as major planning criteria of zoning plans in used in Istanbul Master plans were examined. First Istanbul zoning plans prepared by H. Prost also played a significant role in the development of the city for many years, and the other plans would be built on his principles.

The subject was examined since the beginning of the twentieth century, some old urban planning methods of the early twentieth century, like zoning plans, laws, and regulations recently came-back in the context of sustainability. Some of the laws and regulations made at that time for Turkey, Istanbul were still valid. The planning of Istanbul can be divided into certain periodical phases on these issues, including the main problematic of housing, industrial development and the city's transformations into a sustainable city in the future. Figure 1 Istanbul Master plans first prepared by H. Prost at the beginning of the twentieth century were examined and compared with the recent plans. The planning process of the city was also analyzed by dividing it into 3–4 development phases below.

- 1980s, it was known as a period when climate change issues first became problematic, in the world. Also, the analytical researches are carried out, new innovative design methodologies in order to achieve the environmental design. This period was when the subject was not well known for the city of Istanbul, and its effects were not clear.
- 1990s, it was a period in which sustainability was first recognized with the Earth Summits, held in Rio de Janeiro, in Brazil, 1992. It later began to known with the conference first time was held in Istanbul, 1996. Although, 1996, Istanbul Conference was expected to create more awareness, but did not echoed much.
- 2000s, although sustainability was gained importance in the world as a conceptually more specific issue, however, it still not arouse enough interest in Istanbul.

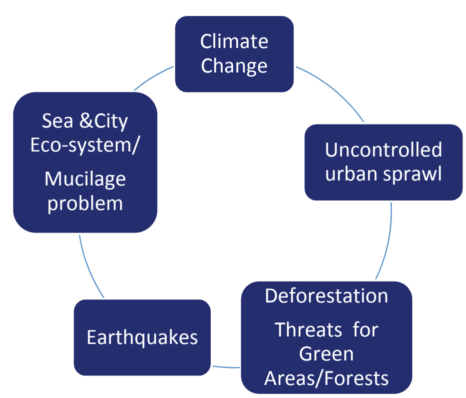


Fig. 1 Main problematics and threats for Istanbul city eco-system

Because just after the 2000s, the city's agenda was almost entirely focussed on the earthquake issue, and regeneration projects were started and carried out rapidly in nearly all regions in the city.

- 2010s, in this period, the chaotic situation still continued in the city experienced the late 1999, earthquake in Istanbul, and the city had to concentrate on urban regeneration projects rather than climate change and sustainability issues. Also focussed on macro projects such as planning an eco-city in Küçükçekmece district, in the west axis or large-scale regeneration projects in Kartal district, in east axis, however, these projects have never been implemented. No action plan was implemented in the context of sustainability yet, and it was a period in which uncontrolled planning in the city continues towards northern forest areas and water basins.
- 2020s: from the Habitat-II, City Summit held in Istanbul, UN Conferences have ensured the acceptance, and spread of Local Agenda 21, the local projections of the principle of global partnership in the world and the strong international foundations of the aforementioned process formed. All activities expected to be carried out by local municipalities were determined as Agenda 21 in Türkiye, Istanbul.

4 French Planner Henri Prost's, Berlin, Paris, Zoning Plans; Dividing Industrial and Residential Areas

The idea of separating "industrial" and "residential areas" in Istanbul, first emerged in the early twentieth century with Paris zoning regulations by French architect-planner Henri Prost. H. Prost and his colleagues prepared some *zones* (zoning) and development plans, PARP, *(Le Plan d'Aménagement de Region Parisienne*) (Development Plans for Paris Region) (Prost, 1949), (Merlin, 1991, p. 60). Figure 2 H. Prost predicted the problems of developing an industrial city at the beginning of the twentieth century which until not any knowledge about the city's limits (Frey, 2011, p. 373).

Due to problems of the heavily industrialisation in Paris city, in 1910, E. Hénard proposed "Project Arrangement for Paris" planning the city with systematically organized regions. In the Paris Regions plan, all activities were transferred to urban matrices through *zones* (zoning) regulations. In 1910, this method first time introduced by E. Hénard, in a German journal of *La Revue Der Stadtebau* (Urban Vision) as *La System General du Reseau de voirie de Circulation pour le Centre de Paris* (The General System of the Road Circulation Network for the Paris Centre), (Bruant, 2011, p. 247). Indeed, E. Hénard's suggestions played an important role in solving the problems that occurred with the industrialization of Paris. on that time.

According to H. Prost's lecture notes in *ÉSA, l'Ecole Spèciale d'Architecture, Paris,* (Special Architecture School) the subject of "Zoning and "*zones non-œdificandi*" (Specially Protected Areas) specified such as: new cities should planned within neighbourhoods, and the "green areas", "working - factory areas", etc., should be divided according to their characteristics" (Prost, 1934). The term "zoning" was a planning tool used at that time by two *l'école* (school); Le Corbusier, CIAM, and some French architects and urban planners (a Group of Architects did not adopted CIAM's ideals) (Table 1) .

Each "settlement unit" was determined according to the regional plan in the whole of the city "a factory building in cities, residential areas and high rise buildings should not be planned side by side. This would create chaos in the cities, and it might be eliminated by dividing the building areas into regions specialized in their own fields". (Prost, 1934). The areas were defined as *zones* (zoning) in the Paris plans, which also included green areas, playgrounds, and sports areas (together with areas such as housing, industry, etc.).

4.1 Istanbul, the Early Twentieth Century, H. Prost's Zoning Plans, Dividing Industrial, Residential and Green Areas

According to the Prost plans, the main planning principles were not concentrated on housing aimed to decentralization of the new industrial areas towards the out of the city walls, also close towns. Although the reasons attributed to H. Prost, the mainly linked to Türkiye's social-political and economic problems in that period. At the beginning of the twentieth century, the Republic of Türkiye was a newly established state which had come out of the First World War with debts, so the Turkish economy was far from providing the capital accumulation that required modernization (Tekeli, 2002, p. 158). Between the two world wars, with the statist politics of the 1930s, the country's limited resources were preferred to devote to industrialization instead of the allocating of housing by the state (Çoban, 2012, p. 78).

Istanbul developed and transformed almost half a century with the newly specified industrial and residential axes in accordance with Prost Master plans. In this period, the industrialization process of the city was not very effective in urban planning and industrial facilities. Some of the old, existing facilities from Ottoman period which were first appeared in the Historical Peninsula along the Haliç banks: *Haliç Tersanesi*, (Marine shipyard in the Golden Horn), *Santral* (Powerhouse), *Feshane* (Cloth factory), Cibali Tobacco factory, or towards to Bosphorus shores: Beykoz shoe factory, and Paşabahçe Glass factory continued to be used.

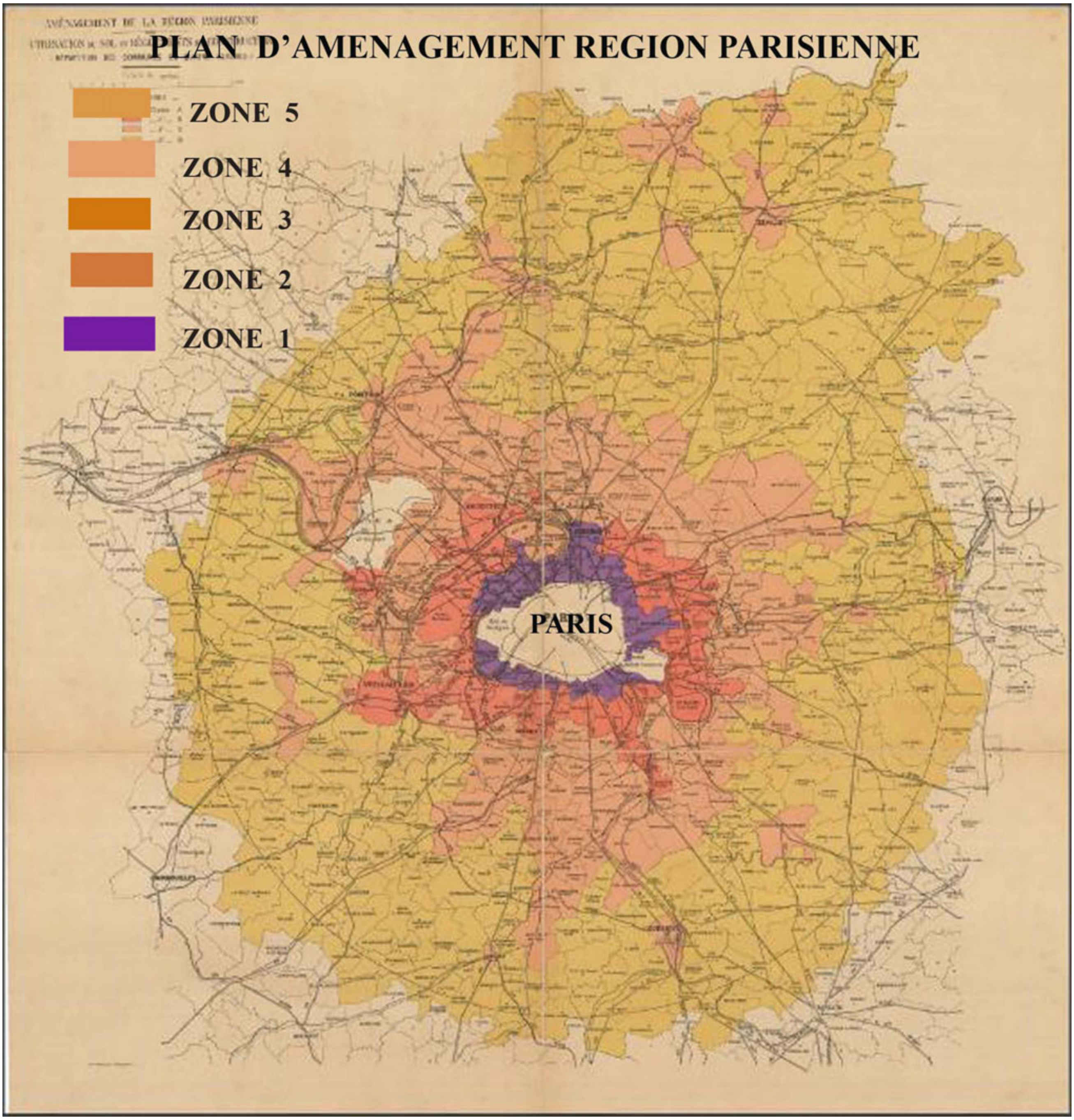


Fig. 2 Paris, Zoning Plan, 1934, French Architect-planner Henri Prost, PARP, (*Le Plan d'Aménagement De Region Parisienne*) (Development Plan of Paris Region) first applicated in Paris later in Istanbul; divided industrial and residential areas. Paris centre (light-pink), *peripherie* (purple), out of city walls, *cité-jardins* (orange), industrial areas, beyond *villes-satelllites* (pink). IFA Archives, Paris

- Istanbul, the Early twentieth Century, Location Choices For Industrial and Residential Areas

From the beginning of the twentieth century, Türkiye was a country where the policies of the state rather than the private sector predominantly applied amongst the factors that would determine the location choices in industrialization. Although the Prost Istanbul Master plans were defined as a modernization plan, which was based on a balanced arrangement between "residential areas" and new "industrial areas". Figure 3 In the beginning, no sufficient data was available on the city's demographic and social structure, ownership, commercial, and industrial activities.

Table 1 The classification and general rules of dividing into as *zones* (zoning)

	The areas were defined as *zones* (zoning) in the Paris plans
1	Industrial areas
2	Business districts
3	Residential areas and quarters for all classes of people (workers, or the wealthy)"
4	Green areas
5	Playgrounds, etc.

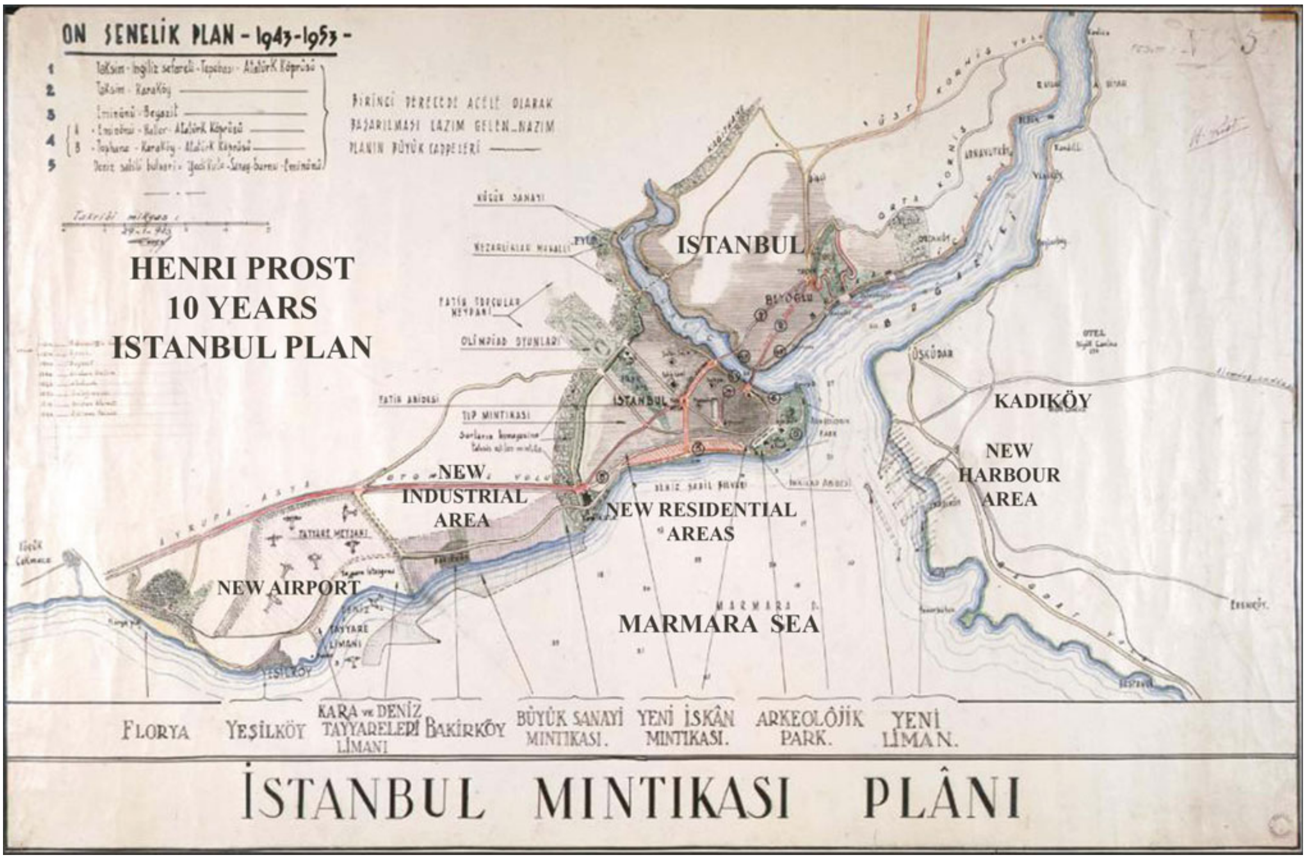


Fig. 3 Istanbul Zoning Plan, 1937, (10 years plan), French Architect-planner Henri Prost, first applicated in Paris, Later in Istanbul; divided industrial areas, left, (grey), residential areas centre (red), V*illes*- satelllites, far left, (blue), next to airport. IFA Archives, Paris

All preliminary researches included the information that would be necessary for the newly planned Prost Istanbul Master plans, and he would establish the Prost plan according to these data especially arranging of new settlements and industrial areas. Finally, Henri Prost centred the main idea rather than an "Expansion plan" (*Le Plan d'Extension*), as in this case of Paris city, and his Istanbul Master Plan had to established a "concentration plan" (*Plan de Concentration*). So, Istanbul Master Plan was organized around a spinal axis that would connect the newly developed residential areas in the north and central commercial districts (Bilsel, 2010a, p. 117).

Hence, the residential areas and production industrial zones were to be re-determined, and a transportation network was needed that would unite the regions to be located in these planned areas. Along with the main railway connection, three main ports of the city: Karaköy, Sirkeci, and Haydarpaşa Ports arranged to supply industrial materials to the Istanbul proposed as new industrial areas. Furthermore, the Yedikule and Bakırköy specified as new industrial districts that connected directly with the European Railway and *Türkiye Devlet Demiryolları* (Turkish Railways) that would be facilitated to development of the new industrial zones. Herewith, H. Prost accepted to relocate the existing old, industrial plants and industrial zone which was located along the Haliç (Golden Horn) from the nineteenth century due to pollution. Figure 4 The Prost Master plans for 10 years (10 years plan) determined that the "industrial areas" and "residential areas"

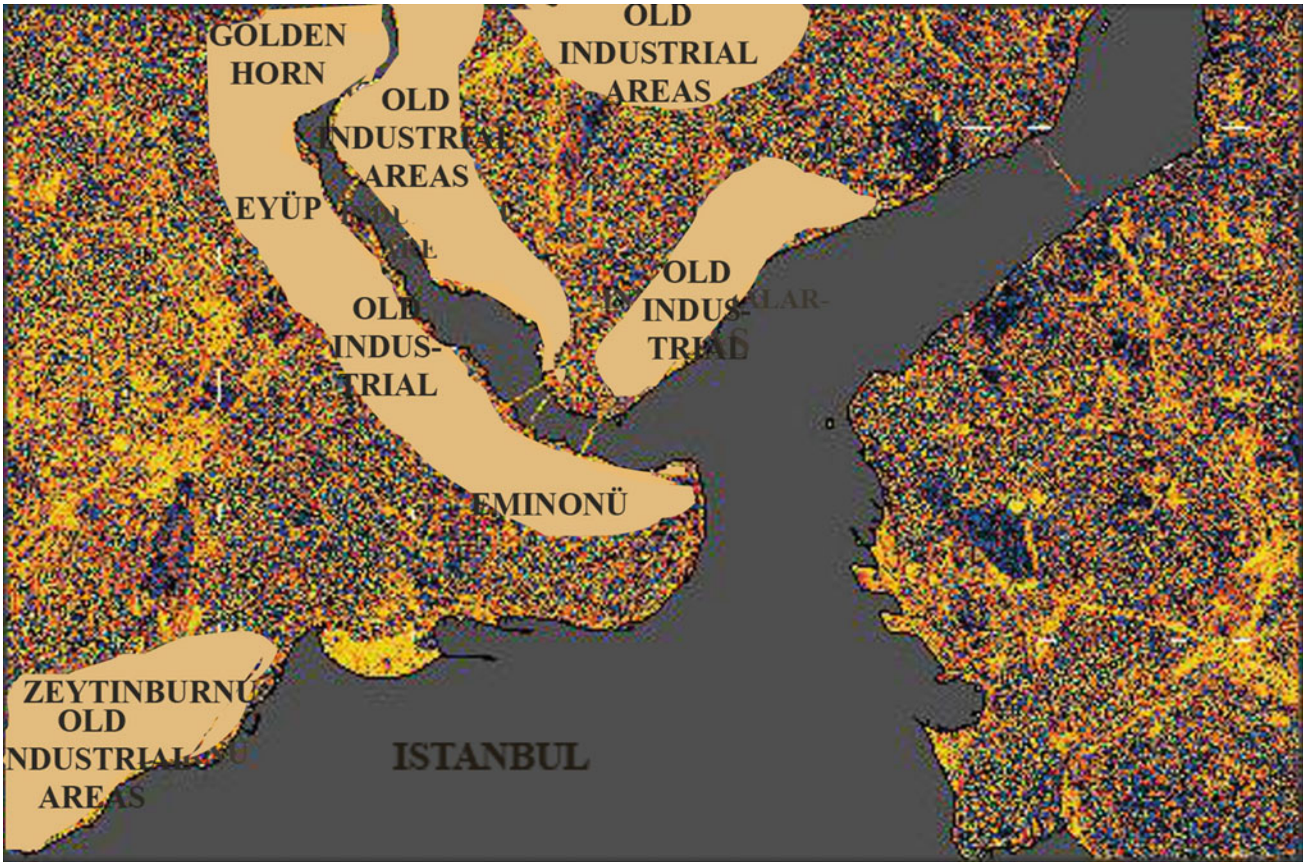


Fig. 4 Istanbul Plan, nineteenth century, old industrial areas developed along the Haliç Shores, (Golden Horn). (marked orange). Map, Anonym and redesigned by H. Coskun

first time woud be moved out of the antique city walls. Figure 3 In this period, industrialization was accelerated and the new Turkish Government preferred to spread industrial facilities whole country, also its effects on Istanbul were less due to this new political specification. Indeed, his decisions would play an important role in the fate of the city for many years centred on modernization, and industrialization problems and housing shortage in the city would not be seen as a problem until the 1960s.

There was a systematic hierarchy observed in Istanbul since the old, Ottoman period, whilst residential areas were planned within the ancient city walls, the industrial areas were always planned beyond it. Figure 4 With the Prost Master plans, this traditional arrangement was not interfered with and partially complied with. An exception to this would be the Haliç, (Golden Horn), the area recommended to be completely free of industrial facilities according to Prost Plans and newly opening housing areas in Historical Peninsula would be reserved for new *Bourgeoise* people. Of Istanbul Figs. 5, 6 and 7.

In this era, new facilities were not planned in Istanbul, and also the existing factories were recommended to move out of the city. Türkiye's economy in the 1923–1950s was based on agriculture and since the majority of its population lived in the countryside, not in the cities, urbanization and the housing shortage could not be mentioned until the 1960s. Therefore, in this period, migration and the demand for labour that would come from the rural areas of the industry was not yet seen.

- The Early twentieth Century, Industrial Zoning Laws and Regulations in Türkiye Still Valid

In 1935, when Prost arrived in Istanbul he was equipped with unlimited authorities, by the *Türkiye Cumhuriyeti* (Turkish Republican State) (The State founded by Atatürk), and he was even given the responsibility to make the necessary urban planning laws and regulations, as well as requested of preparing new Istanbul Master plans. H. Prost arranged the new laws and regulations for the planning of Istanbul by transferring from the originally French laws (Coskun, 2020). Similar to French Sanitation Laws, SHUR, (*Societé l'Hygiène Urban et Rurale*) (Public Health Advisory Commission) in France where significant institution making laws and as a legislative and controlling mechanism

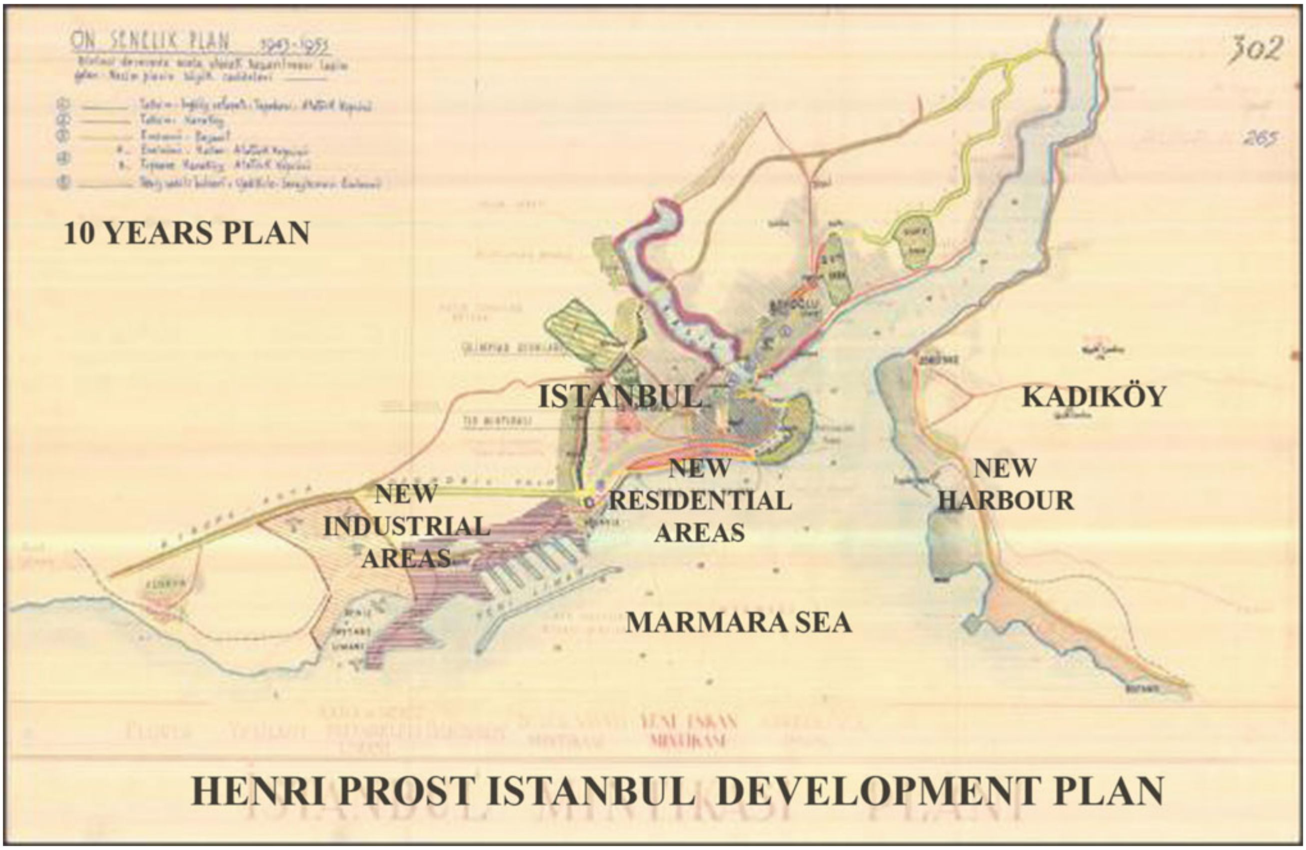


Fig. 5 Istanbul Zoning Plan, 1937, (10 years plan). French Architect-planner Henri Prost. The relocation of old industrial areas out of the City walls old, Haliç Shores (purple). New industrial Areas, (down, striped purple), in Bakırköy Coast, New Housing areas (red) in the Marmara Coast in the west axis. Plan, IFA Archives, Paris

(Rabinow, 1991, p. 251) a Turkish Sanitation law (*Hıfzısıhha Yasası*) were put into effect very short period.

Since the 1930s, Turkish Sanitation laws (*Hıfzısıhha Yasası*) similar to the French laws were significant determination of industrial zones in Türkiye still valid. These laws also included the arrangement of distance between newly developed industrial facilities and residential areas by permission by *Hıfzısıhha Yasası* (Turkish Sanitation Law).

5 Post-prost Period, After the 1960s, Transformation of Istanbul to a Metropolis

Development of the Istanbul city accelerated after the 1960s, with industrial zones and housing areas that were seen on the outskirts of the city out of the antique city walls. In the post-Prost period, in the 1950-the 60s, İstanbul city continued to choatic urban sprawl with internal and external dynamics triggered by internal mass migration that would be a main problematic in the following years of the city with the housing shortage. Indeed, in this period, the most important problem of the city would be immigration which was not foreseen during the Prost period. Ironically, as factories and industrial areas developed in the city, housing shortages would also emerge with immigration. In the late 1960s, the city's hinterland was defined as nearly 50 km area in a broader context, it was already extended towards close towns; Bursa, Adapazarı, Tekirdağ (Kuban, 2004, p. 414) due to execution of H. Prost's planning principles of decentralization of the industrial areas.

- Istanbul, After the 1960s, Historical Peninsula and Old Industrial Area Haliç (Golden Horn)

The development of the city was through the slum settlements with urban sprawl around the newly established factories for many years. As a pragmatic solution of people for the housing problem, the slum houses started to increase on the outskirts of the Historical Peninsula, on the Haliç (Golden Horn), Pera and also in Kasımpaşa districts next to the industrial areas and factories (Coskun, 2017a, p. 199).

The Haliç region (Golden Horn) as a early industrial areas interwoven with various factories in the Haliç banks and the slum areas, (gecekondu) the worker's houses built in a practical way popped up in next to them. The next to factories were on the Haliç (Golden Horn) banks of the

Fig. 6 Istanbul, Master Plan, 1937, French Architect-planner Henri Prost first applicated in Paris, later Istanbul; Historical Peninsula (left) Pera District (top), and Anatolian side (right), Residential areas. Plan, IFA Archives, Paris

Historical Peninsula and Pera regions, mostly unplanned areas which were built by people own without control of the authority with single or two-storeys poor quality housing patterns were taking place on the heights of these regions. After the 1960s, with the modernization projects, nearly, all Historical Peninsula constructed block by block using Prost plans by private constructors by used illegally to open city axis, roads, streets.

The low-income slum dwellings (gecekondu) where workers lived and the new factories densely developed around in these regions due to the lack of transportation network in the city at that time also its proximity to the port, which was vital necessary for the factories, mostly gathered around the Historical Peninsula, Pera, and the Golden Horn. At that time, the minibuses (cheap public transportation vehicles) were the only mechanism that served the whole city, such as the metro, train, and bus that minimized the transportation between the workplace and the workers' residences since the advanced transportation vehicles were not sufficiently existed in Istanbul.

The development borders of the city would go far beyond the limits which determined that with the rapidly increasing internal massive migration after the 1960s. Thanks to heavy industrialization and the slum buildings that the state tolerated especially after the 1980s, a population explosion occurred in Istanbul (Özbay, 2009). Henri Prost envisaged the industrial areas were moved out of the city borders towards to west axis of the city: Bakırköy, Zeytinburnu regions which were previously gathered around the Haliç region, the old antique harbour was known as Golden Horn, next to Historical Peninsula in the nineteenth century Figs. 4 and 8.

As foreseen in the Prost plan, industrial areas were decentralized and moved further away from the city or to nearby towns. The marine pollution, caused by industrial

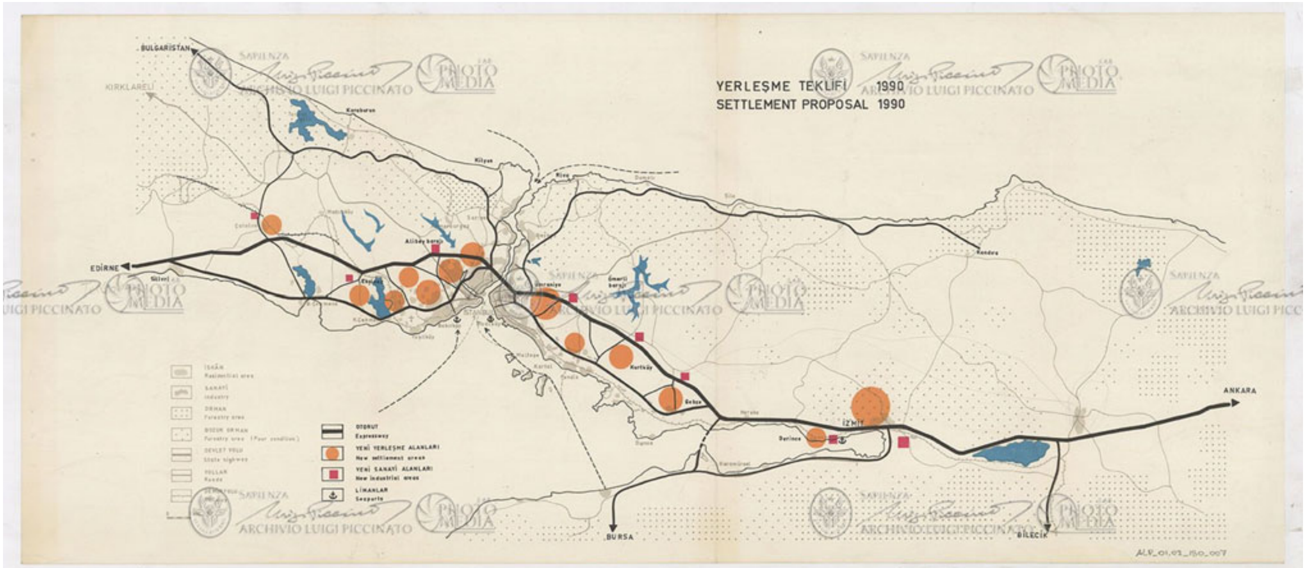


Fig. 7 Istanbul, Zoning Plan, 1955, (Prepared post-Prost, period) by Italian Architect-planner, Luigi Piccinato, Macro-city Plan, settlement areas development of the city with the new Satellite-cities. Plan, Archivio L. Piccinato. L' Universita Roma La Sapienza

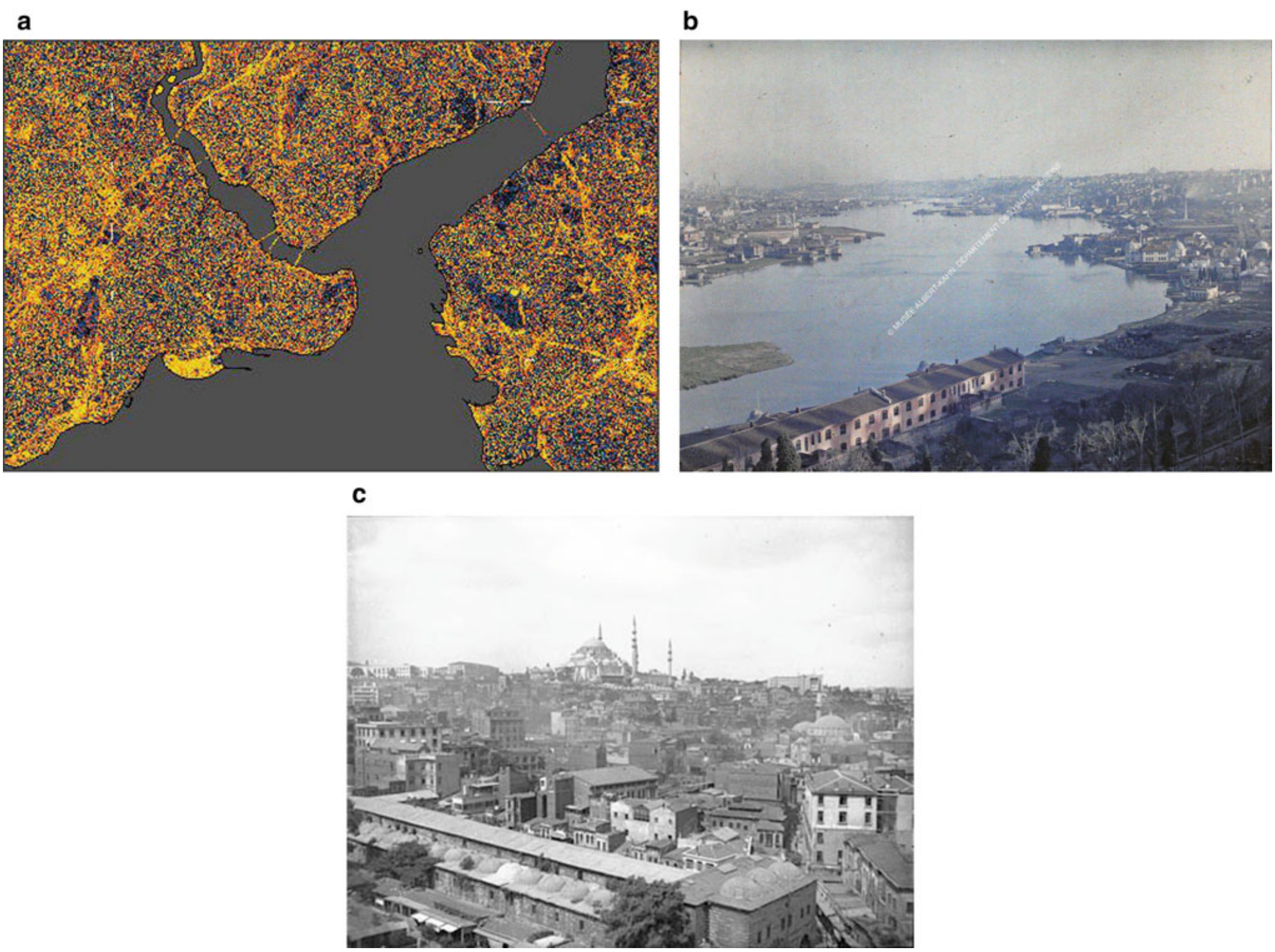


Fig. 8 Istanbul, nineteenth century, Haliç (Golden Horn), old, industrial areas along the Haliç Shores and workers houses and slum buildings (gecekondu). Photo, *Le Musée Albert Kahn*, Paris, H. Coskun Private Archive. Photo, (right), 1937, Istanbul Prost photographs. IFA Archives, Paris

wastes for years, was cleaned by the Mayor of the time, B. Dalan in the 1980s, and gained its relatively cleaner appearance today. The old factories on the shores of the Haliç (Golden Horn) are given a new function, and most of them were converted to museums, universities, etc.

- Istanbul, After the 1960s, European Side; New Industrial Areas and V*ille-satellites* (Satellite-cities)

Due to the decentralization decisions of the industrial areas previously envisaged in the Prost plan, new industrial facilities on a large scale were not opened in Istanbul during this period, but in the city nevertheless some facilities emerged belonging to small industries: leather factories in Kazlıçeşme, readymade factories in Bakırköy, Merter and automotive, etc. In the 1960s, on the European side, the city extended towards to west axis, in Marmara coastal-line, Avcılar, K. Çekmece districts with new residential areas were emerged next to new small industrial areas, attracting low-income workers (Coskun, 2021). After the 1980s, many of these industrial areas moved to Anatolian side: Tuzla, Pendik, etc.

Both residential and industrial areas in this period were previously foreseen by H. Prost's Master plans, and most of them were implemented during the Luigi Piccinato period. In the context of L. Piccinato's *Le Piano Regionale,* a (regional plan) "macro-plan" aimed to the development of the city with the new *ville-satellites* (satellite-cities) in the east-west axis, out of the city walls in the European side, Ataköy, Bakırköy district (Malussardi, 1993, p. 49). (Fig. 9, bottom) However, the development of the city was realized rapidly after that, and with the momentum created by the migrations, the city began to develop uncontrollably.

Since the transportation was insufficient, only by Bosphorus Sea Transportation Ships (*Şehir Hatları*) the, new industrial areas in Prost Master plans were still limited in the Bakırköy and Zeytinburnu Districts (Fig. 9, top and middle) and old factories along with the small Bosphorus villages; Istinye, (old Naval Shipyard), Paşabahçe, (old Glass Factory) and Beykoz Districts (old Shoe Factory) continued to their producing since Ottoman period.

- Istanbul After the 1960s, Anatolian Side; New Industrial Areas, and Residential Areas

As a new industrial area, the new *Haydarpaşa Limanı* (Haydarpaşa Harbour) of the city allocated from the Haliç region (old industrial area and Main Naval Shipyard) to the Kadıköy district as a new industrial enterprise complex with *Haydarpaşa Garı* (Haydarpaşa Central Train Station) and also custom area. Thus, firstly, the transfer of industrial zones on the Anatolian side took place, and the city would develop hastily with newly established factories in the industrial axis. After the 1960s, with the decentralization of the industrial areas developed far from the Haydarpaşa Port and region, towards to nearby cities on the east; Gebze, Kocaeli, etc., and on west axis; Çorlu, Tekirdağ, etc.

With the implementation of the industrial zones new residential, industrial areas and a Haydarpaşa port proposed by Henri Prost "*Le Plan de Côte d'Asie*" *Anadolu Ciheti Nazım Planı* (Anatolian Side Development plan), the juxtaposition of the port in this specific area would be suitable respect to the city in the Anatolian side (Bilsel, 2010b, p. 135). Also, he proposed new garden-city planning especially, in accordance to the Kadıköy region's main historical characteristic which was consisted with old, Ottoman Köşks (two storeys houses with gardens).

From the 1960s, in the Anatolian side shores, in the eastern axis developed with new French style, new *banlieues* along the newly constructed railway called *Banliyö treni* (Banlieue train) in Istanbul were connected to districts in the Marmara Sea Shores. In the Anatolian side, developments for middle-class people in the districts such as Kadıköy, Suadiye, Bostancı, Küçükyalı, İdealtepe, Maltepe, and Pendik districts were planned with "building-blocks" known as Le Corbusien concrete "point-blocks" along the railway like Parisien style *banlieues* (Fig. 10, bottom).

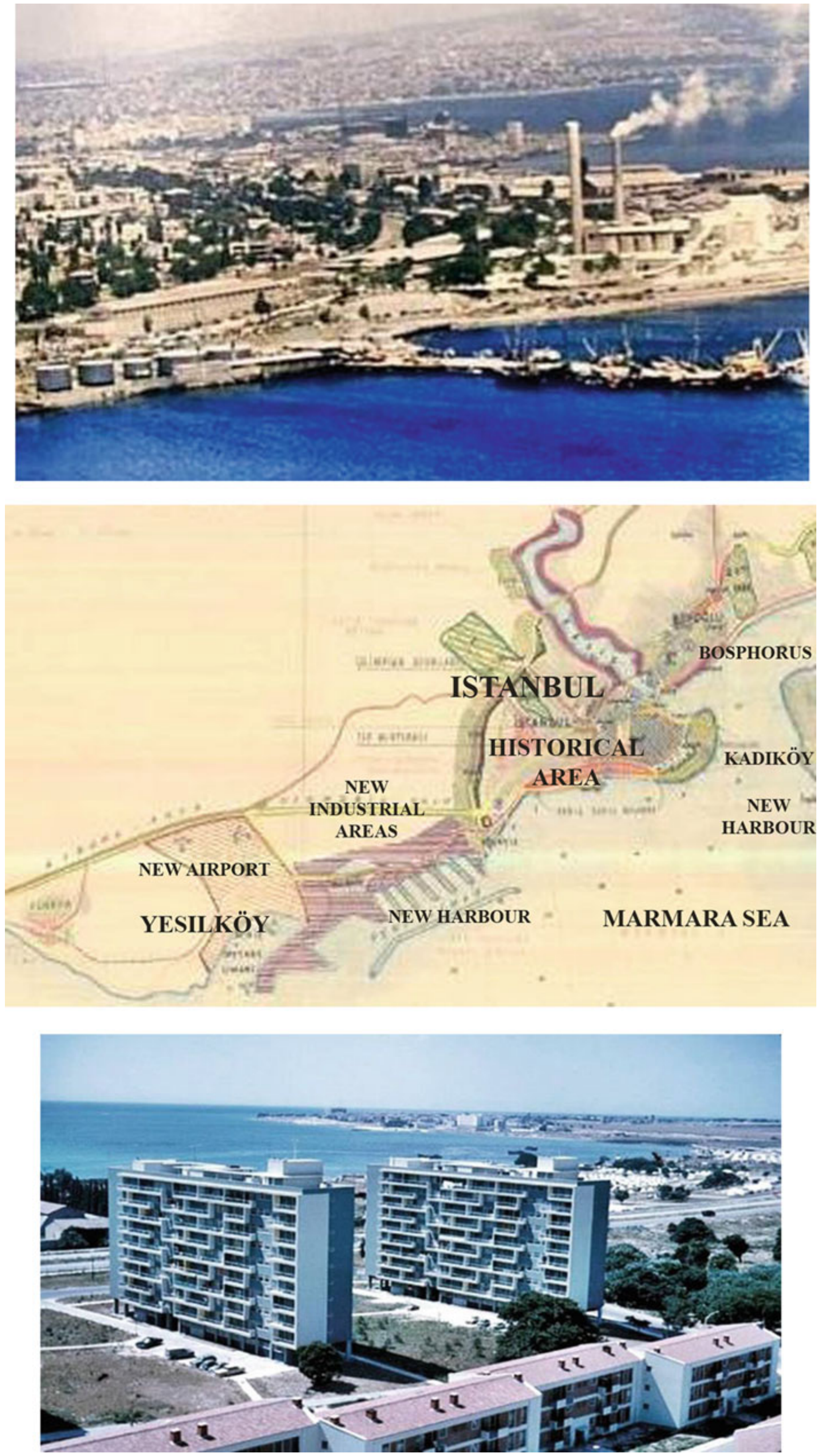
Also, the new slum suburbans mixed with industrial areas developed around the newly opened E5 Highway such as Ümraniye, Sultangazi, Başıbüyük, Kurtköy, etc. The unplanned development of the city was continued from the 1960s until the 1980s, which made Istanbul an uncontrolled metropolitan city. In the following years, the metro lines would also join this transportation network closely paralleled along the E5 Highway and up to Marmara Shores.

After the 1960s, the industrial areas were decentralized and transferred to the various close towns in the immediate vicinity of the Istanbul city: Izmit, Bursa, Tekirdağ, etc. (Iller Bank, 1972) extended the city's industrial hinterland to the close towns. The industrial axis developed along to first Gebze, Çayırova (Automotive, iron, steel, etc.), Yarımca (Oil refineries), Hereke (Cement factories) towns and then towards to Kocaeli, Adapazarı Provinces (Automotive, Train factories) next to Istanbul in the east as well as the developed with the transportation network to be realized within the very short period by train and highway road (Fig. 10).

5.1 The 1980s, the Sustainability, a New Planning Agenda; 1992, Rio, 1996, Istanbul Summits, to Solve Cities Problems

The cities as well as the Istanbul developed rapidly and uncontrollably and turned into mega-city according to United Nations (United Nations, 2007). This changed, both

Fig. 9 Istanbul, after the 1960s, European Side, new industrial areas along the Marmara Sea (top), V*ille- satellites* (Satellite-cities), Ataköy Blocks (right). Photos, Anonym. Prost Master plan, (down). IFA Archives, Paris



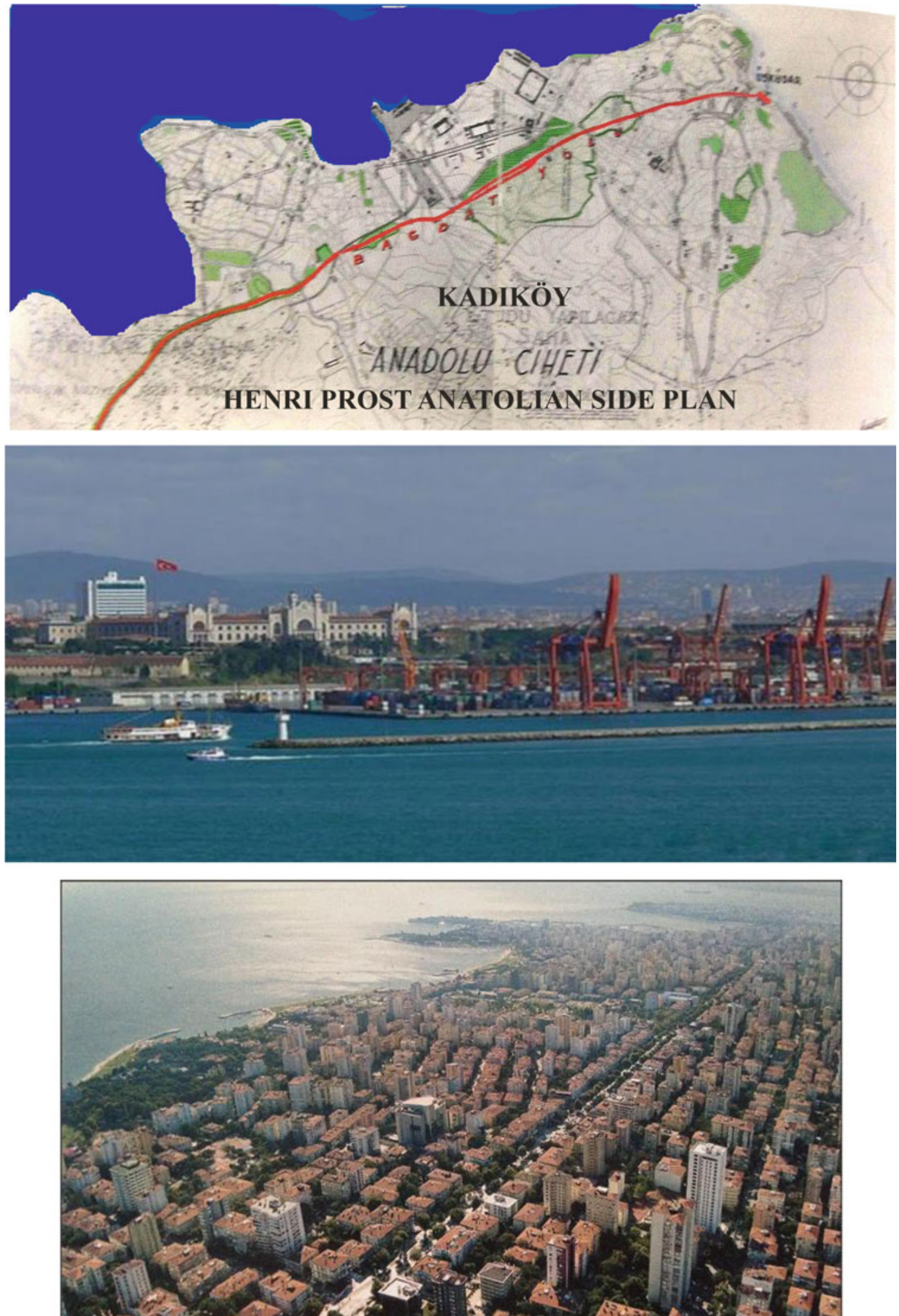


Fig. 10 Istanbul, 1935–1960, Prost Anatolian Side Master Plan (top), new industrial areas and Haydarpaşa Harbour Marmara Coast (down) *Cité-jardins* (Garden-cities), building-blocks, Parisien style *banlieues* (Right). Photo (left), Anonym. Photo (right), Meriç Sümer. Prost Master plan, IFA Archives, Paris

urban and climatic effects, which have been reflected the present day, were also intense and dramatic (Fig. 11). Even though, also some design paradigms needed change in the world at that time Istanbul was struggling its problems such as massive inner migration due to industrialization. Finally, the process of producing more innovative solutions for cities found the opportunity to emerge only after the 1980s with the increasing of climate change concerns. Indeed, the world

Fig. 11 Istanbul, Historical Peninsula, existing houses and building-blocks built in the post-Prost period according the Prost Master plans (block plan by Private Constructers) for new *Bourgeoise* people. Photo, C. Delgado

focussed on new and different urban planning paradigms freeding the old explanatory models beyond the well-known limits (Paquot, 2013, p. 122).

Furthermore, the excessive urbanization triggered by industrialization and the increase in the density of residential areas also threatened the green areas in the cities, and it was inevitable to take measures in the context of sustainable cities. The problems of developing cities were still awaiting solutions in the world like Istanbul that now transformed into a mega-city with a 15 million population. The cities developed under their urban landscapes as new model mega-cities, with strategic regulations orderly city planning (Lehmann, 2011, p. 245). Especially, the industrial cities had become more problematic due to today's rapidly changing urban dynamics considering the climate issues. The cities' functions: business, commercial, and industrial once seen the central have been spread much more broad areas and are now served by sprawling highway networks in peri-urban areas (Pickett et al., 2013, p. 11). Today, the urban sprawl of "industrial areas" and associated with the "residential areas" as well as the highways continued to threaten green spaces and forests in the cities still problematic.

In 1992, the first Earth Summit was held in Rio de Janeiro city, Brazil, by the United Nation debates focussed on "sustainable planning" would later be formulated as Agenda 21. 1992, Rio Conference extended to Habitat-II "City Summit" held in Istanbul, UN Conferences have ensured the acceptance and spread of Local Agenda 21. The 2030 Agenda for Sustainable Developments explicitly mentioned the goal 11, referred to the cities and making human settlements "inclusive, safe, resilient, and sustainable" environment and development operationalized sustainable plannings (Nocca, 2017, p. 3). Although the Earth Summit was held in Istanbul, had not echoed in city and city's planning in this regard a Local Agenda 21, and accepted the local projections of the principle of global partnership. The overpopulated mega-cities where sprawling by uncontrolled industrial and housing areas becoming a threat to existing green areas, forests, and urban ecosystems today new planning agenda of climate change put into effect.

- After the 1980s, Istanbul's Newly Changed City Dynamism: Industrialization, Migrations, and Housing Developments

With the industrialization and the slum buildings that the state tolerated especially after the 1980s, a population explosion occurred in Istanbul so that the number of people living in the city exceeded 10 million by the 2000s (Özbay, 2009). Although the city grew at a controllable rate until the 1970s, the development of the city after the 1980s was realized in nearly an unavoidable way, which led to much more dramatic developments industrial areas, residential areas. Istanbul turned into a choatic industrial city with slum areas (gecekondu), minibuses seen almost whole the city left no green areas to live in (Ünlü et al, 2010, p. 13). The decisions of the decentralization industrial areas were moved towards factories and nearby towns, with the problematic dynamism the industrial areas, small industries, continued to develop, as well as the migrations increased with the trigger of the industry.

After the 1970s, the inner migration problem developed in parallelized with intense industrialization, the parks, and gardens was planned in Prost Master plans which were replaced by newly constructed building-blocks very short period (Coskun, 2020). During the gradual transformation of the city, the existing urban settlements to the isolated interventions that destroyed the originally old, houses replaced them high-rise buildings not matched the existing urban fabric. In the 1973s, the opening of the new Bosphorus Bridge was a new milestone of the city altered to a real Metropolis (Tekeli, 2013, p. 358). (Fig. 12).

H. Prost previously specified the European side as the business centre of the city, whilst the Anatolian side transformed into a residential centre with the new motorway network and the newly opened Bosphorus Bridge. Thus, Bosphorus Bridge was completely re-organized the city's newly deveoped dynamism with new housing areas spreading the Anatolian side from the European side. Likewise, the envisioning previously H. Prost Master Plans, the Anatolian side of the city would consist of garden houses and low-rise residential neighbourhoods.

By the 1980–1990s, the liberal policies by Minister Turgut Özal and his free-trade economy were created a chaotic situation that accelerated the illegal house slum

Fig. 12 Istanbul, after the 1970s, the opening of the Bosphorus Bridge led to Metropolization of the city. Photo, C. Delgado

buildings (gecekondu) and the city's housing problems deepened. The government also encouraged the construction of high-rise buildings and slum areas with newly arranged laws. The free market economy and the liberalization led to the production of legal or illegal housing (gecekondu) in big cities (Erder, 2007, p. 274). Although Istanbul developed under the influence of liberal economies after the 1980s, the significant problem was overpopulation, housing rapid industrialization. With the newly changed agenda of the world with climate change, Istanbul city needed to focus on uncontrolled slum housing, led by liberal policies, and regeneration of houses with poor quality rather than sustainable planning.

5.2 The 2020s, Transforming Istanbul to the Sustainable City; Housing, Industrial Areas

- Foundation of Ministry of Environment and Climate, The Institutions Made Laws and Legislations

Since the scale of the city was at an interventional size, and then planning issue left the authority of specialized institutions *Çevre ve Şehircilik Bakanlığı* (Ministry of Environment and Urbanism). 2010–2013, the Istanbul Regional Plan purposed to preserve natural, cultural, historical values in Istanbul, the Marmara Region, protecting forests and water basins aimed to prevent the development axis of the city towards the Northern Forests, contradicted the Channel Istanbul (Keles, 2015, p. 89). With the declaration of the United Nations Organization, the leadership of the WHO, World Health Organization, a city must have livable characteristics regardless of the value it carries for people, and the importance of the urban eco-system for future generations would be very valuable. In the 2021, an important step taken by the state side on climate change, the name of the *Çevre ve Şehircilik Bakanlığı* (Ministry of Environment and Urbanism) changed to *Çevre Şehircilik ve Iklim Bakanlığı* (Ministry of Environment Urbanism and Climate) (Son dakika Haber, 2021). Today, state institutions have great authority determination of "industrial areas", also the "residential areas" were carried out some times by State institutions TOKI, and sometime, the Istanbul Municipality caused some complex management problems.

- Istanbul Today, Industrial Development of the City, The Policies of Specifying New Industrial Areas

Istanbul has reached a population of nearly 15 million today, due to the inevitable industrialization and the migration that triggered and the rapid increase in the number of slum dwellings. Although the dynamic structures of the city changed drastically, the measures taken were insufficient of increasing immigration, so transnational migrations were also seen in addition to internal migrations. The reason of the industrialization and housing increase for the city and the problems became unsolvable was the liberal policies of the 1980s applicated with extremely toleranced.

Despite H. Prost and L. Piccinato's plans for decentralization of industrial areas, industrialization especially small industrial enterprises in the city still continued to increase. In the years following the World War II, especially after the 1970s, the city rapidly industrialized and closed to become a workshop, factory-working class city and during this period, more than half of Turkey's manufacturing sector was located in Istanbul (Keyder, 2008, p. 511).

Although due some laws have been enacted, these laws have not been very effective in regulating industrial areas so far. Some laws used in in the arranging of "industrial" zones in Türkiye was the *Hıfzısıhha Yasası* (Sanitation Law) still in valid. According to this law dating from the 1930s, industrial areas were divided into three groups: 1st group, industrial facilities must be arranged far away from the existing residential areas. 2nd group industrial facilities that arranged by special permission by *Hıfzısıhha*, (Sanitation Laws) necessary to far away from the residences. The 3rd group was those no objection to their presence amongst the residences (Tekeli, 2009, p. 53). It was the environmental health effects of the selected production process, which was gained a lot of attention in public opinion all over the world in recent years, but it is a fact that the campaigns on the environment in Türkiye did not affect the location selection of the private sector in the city, in practice.

The Prost Master plans and Luigi Piccinato's Regional plans prepared accordance to zoning rules aimed arranging of industrial areas directed to the outskirts of the city and nearby towns. According to the idea of moving industrial zones to nearby towns, new laws were need to made which were called "organized industrial zones" proposed to move industrial areas to the specifically planned areas out of the city. However, these articulated plannings created a specifical regionalization around the Marmara Sea (even a regionalization based on industry) (Genç et al., 2021, p. 71).

Since the industrial revolution, the city centres had been realized as the most suitable place for the industrial area, close to the consumer, labour market, and infrastructure. In the Istanbul city centres, there were still small-scale industry or sub-industry like automotive, small textile workshops, and facilities were available. However, especially after the 1980s, the areas of small industries in the city has decreased significantly.

Although the decision to moving industrial areas out of the city was made at the beginning of the twentieth century, by H. Prost and L. Piccinato, the city continued to develop due to the dynamics of development, and some of these decisions could

Table 2 Istanbul, Industrial Areas, and Projects in Years

Years	Industrial areas	Industrial facilities
Nineteenth century	The inner city; around Golden Horn and Bosphorus, Bakırköy, Beykoz, Paşabahçe, İstinye, etc	Ship building, (Haliç-Istinye), textil, (Feshane), energy (Santral), mills, glass–ceramic (Beykoz), metal working (Bakırköy), food (Bomonti), tobacco (Cibali), etc
Twentieth century early Republican Era	Out of city walls; Bakırköy, Haydarpaşa, Bosphorus, etc. Other Cities, Kocaeli- Bursa	Haydarpaşa Harbour port services, auto industry, glass–ceramic (Beykoz), metal working (Bakırköy), leather manu. (Bakırköy), food (Bomonti), etc
1980s–2000s	Regions; Bakırköy, K. Çekmece, Tuzla, Bayrampaşa, Başakşehir, Levent, etc.	Ready made wearing, metal, machine equipments, textil, food production, electrical, leather manu., auto industry, etc. (Gov. Reports, 2018)
From 2019s	Recently declared 2 new districts; Esentepe and Arnavutköy districts	Miscellenous

only be taken after the 1980s. In the 1980s, the old Mayor of Istanbul, B. Dalan's radical step the old, leather factories in Haliç and Zeytinburnu closed (Bezmez, 2008), and they were moved to green areas of the Tuzla region (Fig. 13). However, the industrialization of Istanbul continued rapidly until the 1990s (Özbay, 2014, p. 177). Today, mostly state institutions have authority determination of "industrial areas" on a regional basis in the cities. The industrial companies with capacity reports in Istanbul, it was seen that the majority of them are primarily located in Başakşehir, Küçükçekmece, Tuzla, and Bayrampaşa. (Fig. 14) These enterprises were generally located in various OIZs or in the form of small clusters formed by themselves and operating in similar sectors in certain regions also, recently Arnavutköy and Esentepe districts were declared as new "industrial areas" by State Institution according to Governmental Reports (Habertürk, 2021). (Fig. 14) (Table 2).

- Specifying New Housing Areas in Istanbul, Towards to New Planning Ideas with the Sustainability

Whilst the city of Istanbul continued to grow towards the forests and green areas in the north, this growth was not seen as a danger for many years. The partly uncontrolled development of the city continued until today with inner mass migrations, and after the 2000s with transnational migrations, the city transformed into a mega-city with its 15 million population. Figures 15, 16 and 17 Recently, even though projection, the allocations of the industrial areas were realized to the close towns but with the unstoppable urban sprawl the housing areas became more critical.

Today, the most important problem of Istanbul is housing shortage due to increasing migrations as well as the earthquake issue, rather than sustainability. After 1999, the earthquake forcibly determined an urgent agenda for the city, and the most significant issue of the city became the regeneration projects. State institutions and the private sector great part of the execution of regeneration projects, mass housing planned out of the city some large-scale "satellite-cities" necessary to accommodate this large population was still under the authority of TOKI, (TOKI, 2021).

In this context, the decisions of the site selections and location choice of the residential areas were mainly under the responsibility of TOKI and the Government. This institution was collaborated by the other private constructors as a joint venture sometimes. TOKI, banks, municipalities, and other private constructors likewise the French housing construction system (Dogrusöz, 1981). A very little part of housing construction, the small-scale projects, individual housing blocks, and apartment constructions were carried out by small contractor groups.

In the 2010s, after the chaotic effects of the earthquake, experienced in 1999, the city's agenda finally found an opportunity to concentrate on climate change issue new and innovative projects. The Küçükçekmece region was allocated to these projects by Küçükçekmece Municipality collaboration with Istanbul Municipality. Focussed on macro projects such as planning an eco-city in Küçükçekmece district, in the west axis or large-scale regeneration projects in Kartal district, in east axis, however, these projects have never been implemented. The organization of these innovative projects such as the specification of areas was realized by the collaboration of state and Istanbul and Küçükçekmece district Municipality and Kartal Municipality. Due to some problems between landowners, the Stateside, and Kartal Municipality, the project was halted (Bozdogan, Akcan, 2012, p. 293). (Table 3).

In the 2020s: from the Habitat-II, City Summit held in Istanbul, Türkiye UN Conferences have ensured the acceptance, and spread of Local Agenda 21, the local projections of the principle of global partnership, all over the world and the strong international foundations of the aforementioned

Fig. 13 Istanbul, Transformation of the Green Areas to the Industrial Areas Tuzla District Transformation to the Industrial Area. Image, designed by H. Coskun

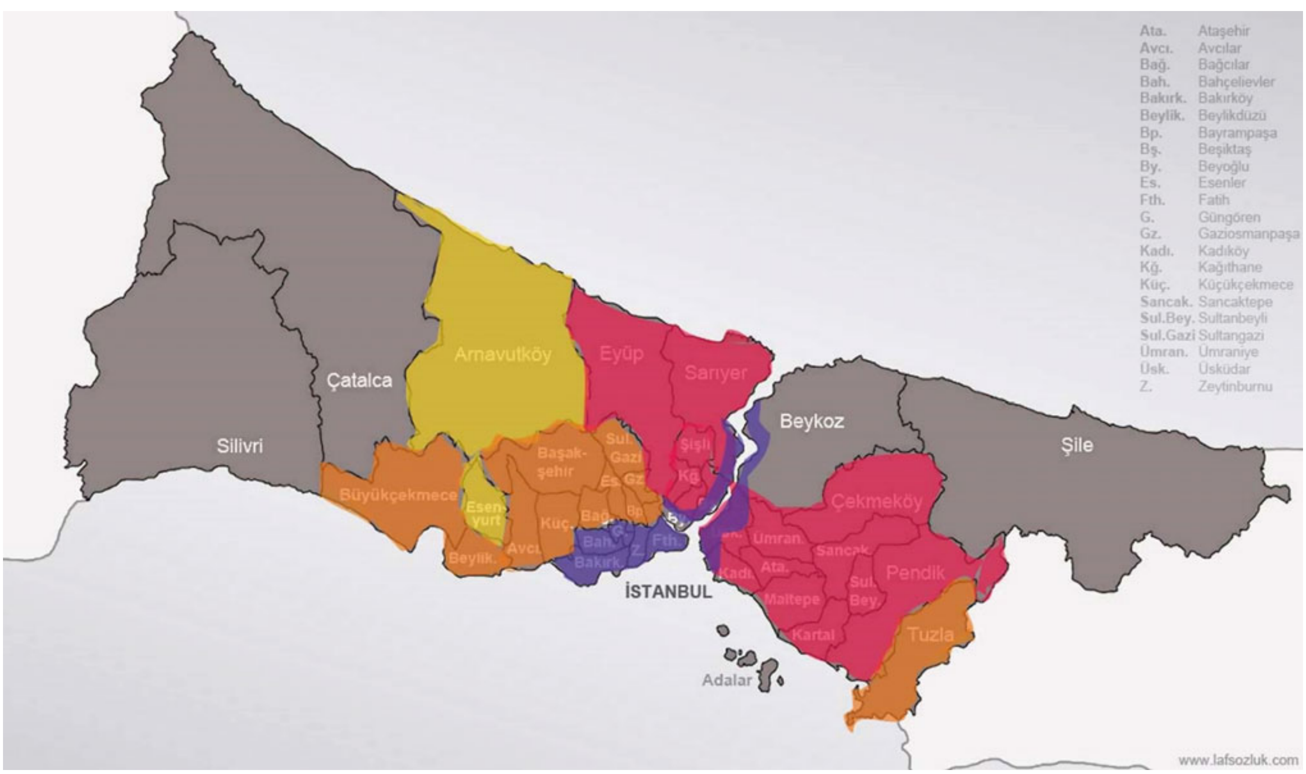


Fig. 14 Istanbul, industrial areas. The old industrial areas (purple). Industrial areas after the 1950s, (first red and after orange); Başakşehir, Küçükçekmece, Bayrampaşa, Tuzla (right). The recent "industrial areas", declared by state, 2018; Esentepe, (yellow-down), Arnavutköy, (yellow-top), (acc. to Habertürk, 2019). Map, designed by H. Coskun

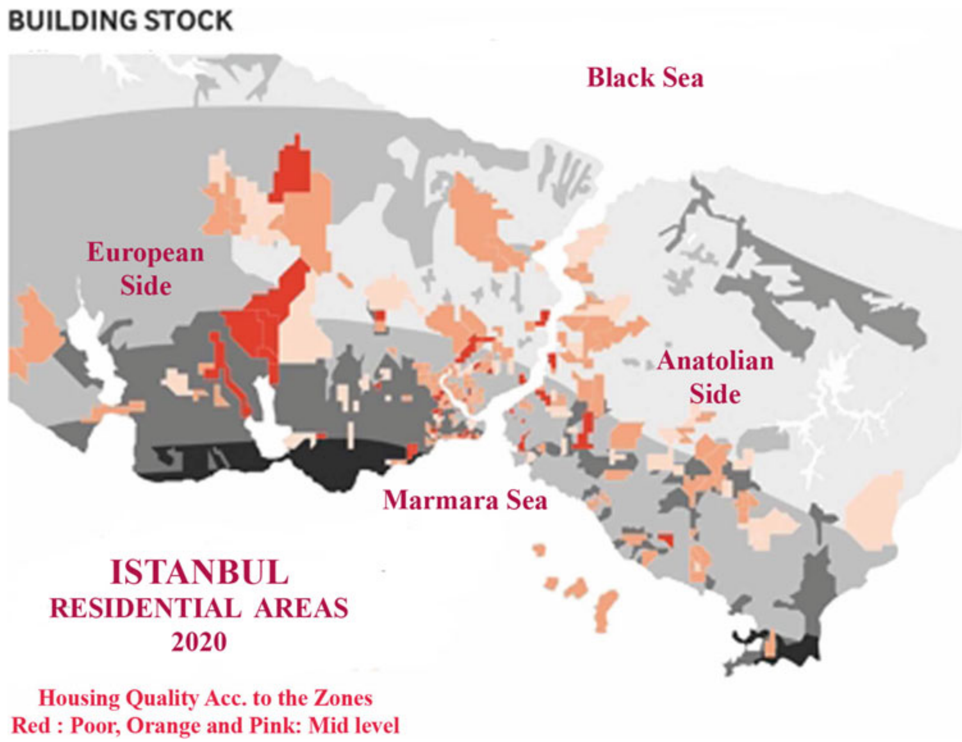


Fig. 15 Istanbul, building stock, also specifying city's urban sprawl to the Nothern Forest from dark grey to the light grey. Densely populated areas (dark shaded) less densely populated areas (grey) and less population (light grey). Map, building stock

Fig. 16 Istanbul, recent Silhouette, high-rise buildings behind the low-rise apartments along the Bosphorus. Photo, Destinozione Istanbul

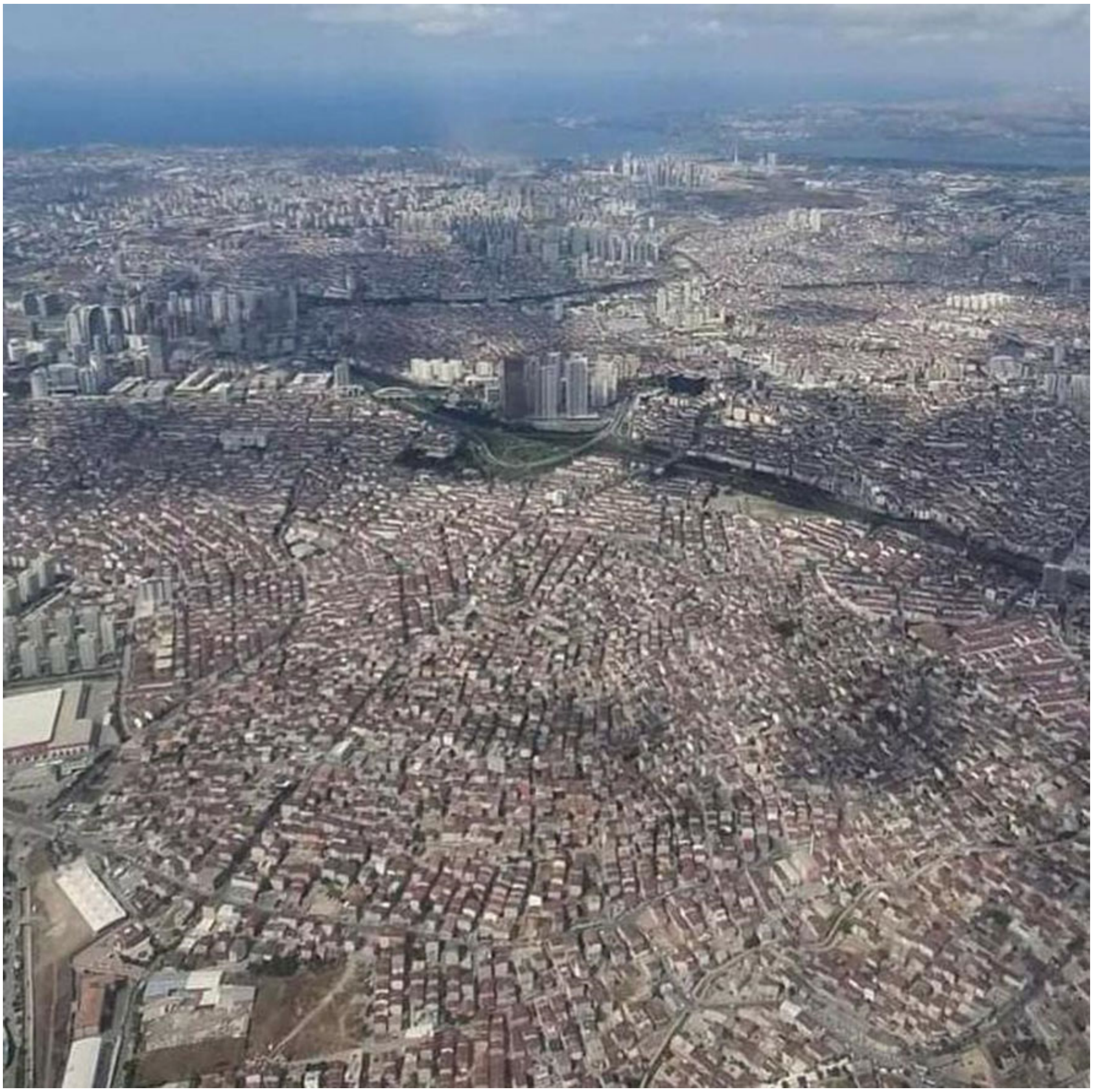


Fig. 17 Istanbul, recent housing density, mixed residential areas, apartments and commercial areas. Photo, Hürriyet newspaper

process formed (Arar, 2021). All activities expected to be carried out by local municipalities were determined as Agenda21 in Türkiye, Istanbul. Recently, some issues were addressed in the studies carried out by the state. In the context of the Agenda21, although 5 regions have been determined as model districts in Istanbul city, (Pérouse, 2014, p. 236), have not any concrete plans yet in this regard.

In recent years, the destruction of forest areas with large-scale projects has continued, and the new law enacted in 2021 was declared that "the forest areas might be opened to new housing settlements if deemed necessary" (Iklim Haber, 2021). This was not beneficial regulation for the protection of forest areas that are already under the threat of industrial areas and housing settlements. Even though the uncontrolled "housing areas" still continued to threaten main forest areas, water basins, woods, and green areas, some projects were introduced as environmentally friendly. On the Anatolian side; some large-scale investment projects by the private sector were projected under the title of Wood and Forest; Acıbadem Wood, S. Forest, etc. (Table 3) Although adequate steps have not been taken yet, recently, according to State Reports threat of the uncontrolled urban sprawl underlined once again; "the land areas were reduced due to uncontrolled urban sprawl, global warming, and increasing intensity with climate change." (Turkish Housing Policy Commission Reports, 2018).

Table 3 Istanbul, planning residential areas and housing projects in years

Dates	Planner	Project origin	City and regions	Project models and typologies
1935–1949	Henri Prost	French *Cité-jardins*	Bank-Houses; Anatolian side; Kadıköy, Acıbadem, Koşuyolu, etc. Bosphorus heights	*Cité-jardins* (garden-cities) and *Cité-parc* (park-cities)
1950–60s	Luigi Piccinato	French *Cité-satellites*	In the West Axis, Ataköy region	*Cité-Satellites* (Satellite-cities)
1980s–1990s	Various	European housing models	Historical Peninsula; Fatih, Kocamustafapaşa, Fındıkzade, etc. European Side; Beyoğlu, Şişli, Levent, etc	Building-Blocks, Apartments
			Anatolian side; Kadıköy, Suadiye, Koşuyolu, Acıbadem	Mixed; *Cité-jardins* (garden-cities) and building-blocks
2000s	Various	Old, English Garden-cities	Northern Regions of both, European-Anatolian sides Country style houses	2000s, new version of old, Garden-cities
2000s	Various, Government TOKI and Private Contractors, etc.		City centres, Anatolian side- European Side	Regeneration Projects After the 1999 Earthquake
2010s	Ken Yeang, MRVD, Kengo Kuma, etc.		Developed in European side Küçükçekmece Region	Eco-cities, other innovative projects, forest houses, kale-house, etc.

6 Conclusion

Studies on "industrial planning" and especially "housing planning" in Türkiye and Istanbul have evolved in a completely different path with the changing mainly the political dynamics since the 2000s. Until that period, the urbanization of Istanbul, immigration, continued uncontrollably with slum buildings (gecekondu) towards to north of the city; Arnavutköy, Büyükçekmece, Küçükçekmece, Esenkent in the European Side, and the Sultangazi, Kurtköy in the Anatolian Side towards to green areas, forest areas.

However, after the 2000s, with the new Government change, the policies altered by TOKI, emerged as the main company to carry out all state-owned projects new housing projects. In the 2000s, another breaking point was 1999, earthquake and urgent measurements to renew the ageing old, housing stock. After 1999, earthquake, this planning started pioneered by TOKI, which was a state institution, and other private construction institutions, in almost every district of the city, as large-scale mass housing renewing activities at the same time.

Today, the city of Istanbul has some planning and controlling problems derived from the administration and responsibility. This administration problem arose from the responsibility of the city's planning sharing authority between the state institutions and the Istanbul Municipality. This situation causes some complex management problems in the determination of new "residential areas" and "industrial areas" in the planning of the city. Today, te State and TOKI were highly authorized state institutions in the determination of "housing areas" as well as the mass housing construction. In Istanbul, the state has quite a lot of authority in areas where the *Istanbul Büyükşehir Belediyesi* (Istanbul Municipality of Metropolitan) does not have the authority and areas in the city.

In terms of "industrial areas" primarily, state institutions have authority determination on a regional basis and Istanbul Municipality of Metropolitan have rights to decisions on a city basis mostly on the small-scale industrial areas (Küçük Sanayi). The industrial areas, since the beginning of the twentieth century, with the foresight of moving industrial areas out of the city, large industrial areas had been distributed to nearby towns with the arrangement of organized industrial zones. Although small industrial facilities are still allowed in the city, the recent declaration of Arnavutköy and Esenkent, which were located in the northern forest area, as industrial areas were also contradicted the decisions taken.

In the research, one of the main findings the issue of sustainability was not considered a significant fact for long years in the city. Indeed, neither the climate change summits ongoing by the 1990s, nor the public activities on the climate issues made awareness of sustainability to become important. Recently in State Reports theoretically considered sustainability as one of the main issues of the Government, according to implementations, however, there was no state agenda

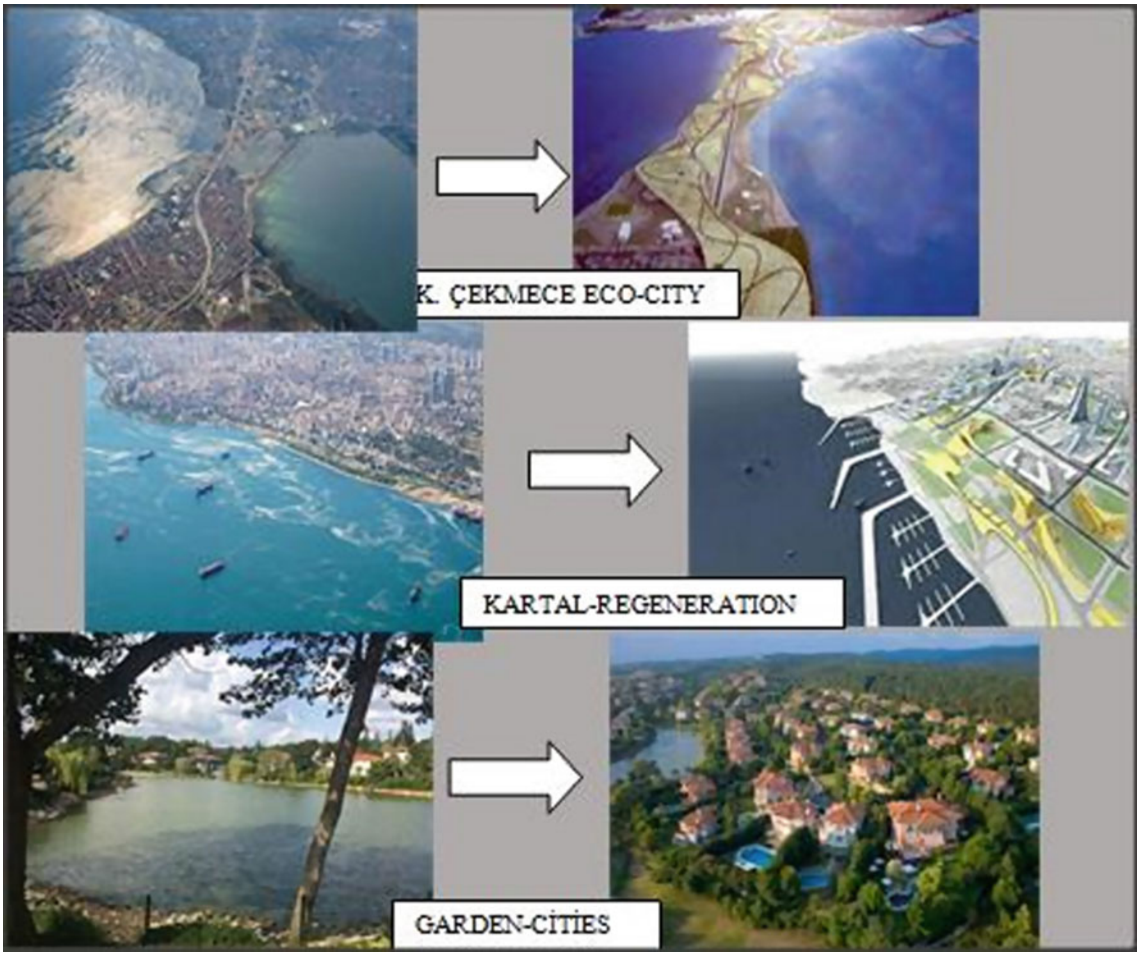


Fig. 18 Istanbul, new and innovative residential projects in the context of the sustainability designed in green areas, forests, and lakes, in the last twenty years. Image designed by H. Coskun

declared as an action plan in practice yet, the uncontrolled planning in the city still continued towards northern forest areas and water basins as a threat. According to State Reports, the issue of sustainability was emphasized as one of the main problematic as well as the disasters: "three main compromises were addressed in this study: to access to enough and equal and social housing, financing, and sustainability in the whole world" (Turkish Housing Policy Commission Reports, 2018).

It was possible to see the state's interest in sustainability issues in the state reports, on the other hand, with some newly made laws, endangering the green areas, forests by uncontrolled future planning of "residential areas" or "industrial areas" were drawn attention as some decisions that were in great conflict with sustainability. (Fig. 13) However, the environmental disasters such as the mucilage in the Marmara Sea that occurred in the last few years, and COVID-19, caused a definite paradigm shift that led to the growing demand for housing areas towards outside the city, excluded city centres. This situation led to the residential areas and industrial areas overlapping in the green areas. In the context of sustainability, this might be only arranged by preparing specific zoning plans; creating specific zoning areas as examined in this research presented as a suggestion, in the determination of "housing areas" and "industrial areas".

The new and innovative projects came to the fore planned with the participation of green areas also protecting them. Also, old, urban planning models come-back to old "garden-city" models might be good models previously well-known alternatives. However, also some good example projects designed and planned in the city would be model of the future planning such as "green-cities", "sustainable cities", and "eco-cities" (Fig. 18).

To prepare specific zoning plans in newly opening "housing areas" as prepared before, and to separated them with a specially prepared zoning plan for new residential areas and industrial areas. In this context, it is necessary to determine the borders of the existing green areas, forest areas, and residential areas to preserve them. Istanbul has to develop city plans in accordance with sustainable planning as well as emergency plans for environmental disasters urgently: climate change, sea disaster, mucilage, water supply, drought, earthquakes, etc.

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Policies and Mechanisms for Heritage Preservation

Environmental Kuznets Curve: A New Functional Form in the Case of Low-Income Countries

Yara Elsehaimy and Dina M. Yousri

Abstract

Since the late 1980s climate change as an incessant controversial topic has occupied the agenda of the top economies, sparking a heated debate among researchers, policy-makers, and international organizations. IMF argued that climate change imposes a huge threat on the long-run development and growth of world nations. While trying to capture the real drivers behind it, the United Nations (UN) reveals that CO_2 emissions that contribute to more than 66% of the greenhouse gases can be claimed responsible. Hence, uncovering the relationship between CO_2 emissions and countries' economic growth is vital. To assess the relationship between CO_2 emissions and economic growth, the paper will use the Environmental Kuznets' Hypothesis (EKC). The previous empirical findings on EKC hypothesis found a bidirectional relationship between CO_2 emissions and growth. Thus, a new functional form is introduced to capture the empirical literature as well as test the normal functional form. Using ARDLand stability testing as econometric techniques. Employing time-series data approaches for 60 years from 1960 to 2018 for the low-income countries group. The results are robust and support the presence of both EKC and its extended version in the long-run in some low-income countries.

Keywords

Environmental Kuznets curve • Co_2 emissions • Economic growth • ARDL • Co-integration • Low-income countries • Green House Gases (GHG)

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1 Introduction

> Global warming has reached a level such that we can ascribe with a high degree of confidence a cause-and-effect relationship between the greenhouse effect and observed warming…In my opinion, the greenhouse effect has been detected, and it is changing our climate now. Dr. James Hansen, testimony before U.S. Senate of Energy and Natural Resources Committee in Congress, 1988.

Since 1988, Climate change is a non-ending controversial topic on the agenda of top economies, policy-makers, international organizations, and researchers. The entire globe has been hit by atypical weather and the hottest temperatures on record. Given the accrues in the average global temperature a series of events are anticipated such as forest fires, droughts, huge storms, unusually cold winters, and floods. These forms of environmental degradations driven by human activities and burning of fossil fuels that increased the release of carbon dioxide (Greenhouse gases) in the atmosphere (WHO, 2018). According to IMF (2020), climate change is imposing a serious threat on the economic well-being and long-run growth of world nations. Green House Gases (GHG) is the main contributor in climate change issues grew by 1.5% from 2009 to 2018, hitting a new peak of 55.3 Giga Tone Carbon Dioxide Equivalent (GT CO_2E2) (Emission Gap Report, UN 2019). With CO_2 consisting of 66% of the total emission GHG and the rest 34% attributed to other gases, studying CO_2 emissions' effect on global economies become a must (Akbostanci et al., 2009; Emissions Gap Report, UN 2019).

Increasing levels of CO_2 emissions are driven by increasing levels of economic growth, population, and energy consumption, according to the Kaya identity equation (Kaya & Yokobori, 1997; Stern & Stern, 2007). On the other hand, lowering CO_2 emissions will decrease economic growth; because energy consumption and specifically CO_2 is the key part of production (Ahmad et al., 2017; Al-Mulali & Sab, 2012; Amano, 1993; Ang, 2007; Asafu-Adjaye, 2000; Fan et al., 2010; Hourcade & Robinson, 1996; Mahadevan

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& Asafu-Adjaye, 2007; Omri, 2013; Omri et al., 2014; Sadorsky, 2011). These controverting arguments have been reflected into three strands of theoretical and empirical literature in the climate change area.

The first strand is pioneered by Kraft and Kraft (1978), where the two economists studied the relationship between energy consumption and gross national income as an indicator for economic growth. Furthermore, the second strand is pioneered by the work of Grossman and Krueger (1991), which is built on Kuznets' Inverted U Inequality Hypothesis. Moreover, the third strand was analyzing the intersection of the first two strands, where researchers empirically examine the dynamic relationship between EG, EC, and environmental pollutants. Economic growth is not only an indicator for the Gross Domestic Product (hereafter GDP) or GNP, but also macroeconomic and financial indicators such as foreign direct investment, trade, financial development indexes.

According to Stern (2004), the negative consequences of climate change are greater than that of WWI and WWII. Thus, empirical studies on the effect of CO_2 emissions on economic growth are of a great importance. Hence, Environmental Kuznets Curve (EKC) is still relevant today and considered a cornerstone in analyzing the environmental degradation in the world. Most of the empirical findings goes in line with EKC hypothesis where a unidirectional causality running from economic growth to CO_2 emissions is present. Furthermore, recent studies have shown a bidirectional causality runs between CO_2 emissions and economic growth, in addition to the unidirectional causality (Acaravci & Ozturk, 2010; Acheampong, 2018; Ahmad et al., 2017; Al-mulali & Sab, 2012; Chang, 2010; Coondoo & Dinda, 2002; Dinda & Coondoo, 2006; Farhani et al., 2014; Ghosh, 2010; Govindaraju & Tang, 2013; Halicioglu, 2009; Lau et al., 2014; Omri et al., 2014; Pao et al., 2011; Pao & Tsai, 2011; Saboori & Sulaiman, 2013; Shahbaz et al., 2013; Tiwari et al., 2013; Zakarya et al., 2015). As a result, the empirical foundation of EKC hypothesis requires an extension to allow for testing economic growth as a function of CO_2 emissions (Extended Environmental Kuznets' Curve—EEKC), besides testing the original hypothesis, which is CO_2 emissions as a function of economic growth (EKC). Therefore, our research will examine the existance of the EEKC hypothesis as well as the EKC.

This study will focus on low-income countries (as per World Bank classification) given that they are known to be more vulnerable to climate change and suffering from several macroeconomic imbalances, institutional problems (corruption), over population, high illiteracy rates, lower productivity levels and generally low quality of life (Al-mulali & Sab, 2012). Moreover, an increase in economic growth seems an obvious target to this income group. Given the dynamic relationship between economic activities and climate change. A time-series data analysis will be employed to capture it from 1960 till 2016. For countries Burkina Faso, Ethiopia, Madagascar, Malawi, Mozambique, Guinea, Sierra Leon, Sudan, Chad, Malawi, Togo, Guinea, Guinea Bissau, Haiti, and Gambia. The uniqueness of this research is in the sample selected and the long time frame covered.

2 EKC Hypothesis: Previous Empirical Findings

Examining Environmental Kuznets Curve hypothesis is pioneered by the seminal paper of Grossman and Krueger (1991). The study was consisting of three main research questions; the first one studies the relationship between air quality and economic growth using panel data in 42 countries. While the second question examined the determinants of trade between the USA and Mexico and whether environmental pollution in the USA affects the trade with Mexico. The third question tackles the effect of pollution on the NAFTA trade agreement. In the first question, Grossman and Krueger (1991) using random estimation technique for 42 countries with daily records of three environmental pollutants for on average 2 years, found that sulfur dioxide and smoke are the main contributors to the changes that occur in growth in low-income countries; however, these two pollutants emissions were decreasing in high-income countries. In testing the following two questions, Grossman and Krueger (1991) used random estimation regressions and computable general equilibrium in the USA, Mexico, and Canada, the results showed that the environmental pollutants decrease after exceeding an income threshold for the sample courtiers, as well as, production in the USA is capital intensive, while labor-intensive in Mexico. In testing paper questions, Grossman and Krueger (1991) utilized Simon Kuznets' econometric technique in capturing income inequality, which is through adding squared and quadratic terms of GDP. This technique is then used extensively in the second strand of literature and named after Environmental Kuznets Curve (EKC) hypothesis.

EKC hypothesis testing continues to develop with the attempts of economists to validate its existence, which is, environmental deterioration measured through CO_2 emissions is increasing in the early stages of development; but lessens as the country develop and have higher economic growth. Moreover, the EKC hypothesis is identified through the presence of an inverted U-shaped relationship between CO_2 emissions and economic growth (Coondoo & Dinda, 2002). Empirically, GDP and GDP squared are incorporated with CO_2 emissions to test for the EKC hypothesis, if the GDP coefficient is positive and GDP square has a negative coefficient; therefore, the EKC hypothesis is confirmed (Acaravci & Ozturk, 2010; Coondoo & Dinda, 2002; Dinda, 2004). Coondoo and Dinda (2002) added that in the EKC hypotheses, CO_2 emission is a function of economic growth, which is consequently resulted in an expected unidirectional causality running from growth to emissions.

In testing 88 countries over 1960–1990, Coondoo and Dinda (2002) used ordinary least squares (OLS), ARDL bound test for co-integration, and Granger causality to investigate the causal relationship between income and CO_2 emissions. The findings demonstrated that for the developed country groups of North America, Western, and Eastern Europe, causality runs from CO_2 emission to income. Besides, for the country groups of Central and South America, Oceania and Japan causality runs from income to CO_2 emission is obtained. Lastly, for the country group of Asia and Africa, causality is found to be bidirectional between CO_2 emissions and income.

On the other hand, Friedl and Getzner (2003) used a time-series approach to check for the validity of EKC hypothesis in Austria from 1960 to 1999 by using OLS, co-integration technique based on Durbin Watson statistic and stationery as econometric techniques. The study findings emphasized that the relationship between CO_2 emissions and economic growth is N-shaped; thus, EKC hypothesis validity is rejected. Likewise, Akbostancı (2009) tested the validity of EKC in India from 1971 till 2006 using ARDL and Granger causality econometric technique. The results illustrated that EKC hypothesis does not hold in the long-run, as well as, there is no co-integration between the variables.

Furthermore, Galeotti and Lanza (2005) examined the EKC hypothesis for a panel consisting of 100 countries from 1980 till 2005. The findings showed that using different functional forms as linear and log-linear forms will lead to the same finding, which is the confirmation of EKC in the tested sample. Galeotti and Laanza (2005) used the OLS estimation technique in investigating EKC hypothesis for panel data. Besides, using panel data set for 29 provinces in China from 1995 till 2012, Hao et al. (2016) investigated the presence of EKC hypothesis through economic growth and coal consumption and incorporating population density along with urbanization rate. The study findings confirmed the validity of EKC hypothesis in China.

Additionally, Coondoo and Dinda (2006) studied the causal relationship between income and CO_2 emissions through a panel dataset for 88 countries from 1960 till 1990. The study incorporates OLS, ARDL bound test, Granger causality, and ECM for testing the research question. The findings of the study supported the presence of bidirectional causality runs between CO_2 emissions and income in the following subgroups, Africa, Central America, America as a whole, Eastern Europe, Western Europe, Europe as a whole, and the World as a whole. Important to realize that the movement of either CO_2 emissions or economic growth will directly affect the other, which is Coondoo and Dinda (2006) and Omri et al. (2014) named as feedback system; thus, decision-makers should pay huge attention to feedback system in order to achieve the highest economic return as possible. Omri et al. (2014) added that the relationship between CO_2 emissions and economic growth can be neutral, in which there is no relationship between them and it is called the neutrality hypothesis.

Comparatively, Ghosh (2010) scrutinized the relationship between CO_2 emissions and economic growth by incorporating energy supply, investment, and employment levels. The study examined the Indian economy from 1971 to 2006, using ARDL bound test and granger causality as econometric techniques. The study exhibited that there is no long-run co-integration or causality relationship between CO_2 emissions, and economic growth. However, there is a short-run bidirectional causality runs between CO_2 emissions and economic growth.

Nasir and Rehman (2011) analyzed the relationship between CO_2 emission, energy consumption, and economic growth by incorporating foreign trade with time-series data approach for Pakistan from 1972 till 2008. The results reveal that the EKC hypothesis is not confirmed in the economy. Nasir and Rehman (2011) emphasized that the study results are unique from the literature; as none of the variables are significant in the applied regression of the EKC hypothesis. Nevertheless, Al-Mulali et al. (2015) explore the EKC hypothesis in Vietnam from 1981 till 2011. The results manifested that the Vietnamese economy did not exhibit the EKC hypothesis; but rather a monotonic increasing relationship between the variables.

Indeed, time-series data is used more extensively in testing the EKC hypothesis; as it better capture the long-run dynamics considering the special economic and environmental nature of each country (Akbostancı et al., 2009). Using time-series approach, Jaunky (2011) examined 36 high-income countries from 1980 to 2005 through GMM econometric techniques. The study findings confirm the validity of EKC hypothesis in Greece, Malta, Oman, Portugal, and the United Kingdom. In addition, Jaunky (2011) examined 36 high-income countries with panel VECM Granger causality for the same period of time; however, the results did not support the existence of the EKC hypothesis.

Govindaraju and Tang (2013) investigated the EKC hypothesis using CO_2 emissions and real economic growth (GDP) incorporating coal consumption. Time-series approach was used for India and China over the period 1965–2009. Besides, Bayer and Hank co-integration test, where multiple co-integration tests are used to provide a conclusive co-integration finding and Granger causality are used as econometric techniques. The findings showed that there is a long-run co-integration relationship between CO_2 emissions, growth, and coal consumption, as well as, a unidirectional causality runs from growth to CO_2 emissions in China. For India, there is only a bidirectional causality run between CO_2 emissions and economic growth.

Moreover, Lau et al. (2014) explore EKC hypothesis using CO_2 emissions and real economic growth (GDP) incorporating foreign direct investment and trade openness. Time-series data approach was applied with ARDL bound test for co-integration and Granger causality for Malaysia from 1970 to 2008. The study findings confirmed the validity of EKC hypothesis in the country; however, the hypothesis is confirmed only with controlling foreign direct investment (FDI) and the trade size of Malaysia. Besides, bidirectional causality runs between CO_2 emissions and economic growth have also been found.

Nevertheless, Ahmad et al. (2017) examined the validity of EKC hypothesis in Croatia for 1992Q1 to 2011Q1 with ARDL, VECM, and Granger causality econometric techniques. The findings support the validity of EKC hypothesis in Croatia. As well as, there is bidirectional causality runs between CO_2 emissions and economic growth in the short-run. On the long-run, there is a unidirectional causality runs from economic growth to CO_2 emissions. The study applies DOLS and FMOLS as robustness techniques for the long-run relationship, and it indicated the same findings.

All the studies that investigate EKC hypothesis used CO_2 emissions as the functional form of economic growth that demonstrates a unidirectional causality runs from economic growth to CO_2 emissions and not vice versa (Coondoo & Dinda, 2002). However, many of the empirical studies found a bidirectional causality relationship runs between emissions and growth, as well as a unidirectional causality runs from CO_2 emissions to economic growth (Acaravci & Ozturk, 2010; Acheampong, 2018; Ahmad et al., 2017; Al-mulali & Sab, 2012; Chang, 2010; Coondoo & Dinda, 2002; Coondoo & Dinda, 2006; Farhani et al., 2014; Ghosh, 2010; Govindaraju & Tang, 2013; Halicioglu, 2009; Lau et al., 2014; Pao & Tsai, 2011; Pao et al., 2011; Saboori & Sulaiman, 2013; Shahbaz et al., 2013; Tiwari et al., 2013; Omri et al., 2014; Zakarya et al., 2015). Thus, the research will introduce an extension to EKC hypothesis (hereafter Extended Environmental Kuznets Curve—EEKC), in which economic growth will be tested as a function of CO_2 emissions, based on the previous empirical results found in literature. As well as, the research will be also test the validity of EKC hypothesis (hereafter NEKC).

3 Methodology

The objective of the paper is to validate EKC hypothesis and its extended version (EEKC) by examining the relationship between economic growth and CO_2 emissions. The research gathers data set from World Bank and OECD databases for the 15 countries in the low-income category from 1960 until 2018, which is the longest period used in assessing the paper objective.

In 1991, and after Grossman and Krueger's paper that introduces the EKC hypothesis, economists start to use a wide different range of techniques, methodologies and variables to examine the relationship between CO_2 emissions and economic growth. This array of differences between researches resulted in three distinct schools in analyzing CO_2 emissions and economic growth. As discussed earlier, each school has its group of variables in analyzing our relation of interest. According to Saboori et al. (2012), Riti et al. (2017), Ahmad et al. (2017), Akbostancı et al. (2009), the theoretical basis for the EKC hypothesis is as follows:

$$C_T = f\left(Y_T, Y_T^2, K_T\right) \quad (1)$$

where C_T represents Carbon Dioxide (CO_2) emissions, Y_T represents gross domestic production (GDP), Y_T^2 represents gross domestic production (GDP) squared, and K_T represents other variables that can cause changes in CO_2 emissions. Saboori et al. (2012), Riti et al. (2017), Ahmad et al. (2017), Du et al. (2012), Yavuz (2014) added that examining the effect of CO_2 emissions on GDP should be kept in the reduced functional form without including further explanatory variables. So that the investigated relationship kept direct, eliminating the risk of omitting relevant variables; due to data unavailability, and reducing the risk of analytical freedom and keeping the model parsimonious. Therefore, the investigated model of the Environmental Kuznets Curve will be as follows:

$$C_T = \alpha_0 + \beta_1 Y_T + \beta_2 Y_T^2 + \varepsilon_T \quad (2)$$

where C_T represents Carbon Dioxide (CO_2) emissions, α_0 is the equation constant intercept, that represents a statistical need and does not have an economic explanation. β_1 and β_2 are the two coefficients of the explanatory variables. Y_T represents gross domestic production (GDP), Y_T^2 represents gross domestic production (GDP) squared. The empirical-based extension for the EKC hypothesis that is suggested by the research has the following functional form:

$$Y_t = \alpha_3 + \beta_1 C_t + \beta_2 C_t^2 + \varepsilon_t \quad (3)$$

where Y_T represents gross domestic production (GDP), α_3 is the equation constant intercept that represents a statistical need and does not have an economic explanation. β_4 and β_5 are the two coefficients of the explanatory variables. C_t represents Carbon Dioxide (CO_2) emissions and C_t^2 represents Carbon Dioxide (CO_2) emissions squared.

According to (Acaravci & Ozturk, 2010; Ahmad et al., 2017; Akbostancı et al., 2009; Friedl & Getzner, 2003; Wang et al., 2011), β_1 is expected to have a positive sign, which represents the direct relationship between emissions and GDP, when the total production increases, CO_2 emissions should increase as well. While β_2 is expected to have a negative sign ($\beta_2 < 0$), which confirms the presence of EKC hypothesis. Which means the relationship between CO_2 emissions and GDP is captured by an inverted U-shaped curve, through which GDP growth threshold can be calculated, the income level at which CO_2 emissions will decline. If $\beta_1 < 0, \beta_2 = 0$ or $\beta_1 > 0, \beta_2 = 0$, there will be linear increasing or decreasing relationship based on the sign of β_1. If $\beta_1 < 0, \beta_2 > 0$, the relationship will be U-shaped. If $\beta_1 > 0, \boldsymbol{\beta}_2 < 0$, the relationship will be inverted U-shaped. Besides, the threshold point of GDP will be calculated as follows: $Y_T = -\frac{\beta_1}{2\beta_2}$ (Ahmed et al., 2017; Akbostancı et al., 2009; Apergis & Payne, 2009; Friedl & Getzner, 2003). Data used are extracted from World Development Indicators by World Bank Statistics annually from 1960 till 2016 using ARDL econometric modeling.

4 Results and Disscussion

According to Table 1, Burkina Faso ARDL test result shows that when GDP changes by 1 unit, CO_2 emissions increase by 29.75 units and 7.279 units in present year and the first one, respectively. Besides, when $GDPG^2$ changes by 1 unit, CO_2 emissions decreases by 2.8476 units, which confirms the presence of EKC hypothesis in Burkina Faso with 99% R^2. Nevertheless, in testing the suggested extension of EKC hypothesis at which GDPG is a function of CO_2 emissions, the results show that when CO_2 increases by 1 unit, GDPG will increase by 0.00462. Also, ${CO_2}^2s$ emissions have a negative coefficient of 1.15E−06, which proves that EEKC hypothesis is also held in Burkina Faso.

EKC hypothesis is confirmed in Ethiopia due to the negative and significant coefficients of GDPG squared with 2.111 value in year one with 10% significance. As for the relationship between CO_2 emissions and GDPG, the coefficient results of GDPG are as follows, 23.27963 at year zero with 5% significance, −29.697 at year one with 5% significance, 26.1633 at year two with 10% significance and −24.17158 at year three with 10% significance. Thus, the net effect between emissions and growth is −4.42613, indicating that when GDPG increases by 1 unit, CO_2 emissions will on average decrease by 4.42613 units. Identically, the EEKC is also confirmed with the negative and significant net coefficient at CO_2 emissions squared of 1.94E−07. Similarly, the relationship between CO_2 emissions and GDPG is changing over time, as in year zero, the relationship is positive at 0.018538 with 1% significance, while at year one, the relationship becomes negative with 1% coefficient with 0.0260, and in year two, the relationship turns to be positive once more at 5% significant with 0.011853 coefficient values. The net effect between CO_2 emissions and GDPG is 0.004391, when CO_2 emissions change by 1 unit, GDPG will increase by 0.004391.

Regarding Gambia, the, ARDL results do not confirm the presence of both normal and EEKC hypotheses in the country. As for the EKC, GDPG coefficients are as follows, when GDPG increases by 1 unit at year one, CO_2 emissions will increase by 2.47 units, as well as when GDPG increases by 1 unit at year two, CO_2 emissions will increase by 4.459596 units, both with 5% significant level. Besides, GDPG squared term is a positive value of 0.112735 at the fourth lag with 5% level of significance. As the result, the shape of the relationship between CO_2 emissions and GDPG is linear increasing line instead of an inverted U-shaped curve. For the extended version, when CO_2 emissions increase by 1 unit, GDPG will increase at year zero with 1% level of significance. GDPG squared has a negative coefficient of 0.000229 at year zero, however, it turns to be positive at year one with coefficient value of 0.000241, and both have 1% level of significance with a net effect of CO_2 square on growth at 0.000012 units.

Table 1 ARDL test results for three low-income countries

	Dependent	CO_2	${CO_2}^2$	GDPG	$GDPG^2$	R^2 (%)
Burkina Faso	CO_2	$(0.789)_{-1}$*** $(0.2916)_{-2}$*		(29.75)** $(7.279)_{-1}$**	(−2.8476)**	99
	GDPG	(0.00462)***	(−1.15E−06)***	$(-0.227)_{-1}$**		15.84
Burundi	CO_2	$(1.009)_{-1}$***		(0.559)	(−0.0529)	90.6
	GDPG	(−0.0362)*	(5.54E−05)	$(-0.01487)_{-1}$		7.998
Chad	CO_2	(1.007132)***		(0.099641)	(−0.017673)	96.257
	GDPG	(−0.058947)*** $(0.082487)_{-1}$***	(5.56E−05)*** $(-7.50\text{E}-05)_{-1}$***	(0.187887)***		17.778

Due to space issues; The rest of the results are available upon request

Furthermore, Guinea findings illustrate that when GDPG increases by 1 unit, CO_2 emissions decrease by 36.586 units in year zero at 10% significance, continue to decrease in year one with 174.46 coefficient at 1% significance, then start to increase in year three with 53 units at 5% significance, and 85.2829 units in year four at 1% significance. Due to the changing behavior of CO_2 emissions in relationship with GDPG, the study calculates the net effect coefficient between two variables at −68.7428, in which, in the long-run, when GDPG increases by 1 unit, CO_2 emissions will decrease by 68.7428 units. As well, the net coefficient of GDPG squared is 24.7, where GDPG squared changes by 1 unit, CO_2 emissions will increase by 24.7 units. However, in the extended hypothesis, when GDPG changes by 1 unit, CO_2 emissions increase by 3.44E−06 units. And when GDPG squared changes by 1 unit, CO_2 emissions decrease by 0.092132 units. Thus, the relationship between CO_2 emissions and GDPG in the EEKC will be an inverted U-shaped curve; as the coefficient of GDPG is positive while the coefficient of GDPG squared is of negative sign.

Guinea Bissau, EKC hypothesis coefficients show that the relationship between CO_2 emissions and GDPG is negative, in which, higher levels of GDPG will lead to lower levels of emissions. Identically, net coefficient of GDPG squared is also negative, in which, higher levels of GDPG squared will lead to lower levels of emissions. Therefore, the regression graph is downward sloping line with one intersection between CO_2 and GDPG. The research then will calculate the point of intersection between two variables; in order to identify where Guinea Bissau is from the dynamics between two variables under study. While EEKC is not hold in Guinea Bissau; due to the insignificance of CO_2 and CO_2 squared emissions.

Regarding Haiti NEKC hypothesis, the relationship between CO_2 emissions and GDPG is positive, when GDPG increases by 1 unit, CO_2 emissions increases by 19.88749 in year zero at 1% significance, but, in year three emissions decrease by 9.258 units at 10% significance. Consequently, the net coefficient of GDPG is 10.6291, in which on the long-run when GDPG increases by 1 unit, the emissions will increase on average by 10.6291 units. GDPG squared shows a negative relationship with CO_2 emissions is year zero with 2.04846 coefficient at 1% significance and a positive one in year one with 2.40639 coefficient at 5% significance. The net coefficient of GDPG squared is 0.35793, in which on the long-run when GDPG squared increases by 1 unit, the emissions will increase on average by 0.35793 units.

EEKC hypothesis of Haiti shows variation in coefficients of CO_2 emissions over year zero, one, three, and four at 1% level of significance, except for year three at 5% level of significance. Thus, the net effect of CO_2 emissions coefficient is −0.006128, when CO_2 emissions increases by 1 unit, GDPG will decrease by 0.006128. Also, the net coefficient effect of CO_2 emission squared is 0.00000652, when CO_2 emissions squared increases by 1 unit, GDPG will increase by 0.00000652. EEKC hypothesis will have U-curve shaped graph, representing the relationship between examined variables.

Madagascar findings illustrate that EKC hypothesis is confirmed with the significance of both GDPG and GDPG squared, besides the negative sign of the latter. When GDPG increases by 1 unit, CO_2 emissions increases by 19.87 units, indicating the direct and positive relationship between two variables. Moreover, GDPG squared has a negative coefficient of 2.606 at year zero that turns to be positive value of 2.4 in year one, and lastly turns to negative again with coefficient 2.96711 in year two; thus, the net effect of GDPG squared is −3.167394. Coefficients in Madagascar are all significant at 99% level of confidence. On the other hand, EEKC hypothesis findings demonstrate that it is not confirmed; due to the insignificance of CO_2 emissions square. Yet, CO_2 emissions show 5% significance findings with 0.008097 and −0.007122 at year one; as the result, when CO_2 emissions increases by 1 unit, GDPG will increase by 0.000975 units on average.

Malawi findings show that EKC hypothesis do not hold in the country; due to the insignificance of both GDPG and GDPG squared, yet, extended hypothesis is confirmed. For the extended hypothesis, when CO_2 emissions increase by 1 unit, GDPG will decrease by 0.041569 as a net effect over the long-run. But, the relationship between emissions and growth is positive at year zero with 0.070142 coefficient with 5% significance, however, it turns to be negative in the following year with 0.111711 coefficient values at 1% level of significance. As for GDPG squared, it has a net positive coefficient of 0.0000255 over the long-run. However, on the short-run, GDPG squared has a negative relationship with 0.0000306 coefficient value. Thus, on the short-run, Malawi EEKC hypothesis graph will have the shape of inverted—U-curve, while U-curve on the long-run.

Moving to Mali's economy, the findings confirm the presence of EKC hypothesis in the country. When GDPG increases by 1 unit, CO_2 emissions will increase by 5.9 units. Besides, GDPG squared has negative and 1% significant coefficient of 0.473492 value, indicating that Mali has the typical inverted U-shaped curve. Yet, the EEKC is not confirmed; due to the insignificance of both CO_2 emissions and CO_2 emission squared.

Identically, Mozambique findings confirm the presence of NEKC hypothesis with the 10% significance of both GDPG, and GDPG squared. Accordingly, when GDPG increases by 1 unit, CO_2 emissions increase by 56.60425 units, indicating that slight increase in production in the country, emissions will be more than doubled. Besides, when GDPG squared increases by 1 unit, emissions will decrease by 2.050 units, indicating the presence of normal inverted U- shaped curve for EKC. Albeit, the findings do not confirm the presence of the EEKC hypothesis in Mozambique; due to the insignificance of both CO_2 and CO_2 squared emissions.

Comparatively, Sierra Leone findings show non-existence of EKC hypothesis; due to the insignificance of GDPG squared term. However, findings verify a positive and 1% significant relationship between CO_2 emissions and GDPG. In which, GDPG increases by 1 unit, CO_2 emissions will increase by 5.6877 units. On the other hand, EEKC hypothesis is confirmed in Sierra Leon, where net effect of CO_2 squared coefficient is −0.0000126. In which, CO_2 emissions increases by 1 unit, GDPG wil1 increase by 0.0000376 at year zero and then decreases in the following year by 0.0000502, both at 10% level of significance.

Moreover, Sudan findings support the non-existing EKC hypothesis; due to the insignificance of GDPG coefficient. However, GDPG squared show negative and significant coefficient at 10%. The findings prove the presence of the diminishing feature of CO_2 with GDPG over years. Yet, the EKC hypothesis still does not hold in Sudan. On the other hand, the EEKC hypothesis is verified in Sudan. To emphasize, when CO_2 emissions increases by 1 unit, GDPG will increases at year one with 0.004284 coefficient at 10% significance, and with 0.004971in year three at 1% significance. As well, CO_2 squared has a negative coefficient of 2.36E−07 with 1% significance.

Togo findings support the non-existence of EKC hypothesis; due to the insignificance of GDPG. Yet, GDPG squared is negative and significant at 10%, indicating the presence of diminishing feature of CO_2 emissions; but the insignificance of GDPG leads to inconclusive results about the full shape of the curve. In addition to, the EEKC hypothesis does not hold on the long-run in Togo. Since, on the long-run, the net effect that CO_2 and CO_2 squared have is −6.3E−05 and 8E−07, respectively, on GDPG. Therefore, the relationship will be monotonic decreasing relationship. To emphasis, when CO_2 increases by 1 unit, GDPG will increase by 0.020169 units in year one with 1% significance, while will decrease by 0.020232 in year two with 1% level of significance. As well, CO_2 squared has a negative coefficient of 3.97E−06 at 1% significance in year one and positive coefficient of 4.77E−06 at year two with the same level of significance.

On the other hand, in testing EKC hypothesis presence in Chad the results does not confirm the presence of the hypothesis reflected in the insignificant coefficients. As well as, when testing the EEKC hypothesis, the results confirm the presence of the hypothesis. When CO_2 emissions change by 1 unit, GDPG decreases by 0.0726 in year zero, 0.0666 in year three and started to increase at year four with 0.0454. In which, the net effect of emissions on growth is a degreasing one with 0.0938 over years of analysis. The decreasing effect indicates that higher emissions that resulted in lower economic growth on the long-run. Nevertheless, emissions squared term is negative with 7.37E−05 coefficient, which confirms the presence of monotonic decreasing relationship, summerized in Table 1.

In addition to, Congo Demp. Rep. results show that neither EKC hypothesis nor the extended version is confirmed in the country. The two hypotheses cannot be confirmed due to the insignificance of GDPG squared and CO_2 squared terms, in normal and extended versions, respectively. However, in the NEKC hypothesis, the results show that when GDPG increases by 1 unit, emissions increase by 0.752941 units in year zero and 0.434001 in year three. Therefore, relationship between CO_2 emissions and GDPG is direct positive relationship with net effect of 1.18642 on the long-run. As well as, in the extended version, results show that when GDPG increases by 1 unit, emissions will decrease by 0.0022 units in second year lag.

Equally, Somalia findings illustrate the non-existence of both normal and EEKC hypothesis. However, only the GDPG is the insignificant variable in the equation, and GDPG squared has a net coefficient value of −0.2612 that confirms the presence of the diminishing feature CO_2 emissions in the long-run. But, the insignificance of GDPG leads to inconclusive insights about the trend of the relationship before the threshold point. Furthermore, the EEKC hypothesis is insignificant; due to the insignificance of both CO_2 and CO_2 squared emissions.

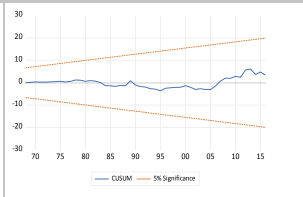
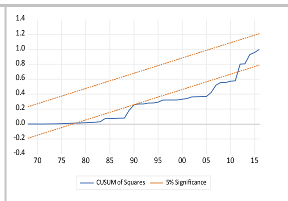
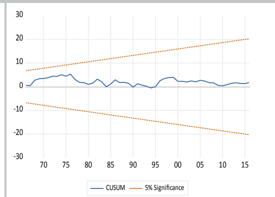
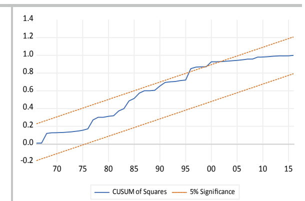
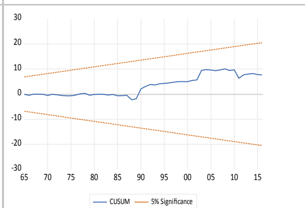
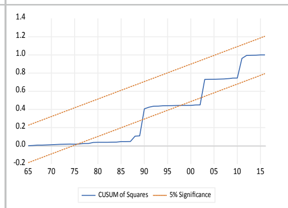
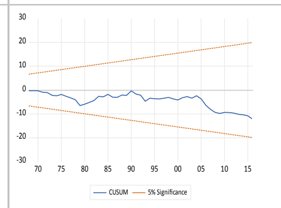
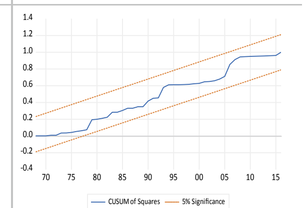
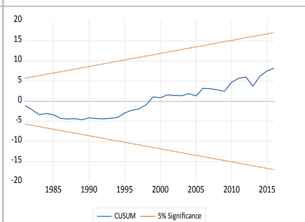
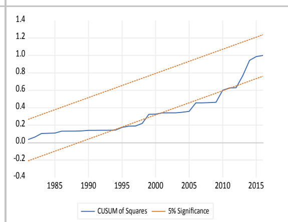
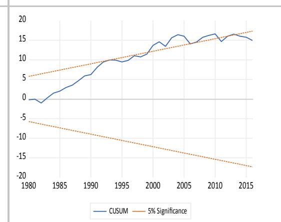
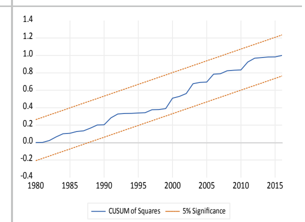
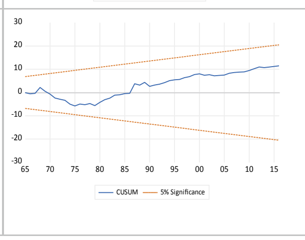
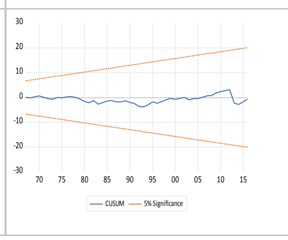
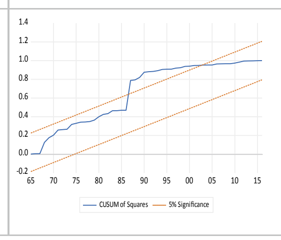
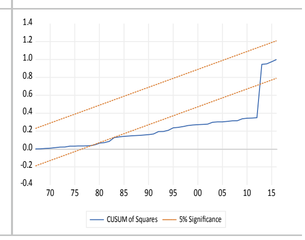
Lastly, in Burundi, Central African Republic (CAR), Niger, Rwanda, and Uganda both normal and EEKC hypothesis are not verified; due to the insignificance of GDPG in NEKC regression, as well CO_2 squared in the EEKC regression.

4.1 Stability Test

According to stability test results in Table 2, there are four main categories of stability test results of low-income countries. The first category is the countries where both normal and EEKC hypotheses are stable over time. In which, reliable policy recommendations and decisions can be made based on the estimated coefficients of both normal and EEKC; as they are stable over time. Countries that have stable normal and EEKC hypotheses are Chad, Ethiopia, Guinea, Guinea Bissau, Madagascar and Malawi.

Second, the following category contains countries where both normal and EEKC hypotheses are unstable over time. In which, accurate and effective decisions and recommendations cannot be made based on the estimated coefficients

Table 2 Stability test results for four low-income countries

Country	$CO_2 = f(GDP_g)$		$GDP_g = f(CO_2)$	
Burkina Faso				
Chad				
Gambia, the				
Central African Republic (CAR)				

Due to space issues; the rest of the results are available upon request

of both normal and EEKC; as the estimated relationship are not stable over time. Countries that have instable normal and EEKC hypotheses are Gambia, the, Mali, Niger, Togo, Uganda, represented in Table 2.

Third, this category contains countries where only NEKC hypotheses is stable over time and extended version is unstable (Table 2). In which, only the estimates of NEKC hypothesis can be used in decision making and policy recommendations and not extended version; as the normal one is only of stable estimates over long-run. Countries that have stable NEKC hypothesis and instable EEKC are Central African Republic (CAR), Rwanda and Sierra Leone.

Lastly, according to Table 2, the fourth category contains countries that have stable EEKC hypotheses. In which, only the estimates of EEKC hypothesis can be used in decision making and policy recommendations and not normal version; because the extended one is only of stable estimates over long-run. Countries that have stable EEKC hypothesis and unstable NEKC are Burkina Faso, Burundi, Congo Damp. Rep, Haiti, Mozambique, Somalia and Sudan.

5 Conclusion and Implications

Since CO_2 emissions are of the largest percentage from both energy consumption and greenhouse gases emissions; therefore, the study investigated the existence of the EKC hypothesis in low-income countries by examining the relationship between CO_2 emissions and economic growth proxy through GDP growth rates. According to EKC hypothesis, a unidirectional causality should run from GDPG to CO_2 emissions, supporting the used functional form used, which is CO_2 emissions is a functional form of GDPG. However, the exiting empirical finding in environmental literature is supporting the presence of bidirectional causality between CO_2 emissions and GDPG rates (see Table 1). Thus, the research will extend the EKC hypothesis with an additional functional form, in which GDP is a function of CO_2 emissions. The examined extension will be called extended environmental Kuznets curve (EEKC) and the normal environmental Kuznets curve will be called

(EKC). Both EKC and EEKC will be examined in the research through ARDL and stability econometric techniques. In addition to, the sample size will be from 1960 till 2016, which is the longest examined sample in EKC strand for Burkina Faso, Ethiopia, Madagascar, Malawi, Mozambique, Guinea, Sierra Leon, Sudan, Chad, Malawi, Togo, Guinea, Guinea Bissau, Haiti and Gambia.

The first group of countries consists of Burkina Faso and Ethiopia, where both EKC and EEKC hypotheses are confirmed. These countries have a positive long-run co-integration relationship between CO_2 and GDPG, where the production in the country increases, emissions also increase. According to EKC hypothesis, when GDPG reaches maximum of 2.04% and 5.513% for Burkina Faso and Ethiopia, respectively, emissions will start to decrease and growth will continue increasing. In addition to, EEKC hypothesis, GDPG will start to increase after the threshold of CO_2 emissions, which is 2008.696 and 9087.25 for Burkina Faso and Ethiopia, respectively. However, these countries should start to improve environmental laws and regulations in the economy, in which environmental constraints should be imposed on CO_2 emissions. Alternatively, the economy of these countries should be diversified and include service sector as well as industrial one.

The second group of countries consists of Madagascar, Malawi and Mozambique, where only EKC hypothesis is confirmed. Only Madagascar has positive long-run co-integration between emissions and economic growth. According to NEKC hypothesis, when GDPG reaches the maximum of 3.812%, emissions will start to decrease and growth will continue increasing. But, close attention to emissions level in the country, along with enhancing environmental regulations should be given. On the other hand, Mali and Mozambique have a positive relationship between emissions and growth. According to Akinlo (2008), in such case each country should revise its energy conservation policies appropriately, with regard to its conditions.

The third group of countries consists of Guinea, Sierra Leon, Sudan, Chad, Malawi and Togo, where EEKC hypothesis is confirmed. It is only confirmed in the short-run for Malawi and Togo. According to EEKC hypothesis, both GDPG and emissions will increase till reaching the maximum point of emissions, then emissions will decrease and growth will continue increasing. Nevertheless, these countries should start to improve environmental laws and regulations in the economy, in which environmental constraints should be imposed on CO_2 emissions. Alternatively, the economy of these countries should be diversified and include the service sector as well as the industrial one.

The last category consists of Guinea, Guinea Bissau, Haiti and Gambia, The, in which both EKC and EEKC are rejected and the data show another type of relationship. To start with, Guinea EKC and Haiti EEKC show a negative relationship between CO_2 and economic growth, where higher emissions resulting in lower growth. Therefore, higher production levels should be attained in both countries with enhancing the environmental quality regulations. While Guinea Bissau NEKC reveal a negative relationship between CO_2 emissions and GDPG, resulting in a monotonic decreasing relationship. Thus, the higher the growth will result in higher emissions and vice versa; so conservative energy consumption policies should be applied. In addition to, Haiti NEKC, and Gambia, the NEKC and EEKC shows a monotonic increasing relationship; thus, countries should apply restrict energy consumption regulations in favor for environmental quality. Besides, according to Pao and Tsai (2011), in order to reduce the negative effect of emissions on growth, governments should apply dual strategy, in which, investments in energy infrastructure increases, as well as, increase conservation policies. Consequently, the energy productivity will increase and energy wastes will sharply decrease.

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A Discovery of the True Relationship Between Biodiversity and Economic Growth in Light of COVID-19

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Abstract

For decades, societies have been planting the seed of their own destruction. The environmental degradation catastrophe has become so voluminous and complex, seen in many forms and extending across various dimensions of nature. Air pollution, water pollution, and soil pollution have caused tremendous amounts of damage. Species extinction and the loss of various forms of life have been massively increasing at an unprecedented rate. It is calculated that approximately 0.01–0.1% of all known species will become extinct each year. This raises a major concern: Could biodiversity loss affect the wellbeing of nations through hindering economic growth? If so, to what extent? This is the question that this study aims to investigate. The case of COVID-19 has been a powerful example enabling the world to witness how biodiversity loss could affect economic growth, which has posed as an economic threat to all nations. This study, therefore, investigates the relationship between biodiversity and economic growth utilizing a fixed effects panel regression conducted using a selected sample of OECD countries. Findings of this study indicate that biodiversity does in fact hinder GDP growth in the long run.

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Keywords

Biodiversity • Sustainability • Economic growth • COVID-19 • Green economic growth • OECD • Fixed effects • Panel • Extinction • Conservation • Ecosystem • Environmental economics • Farmland birds indicator • GDP

1 Introduction

Ever since the industrial revolution, the emissions of greenhouse gases have increased drastically, which has led to the progressive accumulation of heat trapped into the earth's atmosphere. The state of the environment is one of the most critically important concerns of the world today, more than ever before. Environmental degradation has become immensely complex, amplifying across the various interrelated dimensions of climate change, the ozone layer, air pollution, waste generation, deforestation, fish resources, water quality, energy resources, and last but not least, biodiversity loss. This is just to name a few of the most prominent predicaments discussed and investigated by the OECD (OECD, 2008; Tietenberg & Lewis, 2018). Biological diversity or biodiversity is the term used simply to refer to the variety of life on Earth. This diversity is seen at numerous levels including the variety of genes found in all species and the ecosystems that these species compose. Biodiversity is composed of numerous plants, animals, and other organisms including humans (Chivian and Bernstein, 2010).

It is important to acknowledge that almost all drivers of environmental degradation are drivers of biodiversity loss, as the loss of species is a form of environmental damage (Forester et al., 1996). As a life-support system, biodiversity loss belongs to a distinctive class of environmental damage because it encompasses complex ecosystems and their eradication cannot ever be recovered by technological advancements. It is believed that we are facing a biodiversity

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crisis, tumbling into extinction levels that could possibly be equivalent to the extinction of dinosaurs (Asafu-Adjaye, 2003). It is a catastrophe because mankind is dependent on the richness of nature for survival, for maintaining a decent quality of life, and for sustaining prosperous economies. We rely on natural ecosystems for energy, food, clean water, clean air, and raw materials (Eurostat, 2019). Global biodiversity is being lost at an alarming rate because of anthropogenic activities. This includes climate change, air pollution, water pollution, pesticide usage, noise pollution, and many more sources of environmental degradation that cause habitat loss and species death through the loss of genetic variation and population viability of species. This ultimately leads to extinction. Biodiversity loss is one of the most severe global environmental disasters today (Forester et al., 1996). Current statistics of species loss are shocking. According to the World Wildlife Fund report (Grooten & Almond, 2018), it is calculated that approximately 0.01–0.1% of all known species will become extinct each year. Currently, there are around 2 million known species on earth, meaning that between 200 and 2000 species will become extinct annually.

Therefore, the environment and particularly biodiversity must be well preserved; and sustainable economic growth must be sought. In addition, it has been proven that biodiversity loss is strongly correlated with an increase in the rise of contagious diseases such as SARS, MERS, Ebola, dengue, HIV, and COVID-19. In fact, biodiversity loss and ecosystem degradation created favorable conditions for the emergence of COVID-19 and have actually made it possible (Hassan et al., 2020; Platto et al., 2020; Quammen, 2020; Vidal, 2020). The COVID-19 pandemic has spread extremely rapidly across the world, infecting millions of people globally and halting economic activities worldwide as governments imposed movement restrictions. In addition to the human lives lost due to the pandemic, this period has been recognized as the largest economic shock the world has seen in decades. It has been recognized to be more severe than the great depression and WW2 (World Bank, 2020). COVID-19 has been triggered by natural ecosystem disruptions that have shaken viruses out of their natural hosts and caused them to spread over to humans (Quammen, 2020). The loss of biodiversity causes the degradation of the ecosystem service that buffers the spread of pathogens from animal hosts to humans, which is known as the dilution effect (Keesing et al., 2010). In addition, as we experience increasing extinction rates for most species, other species tend to survive and increase in population, which happen to be those that spread viruses to humans, such as bats and rats (Jones, 2008). As a result of COVID-19, the world experienced a massive recession as GDP levels plunged the world economy into a deep contraction. Not only has this led to economic losses, but the COVID-19 crisis has also cost millions of lives, healthcare burdens, production losses, poverty, and job losses, along with many other ramifications posed by the emergence of COVID-19. The fact that biodiversity loss is affecting economic performance through the emergence of infectious diseases is catastrophic; this raises a question about the dynamics between environmental and economic conditions.

2 The Economics of Biodiveristy Loss

Natural resources such as agriculture, fisheries, and forestry are directly and indirectly important for many industries including pharmaceuticals, food and beverage, tourism, and many more industries on which economic growth depends (Pearce, 2001). For example, in Switzerland, the ecosystem services supplied by species such as bees doing the pollination work, underpins about 231 million dollars' worth of agricultural sales per year. Honey production generates a value of approximately 1.1 billion dollars annually (TEEB, 2010). Furthermore, the global aggregate economic value of insect pollination is worth approximately US$ 153 billion, which accounts for 9.5% of the global agricultural production of the year 2005 alone (Gallai et al. 2009). In addition, wildlife also helps prevent pests and diseases, without which governments will be harmed as they spend massive amounts of money on healthcare provision.

According to Tammi et al. (2016), the regulating ecosystem services of the temperate regions in Finland amount to approximately 1 Billion Euros. Furthermore, ecosystem services such as carbon sequestration which has a value of 31 million dollars, pollination which amounts to 9.9 million dollars, and nutrient retention which generates a value of 54 million dollars. Therefore, these are values that contribute to the economic growth of Finland alone. A study conducted by Remme et al. (2015) in the Netherlands estimates the economic value of air quality regulation services, which has been found to be worth 2 million Euros approximately. Similarly, a study done in Denmark found that the economic value of carbon regulation is around 0.4 million dollars (Ghaley et al. 2014), and the economic value of climate regulation in the Czech Republic is 267.32 million dollars (Balasubramanian, 2019).

The overall values of biodiversity have been split into two categories: use values and non-use values. Utilizing such valuation techniques has been gaining popularity in recent literature simply because this is exactly what is needed for decision-making and policymaking (Biller & Bark, 2001). The notion of a total economic value of ecosystem services is used to portray all the utilitarian values obtained from that ecosystem (Turner & Pearce, 1990). The components of the total economic value (TEV) are shown in Fig. 1.

Brander et al. (2018) explain that the TEV is composed of use values and non-use values. Use values are the useful

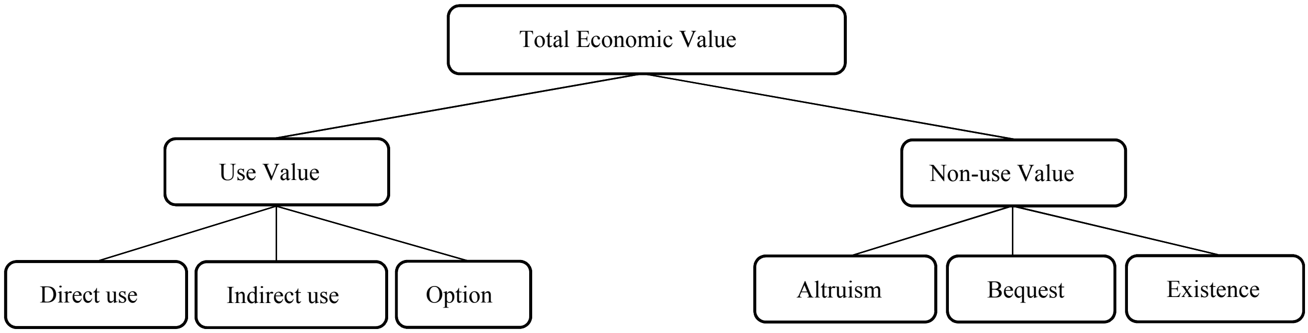

Fig. 1 The total economic value of an ecosystem and its components. *Source* Brander et al. (2018)

gains obtained from physical resources. Direct use values include consumptive value resources such as fuel, wood, or fish, as well as non-consumptive activities such as recreation. Indirect use values are useful benefits that are only related to the resource and are non-consumptive values. Examples of indirect resources include climate regulation and pollination. An option value refers to the benefit of maintaining the option to utilize the resource. Non-use values include altruism (maintaining a resource for others), existence (conservation unrelated to utilization), and bequest (for future generations). Such economic valuation calculated from the utilitarian consumption of ecosystem services is an indicator of human welfare and is used to aid in decision-making by identifying and quantifying the benefits of ecosystem services (Bräuer, 2005; Brander et al., 2018; Biller & Bark, 2001). Such ecosystem valuation has shed light on the degree to which biodiversity matters to economic performance. Hence, as suggested by this study, the loss of biodiversity would undoubtedly entail severe repercussions that obstruct economic growth by causing drastic economic losses. The severity of such repercussions could reach a point where it drives some of the world's strongest economies into recessions.

Therefore, it is vital to investigate the nature of the relationship between biodiversity loss and economic performance and to eradicate the crisis of biodiversity loss for the sake of economic growth and ultimately for the sake of human survival (Juniper, 2013). Currently, there is a research gap of empirical analysis investigating the impact of biodiversity loss on economic growth. However, there is some empirical research testing the inverse relationship, examining the impact of economic growth on biodiversity loss, as well as empirical investigations of the impact of environmental degradation in general on economic growth. A summary of the most prominent empirical studies examining similar relationships is presented below.

Yousri and Richter (2019) investigate the long-term impact of climate change on economic growth in Egypt using the threshold autoregressive model (TAR) for a 98 year period from 1917 to 2015. Findings have indicated an interesting relationship. Temperatures above 22.9 °C and below 22.4 °C have a statistically significant negative impact on GDP as such extreme changes tend to hinder GDP. This suggests that environmental degradation causing climate change would clearly impede economic growth. Similarly, Azam (2016) tested the effect of environmental deterioration by carbon dioxide emissions on economic growth for 11 Asian countries for the period 1990–2011. The study employed fixed effects and random effects panel methods. Empirical results indicate that environmental degradation has a significantly negative impact on economic growth.

Asafu-Adjaye (2003), however, has investigated the inverse relationship which tests the impact of biodiversity loss on economic growth for 100 countries grouped into high-income, middle-income, and low-income. The study methodology is composed of cross-sectional ordinary least squares (OLS) analysis. Findings indicate that there is a negative significant relationship between national income and biodiversity. The rate of economic activity represented by the level of national income has a significant negative impact on the species density of birds and mammals but not plants. National income also seems to have an inverse relationship with the average annual growth rate of mammal species. The proxy for the agricultural composition of economic productivity is highly significant for the average annual growth rate in the number of mammal species.

The results suggest that the effect on the average annual percentage change in the number of known mammal species is significant for countries of high, middle, and low-income groups but is more prominent in low-income countries. This can be explained in two ways. First, agriculture tends to form a higher component of economic production in low-income countries compared to high-income countries. Secondly, harmful agricultural practices such as slash-and-burn cultivation methods and un-monitored use of insecticides and pesticides are more prevalent in low-income countries.

Similar to the study conducted by Asafu-Adjaye (2003), Freytag et al. (2009) examined the impact of GDP growth on bird species richness in 208 countries using an adjusted OLS estimator for the period 1980–2005. The authors used bird species as a proxy for species richness in general. The study found that economic growth significantly harms species richness; however, the presence of good institutions prevents this impact which might possibly suggest that economic growth is not necessarily related to losses of biodiversity. With developed institutions, biodiversity loss could be prevented.

Likewise, Dietz and Adger (2003) investigate the relationship between biodiversity and economic growth; however, the relationship has been investigated in light of the environmental Kuznets curve (EKC) hypothesis. The study employed fixed and random effects models as well as an OLS cross-sectional model. The proportion of species conserved (based on deforestation rates) was used as a proxy for biodiversity, while GDP per capita was used as a measure of economic growth. The sample is composed of 35 tropical countries from different continents examined over the year 1972–1992. It was concluded in the study that an environmental Kuznets curve relationship between economic growth and biodiversity does not exist. The study has also concluded that it is unlikely that nations have ever been able to raise the levels of species richness as national income increases. The authors argue that, although the data utilized is problematic, their models imply that environmental preservation efforts can only ever cause a partial slowing down of biodiversity loss because protected areas serve multiple purposes and are not necessarily made for the conservation of biological diversity.

Mills and Waite (2009) also test the EKC in an attempt to imitate the study conducted done by Dietz and Adger (2003) in order to challenge their opposition to the EKC theory, using more robust econometric techniques. Mills and Waite (2009) attempted to imitate the study as accurately as possible but with some exceptions. Their study utilized the same set of data for the same time frame as well as having the same dependent and independent variables. However, unlike Dietz and Adger (2003), Mills and Waite (2009) added spatial covariates to the independent variables. This was done to address the spatial autocorrelation between countries because many countries in the dataset were only differentiated from each other by national borders but had very similar species and ecosystems. Lack of correction for spatial autocorrelation would lead to the detection of a significant relationship when it is not. This is one way this study augments the model originally constructed by Dietz and Adger. Another major difference between the two studies is that Mills and Waite used quantile regression (least absolute squares regression) while the other study used OLS, FE, and RE. Quantile regression estimates have been proven to be more robust against outliers.

In addition, Dietz and Adger (2003) used only the linear and hyperbolic functions and did not consider a parabolic model arguing that the rising segment of the EKC was a theoretical impossibility because it would only occur if the growth rate of species were to exceed the extinction rates. Mills and Waite on the other hand included parabolic, hyperbolic, and linear models, explaining that the rising segment of the EKC could perhaps be possible.

Mills and Waite (2009) initially found results supporting the EKC theory suggesting that increased income per capita leads to a higher proportion of species conserved due to decreasing rates of deforestation. However, when the authors conducted a panel analysis with dummy variables specific to each country, the initial support for the EKC was rejected. This is because reverse results have been found, refuting the EKC hypothesis. This suggests that the initial false support of the EKC was simply because of the differences between countries. Therefore, both Mills and Waite (2003), Dietz and Adger (2003) have reached the same outcome of refuting the EKC despite their different methodologies. Provided in Table 1 is a summary of all the previous empirical findings of studies exploring the relationship between biodiversity loss and economic growth, or closely similar relationships.

3 Theoretical Foundation

This study builds upon 3 main theoretical frameworks, namely (1) the environmental Kuznets curve hypothesis, (2) the Malthusian theory of population, and (3) Ehrlich's theory of the population bomb. Firstly, the environmental Kuznets curve hypothesis suggests an inverted U-shaped relationship between environmental degradation and GDP/capita. Specifically, the theory states that environmental pressures rise up to a specific level as income increases; after that, it declines. In essence, Kuznets's theory suggests that environmental damage is reversible in the long run (Kuznets, 1955). This study, however, suggests otherwise, because biodiversity loss is irreversible, and biodiversity is an integral part of the environment which makes biodiversity loss one of the clear forms of environmental degradation. Therefore, environmental degradation cannot be reversed in the long run; and if it can, Kuznets's theory would not apply to biodiversity loss. This study, therefore, simply adjusts upon Kuznet's EKC theory.

The theory that is more applicable to biodiversity loss is the Malthusian theory of population. Thomas Malthus hypothesized that as long as populations grow exponentially and resources increase linearly, the result would be that the resources necessary for survival will not be able to sustain life on earth anymore, given such enormous populations (Malthus, 1992). This study extends on the Malthusian theory because as human populations increase, this would begin to outstrip the productive capabilities of natural resources as they become degraded over time due to their

Table 1 Summary of the previous empirical studies (biodiversity and economic growth)

Study	Country	Period	Methodology	Relationship tested	Results
Yousri and Richter (2019)	Egypt	1917–2015	Threshold autoregressive model	The impact of climate change on GDP	Temperatures above 22.9 and below 22.4 have a negative impact on GDP
Asafu-Adjaye (2003)	100 countries of low, mid, and high income	1989–1999	Cross-sectional OLS	The impact of GDP on biodiversity	Negative relationship
Freytag et al. (2009)	208 countries	1980–2005	Adjusted OLS cross-section	The impact of bird species richness on GDP	Negative relationship
Dietz and Adger (2003)	35 tropical countries	1972–1992	–FE and RE –OLS cross section	The impact of the proportion of conserved species and GDP	EKC relationship does not exist, as there is no turning point to raise GDP
Mills and Waite (2009)	35 tropical countries	1972–1992	–Least absolute deviation quantile regression –FE country specific and region specific	The impact of the proportion of conserved species and GDP	EKC relationship does not exist, as there is no turning point to raise GDP
Azam (2016)	11 Asian countries	1990–2011	FE and RE	The impact of CO_2 emissions on output growth	Negative relationship

over-exploitation. To fulfill the needs and wants of an excessively growing world population, producers have to engage in activities such as over-fishing, mass deforestation, mass production, and therefore pollution and environmental degradation take place. Such resources causing environmental damage would eventually lead to the loss of all of our natural resources. As natural resources become limited, economies begin to crumble, in addition to famines and wars as stated by the Malthusian theory. This study, therefore, extends upon the Malthusian theory by connecting the environment and the economy with the Malthusian theory of population.

Similarly, this study also goes in line with the theory of Ehrlich's (1968) first presented in his book "The Population Bomb", which explores the relationship between population size and GDP per capita. Ehrlich argues that overpopulation could have numerous consequences such as limited resources and food production as well as serious impacts on human life through environmental degradation, destabilization of the ecosystem, and disease infections. Specifically, Ehrlich explains that population pressures will likely cause shortages in freshwater supply, erosion, degradation of soils, climate change, rising sea levels, and biodiversity loss. He explains that such ramifications will eventually cause higher death rates due to famine and disease emergence (Ehrlich, 1968; Ehrlich et al., 1993). This study builds upon Ehrlich's theory because all of the mentioned consequences entail serious ramifications to economic growth. In other words, overpopulation leads to further environmental damage and species loss, which consequently leads to economic turmoil and a plunge in economic performance.

4 Methodology

4.1 Indicator of Biodiversity and Economic Performance

It worth mentioning that a good biodiversity indicator is the one that reflects the average behavior of entire species and acts as a proxy for ecosystem health. It should be easily affected by environmental change over a short time span in order to allow for quick identification of trends as an early warning of environmental problems. It should be consisting of data that is realistic to collect, and it should aim to provide signals to policymakers (Dallmeier et al., 2013).

Accordingly, The farmland bird indicator (FBI) is an optimal measure of biodiversity loss as Gregory et al. (2005) have specifically developed it for providing a signal of biodiversity health to help policymakers develop policy measures. The FBI has been adopted as a sustainable development indicator by the EU. It has been deemed an accurate indicator of environmental degradation (Butler et al., 2007; Chamberlain et al., 2000; Fox & Heldbjerg, 2008; Newton, 2004). Evidently, a decline in farmland birds in Europe has been attributed to a reduction in the availability of critical resources utilized as nest sites and food, as a result of agricultural intensification (Traba & Morales, 2019). The loss of such key resources implies negative impacts on the broad state of wildlife, which is why taking farm birds as a proxy for the entire ecosystem is suitable. As a matter of fact, the use of the FBI as an indicator for the general health of the ecosystem is optimal for numerous reasons. Farmland birds are usually around the top of the food chain and are therefore rapidly responsive to environmental changes (e.g., pollution and climate change) that accumulate through the chain. Trends of farmland birds have been well-monitored since 1967 which indicates data availability and quite feasible data analysis. Moreover, birds have a wide range of habitat distribution, they are moderately abundant, and they have moderate body size and a moderate life span which results in population responses to environmental change at moderate spatial and temporal scales (Baessler & Klotz, 2006; Geiger, 2011; Tucker et al., 1997). Studies in Europe have shown that many plant, insect, and vertebrate species have declined in parallel to farmland birds. This indicates that bird population trends on farmlands are positively correlated with trends in other taxa (Balmori & Balmori-de la Puente, 2020; Lawton & Gaston, 2001).

The FBI contains 19 bird species, and the index shows the species' percentage change (RSPB, 2020). According to CBS (2021), the FBI is calculated as follows: the yearly indices of population numbers are geometrically averaged over all included species (index 2000 = 100). A smoothing algorithm is applied to determine flexible trends.

Whereas, the economic performance is measured using annual growth rate of gross domestic product (GDP) per capita capturing the value of all goods and services produced inside an economy during one year. It is one of the most reliable and commonly used measured to asses' countries performance (Roser, 2013).

4.2 Methodological Approach and Sample Size

This study uses quantitative analysis in order to test how biodiversity loss is affecting economic growth. Data from 1998 to 2015 has been gathered for a selection of 18 OECD countries. This sample has been chosen specifically due to data availability. The gathered data has been obtained from the OECD statistics database for the following variables: GDP per capita growth rate and the farm birds indicator (FBI). The methodological approach used in this study is a fixed effects (FE) panel regression. After conducting the Hausman test for each econometric model, as shown in Tables 4 and 5 in the appendix, it has been apparent that the null hypothesis of RE is rejected, and therefore, it has been concluded that FE is the appropriate choice.

Conducting the Hausman test differentiates between RE and FE for every model. It examines whether or not country-specific effects are correlated with the regressors; if so, then FE is favored. The presence of unobservable international differences such as socioeconomic and natural factors not captured by the regressor is likely to occur with panel data. This necessitates the employment of FE in order to allow the relationship to vary for each country. Country-specific effects may bias the outcome variable. Therefore, fixed effect regression is used to control for such a bias, taking out any component that is constant over time.

Fixed effect models allow for the intercept to vary for each country in order to account for country-specific effects. However, beta coefficients that measure the effect of the regressors remain the same across all countries and all time periods. This model, therefore, maintains the restrictive assumption of commonality across countries. Hence, the FE estimated relationships in this study have the same functional form for all countries and all time periods. In other words, while the model estimation accounts for country-specific effects, the model still retains the assumption that the shape of the relationship remains the same for all countries.

5 Econometric Models and Results

In order to model the relationship between FBI growth rate and GDP per capita growth rate, Eq. 1 has been constructed, where farm birds index (FBI) is used as a proxy for biodiversity loss. A 5-year lag of FBI has been used because it has shown the highest significance. This makes sense because the impact of biodiversity loss will not be manifested on GDP growth immediately; it would take a few years for the impact to show. Given the vibrant natural dynamics between environment and economic activities, GDP GR is gross domestic product growth rate per capita. Moreover, 0 is the constant and is the country-specific intercept of country i. In other words, it is the unobserved fixed effect of country i that influences the dependent variable. Finally, u is the error term.

$$\begin{aligned} \text{GDP GR}_{it} = \alpha_i + \beta_1(\text{GDP GR})(-1)_{it} + \beta_2(\text{GDP GR})(-2)_{it} \\ + \beta_3(\text{FBI})(-5)_{it} + u_i \end{aligned} \tag{1}$$

The number of lags in the model was determined by following the general-to-specific procedure (G-to-S); where we start with an over-parameterized model including 10 lags for both variables, and then gradually removing the insignificant lags, till an appropriate estimation is reached, which is the one shown in Table 2, where all included variables are significant at 5% level.

The fixed effect regression results reported in Table 2 include only 13 years (2003–2015) due to the presence of a 5-year lag. The results reported show an R^2 of 38% which indicates that 38% of the variation in the GDP per capita growth rate is attributed to the 1 year and 2 year lags of GDP in addition to FBI which is a proxy of ecosystem health and environmental health overall. This is a very strong indication that ecosystem health and environmental

Table 2 Fixed effects regression of FBI on GDP (short run)

Dependent variable: GDP_GR				
Method: panel least squares				
Sample (adjusted): 2003 2015				
Periods included: 13				
Cross-sections included: 18				
Total panel (balanced) observations: 234				
Variable	**Coefficient**	**Std. error**	***t*-statistic**	**Prob**
C	1.592038	0.283266	5.620298	0.0000
GDP_GR(-1)	0.539007	0.068431	7.876700	0.0000
GDP_GR(-2)	−0.321657	0.068621	−4.687426	0.0000
FBI_GR(-5)	−0.125449	0.043212	−2.903113	0.0041
	Effects specification			
Cross-section fixed (dummy variables)				
R^2	0.382248	Mean dependent var.		2.187619
Adjusted R^2	0.324243	S.D. dependent var.		4.176014
S.E. of regression	3.432869	Akaike info criterion		5.390128
Sum squared resid	2510.117	Schwarz criterion		5.700221
Log likelihood	−609.6450	Hannan-Quinn criter		5.515157
F-statistic	6.589927	Durbin-Watson stat		1.927951
Prob(*F*-statistic)	0.000000			

wellbeing strongly affect GDP, as the relationship is significant. However, the overall coefficient shows a negative relationship in the short run, as a 1% increase in FBI is associated with a 0.12% decrease in GDP. This suggests that there is a negative relationship between biodiversity and economic growth in the short run. However, the relationship in the long run is positive as illustrated in Table 3.

While Eq. 1 represents a model that tests the short-term/medium-term relationship between FBI and GDP, Eq. 2 explores the long-term relationship between the two variables.

$$\text{GDP GR}_{it} = \alpha_i + \beta_1(\text{GDP GR})(-1)_{it} + \beta_2(\text{FBI})(-15)_{it} + u_i \quad (2)$$

where GDP GR represents GDP/capita growth rate and FBI represents the farmland birds indicator growth rate. 0 represents the constant term, and the estimated time variant covariates are denoted by 1 and 2. Moreover, it is the country-specific intercept of country *i*. In other words, it is the unobserved fixed effect of country *i*. Finally, *u* is the random error term for country *i* at time *t*. The number of lags in the model was determined by following the general-to-specific procedure (G-to-S); where we start with an over-parameterized model including 10 lags for both variables, and then gradually removing the insignificant lags, till an appropriate estimation is reached, which is the one shown in Table 3, where all included variables are significant at 5% level.

The fixed effect regression results reported in Table 3 show an R^2 of 81% which indicates that 81% of the variation in the GDP per capita growth rate is attributed to FBI which is a proxy of ecosystem health as well as environmental health overall. The variation in GDP is also attributed to the 1 year lag of GDP. A 1% increase in the GDP/capita growth of the previous year is associated with a 1.27% increase in the GDP/capita growth of the current year. In addition, the results indicate that for every 1% increase in the FBI growth rate 15 years before, the current year GDP/capita increases by 0.213877%. This makes perfect sense as there is a long-term relationship between GDP and species loss, ecosystem degradation and ultimately environmental degradation, where the impact of ecosystem degradation on GDP growth is observed over many years. This provides evidence refuting the EKC theory as the results indicate that species loss is irreversible and does not recover in the long run.

This is similar to the findings of Dietz and Adger (2003) as well as Mills and Waite (2009), where both studies refuted the EKC hypothesis based on empirical evidence, the species loss is irreversible in the long run, and there is no turning point at which the environment recovers its lost

Table 3 Fixed effects regression of FBI on GDP (long run)

Dependent variable: GDP_GR				
Method: panel least squares				
Sample (adjusted): 2013 2015				
Periods included: 3				
Cross-sections included: 18				
Total panel (balanced) observations: 54				
Variable	**Coefficient**	**Std. error**	***t*-statistic**	**Prob**
C	0.637209	0.351160	1.814583	0.0784
GDP_GR(-1)	1.278089	0.192349	6.644644	0.0000
FBI_GR(-15)	0.213877	0.084368	2.535046	0.0160
	Effects specification			
Cross-section fixed (dummy variables)				
R^2	0.812223	Mean dependent var.		2.396701
Adjusted R^2	0.707289	S.D. dependent var.		3.522492
S.E. of regression	1.905765	Akaike info criterion		4.405761
Sum squared resid	123.4859	Schwarz criterion		5.142422
Log likelihood	−98.95554	Hannan-Quinn criter		4.689862
F-statistic	7.740329	Durbin-Watson stat		2.263017
Prob(*F*-statistic)	0.000000			

species. Also supporting the findings of this study, Asafu-Adjaye (2003) found that the level of economic activity has a significant negative effect on the density of not only birds but also mammals. Accordingly, the reported results of this study go in line with results provided by Yousri and Richter (2019) suggesting that environmental degradation causing climate change would clearly impede economic growth. Logically, this is due to the fact that climate change is one of the main factors affecting biodiversity (Forester et al., 1996).

However, the results reported in Table 3 show that a 15-year lag of FBI has been introduced to a regression that is composed of a dataset of only 17 years. This indicates that the relationship captured above is only applied to 3 years, specifically 2013, 2014, and 2015. Therefore, a better representation of this phenomenon would be captured if there were longer datasets available.

6 Conclusion

In conclusion, this study explores how economic growth is affected by biodiversity loss. According to the World Wildlife Fund report (Grooten & Almond, 2018), reported calculations estimate that approximately 200–2000 species will become extinct annually, which raises a major concern about whether or not economies will be affected by such a catastrophe. The case of COVID-19 has been a powerful example enabling the world to witness how biodiversity loss could affect economic growth, which has posed an economic threat to all nations. Utilizing a sample of 18 OECD countries, the findings of this study indicate that there is a negative relationship between biodiversity and economic growth in the short run. Specifically, the short run coefficient indicates that a 1% increase in FBI is associated with a 0.12% decrease in GDP. Meaning, that declining biodiversity is associated with rising GDP growth. However, in the long run, there is a positive relationship between biodiversity and economic growth, where a decline in biodiversity is associated with decreasing GDP growth. This indicates that biodiversity is necessary for economic prosperity. Evidently, the long run coefficient indicated that for every 1% increase in the FBI growth rate 15 years prior, the current year GDP/capita increases by 0.213877%. This result is logical because there is a long-term relationship between GDP and species loss, ecosystem degradation and ultimately environmental degradation, where the impact of ecosystem degradation on GDP growth could only be observed over many years. This explains the reason why the results showed a negative relationship in the short run but a positive one in the long run. The findings of this study have to be seen in light of some limitations. For example, the limited data available for our environmental measure. Given the nature, of the studied variables better representation of this phenomenon could be captured if there were longer datasets available.

7 Implications for Future Research

It is absolutely necessary for policymakers to take a more ambitious stance to prevent further loss of biodiversity and to protect our economies and nations. Scholars, scientists, and international organizations have been calling for immediate action for years, yet policy responses have been extremely slow and in many cases ineffective (Kumar et al., 2019). This calls for new research to be conducted investigating why this is the case, and what type of action must be taken by governments and policymakers to promote the growth of biodiversity and economic growth hand in hand. In addition, the findings of this study show how much biodiversity could boost GDP, and this calls for additional research about how nations could optimize the utilization of biodiversity for GDP growth purposes. How could nations mobilize natural resources to promote economic growth in the short run and the long run? Are there ways to unlock our potential for the achievement of sustainable economic growth without sacrificing too much national GDP? These are all questions that indicate a research gap to be filled by researchers in the fields of social sciences and natural sciences.

Appendix

See Tables 4 and 5.

Table 4 Hausman test of the relationship between FBI and GDP growth (short run)

Correlated random effects—Hausman test				
Equation: untitled				
Test cross-section random effects				
Test summary		**Chi-Sq. statistic**	**Chi-Sq. d.f**	**Prob**
Cross-section random		21.611546	3	0.0001
**WARNING: estimated cross-section random effects variance is zero				
Cross-section random effects test comparisons				
Variable	**Fixed**	**Random**	**Var(Diff.)**	**Prob**
GDP_GR(-1)	0.539007	0.628947	0.000382	0.0000
GDP_GR(-2)	−0.321657	−0.228766	0.000456	0.0000
FBI_GROWTH_RATE(-5)	−0.125449	−0.143710	0.000134	0.1150
Cross-section random effects test equation				
Dependent variable: GDP_GR				
Method: panel least squares				
Date: 10/19/20 Time: 11:11				
Sample (adjusted): 2003 2015				
Periods included: 13				
Cross-sections included: 18				
Total panel (balanced) observations: 234				
Variable	**Coefficient**	**Std. error**	***t*-statistic**	**Prob**
C	1.592038	0.283266	5.620298	0.0000
GDP_GR(-1)	0.539007	0.068431	7.876700	0.0000
GDP_GR(-2)	−0.321657	0.068621	−4.687426	0.0000
FBI_GROWTH_RATE(-5)	−0.125449	0.043212	−2.903113	0.0041
Effects specification				
Cross-section fixed (dummy variables)				
R^2	0.382248	Mean dependent var.		2.187619
Adjusted R^2	0.324243	S.D. dependent var.		4.176014
S.E. of regression	3.432869	Akaike info criterion		5.390128
Sum squared resid	2510.117	Schwarz criterion		5.700221
Log likelihood	−609.6450	Hannan-Quinn criter		5.515157
F-statistic	6.589927	Durbin-Watson stat		1.927951
Prob(*F*-statistic)	0.000000			

Table 5 Hausman test of the confirmation of the long run relationship between FBI and GDP

Correlated random effects—Hausman test				
Equation: untitled				
Test cross-section random effects				
Test summary		**Chi-Sq. statistic**	**Chi-Sq. d.f**	**Prob**
Cross-section random		7.440090	6	0.2821
** WARNING: estimated cross-section random effects variance is zero				
Cross-section random effects test comparisons				
Variable	**Fixed**	**Random**	**Var(Diff.)**	**Prob**
RGDP_CAP_GR(-2)	−0.389172	−0.343872	0.000343	0.0145
FBI_GR(-7)	−0.112415	−0.120107	0.000117	0.4762
FBI_GR(-8)	−0.184895	−0.188796	0.000191	0.7776
FBI_GR(-9)	−0.130448	−0.126667	0.000118	0.7282
FBI_GR(-16)	0.104436	0.110302	0.000059	0.4467
FBI_GR(-18)	0.074791	0.078810	0.000049	0.5655
Cross-section random effects test equation				
Dependent variable: RGDP_CAP_GR				
Method: panel least squares				
Date: 06/02/21 Time: 15:24				
Sample (adjusted): 2008 2019				
Periods included: 12				
Cross-sections included: 8				
Total panel (balanced) observations: 96				
Variable	**Coefficient**	**Std. error**	***t*-statistic**	**Prob**
C	0.943710	0.306206	3.081940	0.0028
RGDP_CAP_GR(-2)	−0.389172	0.079325	−4.906030	0.0000
FBI_GR(-7)	−0.112415	0.046106	−2.438185	0.0169
FBI_GR(-8)	−0.184895	0.051015	−3.624320	0.0005
FBI_GR(-9)	−0.130448	0.044490	−2.932112	0.0044
FBI_GR(-16)	0.104436	0.037667	2.772636	0.0069
FBI_GR(-18)	0.074791	0.031685	2.360438	0.0206
Effects specification				
Cross-section fixed (dummy variables)				
R^2	0.407742	Mean dependent var.		0.728404
Adjusted R^2	0.313847	S.D. dependent var.		2.786795
S.E. of regression	2.308423	Akaike info criterion		4.645044
Sum squared resid	436.9631	Schwarz criterion		5.019012
Log likelihood	−208.9621	Hannan-Quinn criter		4.796208
F-statistic	4.342551	Durbin-Watson stat		1.924103
Prob(*F*-statistic)	0.000016			

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Devastating Impact of Climate Change Threatening Egyptian Outputs: An Empirical Analysis Since 1900s

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Abstract

The disturbing change in climate and its associated risks are putting dire pressure on the ability of humanity to feed itself. Empirical findings are forecasting that the window to address this threat is closing rapidly. This could be contributed to the unprecedented increasing rates of environmental deterioration and resources exploitation. Since the eighteenth century, human activities seen in industrial processes, burning of fossil fuels, and deforestation have released huge amounts of gases into the atmosphere. Leading to the phenomena of global warming, the increase in temperature is affecting the entire globe, and Egypt is not any different. Recent evidence suggests that nation's 3.1 million hectares of agricultural land are at high risk of complete destruction in the foreseeable future. Starting 2009, the remarkable rise in desertification problem is placing a great burden on Egypt's progress, with an estimated annual loss of 11,736 hectares of agricultural land. Until the 1960s, agriculture was Egypt leading economic sector with export value constituting around 87% of total goods. Nowadays, agriculture is still one of the main contributors to the GDP with around 14.5% of its total value and provides 28% of all jobs in the market, and 45% of women employment. This paper has two folds, firstly, it quantifies the long-term impact of increasing temperature on production activities and secondly, determine the exact threshold point after which production activities are threatened by temperature change in Egypt over a time period of almost 100 years using a threshold model. The results reveal interesting and unique relationship. If the temperature is between 22.4 and 22.9, GDP will have a positive trend, while if the temperature is below 22.8 Co, GDP will follow a negative trend. The negative trend is bigger with a higher temperature than with the lower one. What we learn from this threshold regression is that the economy needs an "optimal" temperature.

Keywords

Agriculture • Climate change • Economic growth • Production • Greenhouse gases • Temperature • Sustainability

1 Economic Performance of Egypt

Since the time of William Petty to David Ricardo and with the growing systematic economic analysis, the perplex of economic growth, its sources, forms, and effects have been a controversial and much-disputed subject among the economists. In essence, the economic growth problem is historically intrinsic in different economies, whether stationary or not. Economic expansion was claimed to different considerations throughout economic history. Studying the economic growth performance of Egypt as a developing country presents interesting findings. Egypt has always been a leading country in the Middle East, and it has been in the center of events either affecting or being affected by the radical changes caused by profound events. Overall, Egypt's economic performance varied significantly over the last seven decades (1961–2020) as shown in Fig. 1. The GDP growth rate averaged 5.1%, while real GDP per capita growth averaged 2.55%. This period mainly characterized by low increases of per capita income and GDP growth if compared to other developing countries in the same period. In the main, it is plausible to argue that the economic performance of Egypt is challenged by a number of economic, institutional, and sociological factors that is causing these fluctuations. According to the study by Yousri and Richter (2018), high-fertility rate, corruption, and urbanization continue to hinder the economic growth of Egypt.

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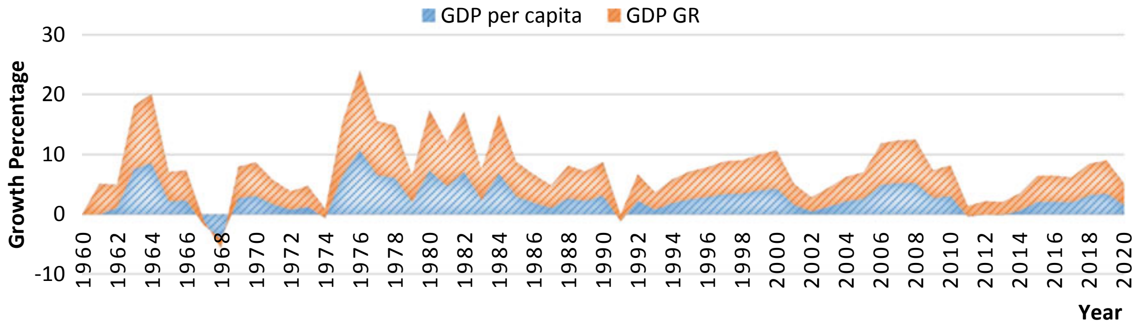

Fig. 1 GDP growth rate and GDP per capita of Egypt from 1960 to 2020. *Source* World Bank (2021)

Nevertheless, the last four years, namely 2016–2020, have shown some improvements reflected on increasing economic growth despite COVID-19 pandemic, with the reforms adopted by the Egyptian government and mega developmental projects (World Bank, 2021).

2 Overview

Egypt is a developing country although known for its diverse resources yet a main challenge for the country is reaching the balance between proper allocation of the latter and its accelerating population growth at a 2% annual rate, reaching approximately 102 million citizens in 2020. Egypt is a living example for the overpopulation problem. Ehrlich (2015) determined overpopulation given simple criterion; the ability of a country to produce enough food to feed their populations (Reed, 2008). Overpopulation in Egypt has been a rising problem for a considerable time. The 2013s population boom aggravated the problem with an addition of 2.6 million births in the given year, while Egypt was facing great difficulty in satisfying already existing needs. Egypt categorized as the most populated Arab country with a significant number of citizens under the poverty line around 32.5% in 2019. Given the large population base in Egypt, population growth will remain a problem even with a low-population growth rate (CAPMAS, 2021).

By 2050, the world population estimated to reach between 9.4 and 10.2 billion, the major contributor to this increase will be developing countries, and 17 out of 20 people will be living in the poorer nations with an estimated population increase of the double. More precisely, it is expected that namely ten countries will cause more than half of the anticipated increase over the period 2017–2050. Egypt ranked number ten (UN, 2017; UN-Habitat, 2008; UNDP, 1999).

Owning to its desert nature, the whole population is allocated to only 4% of the total area of the country. Unsurprisingly, the Nile valley, from Aswan in the south to Cairo in the north, and the Delta together represent 2.5% of the aforementioned 4%; as the River Nile is considered the main source of water and plays a major role in the country's livelihood providing 95% of water needs (Eid et al., 2007). From which 80% consumed in agriculture, the warm weather, quality of land, and plentiful water making it convenient for intensive agriculture throughout Egypt's history (El-Raey, 1999; El-Shaer et al., 1997).

Nevertheless, recent evidence suggests that nation's 3.1 million hectares of agricultural land are at high risk of complete destruction in the foreseeable future. Starting 2009, the remarkable rise in desertification problem is placing a great burden on Egypt's progress, with an estimated annual loss of 11,736 ha of agricultural land every year, claimed to change in climate and human activities. Furthermore, the increasing water salinity assumed to seawater intrusion and other factors is negatively affecting irrigated agriculture that was estimated to be 25% in 2011 and thus constraining agricultural productivity. In 1960, agriculture was considered Egypt leading economic sector with export value constituting around 87% of total goods, yet it lost it in the 1970s, with a drop to 35% only (The New Humanitarian, 2011). Nowadays, agriculture is still one of the main contributors to the gross domestic product with around 14.5% of its total value and provides 28% of all jobs in the market, out of the total women workforce 45% are working in the agriculture industry (USAID, 2017).

According to the studies by UN (2018) and Thorpe and Ogle (2011), climate change threating impact on humanity has been increasing lately at a great pace and will be seen all over the world. Lekwot et al. (2012), Pittock (2017), Campbell-Lendrum et al. (2003), Graßl et al. (2003), Gruner et al. (2002), and McCarthy et al. (2001) argue that environmental change drivers are seen to have a significant negative impact on human health directly or indirectly and hence their productivity and productive life years. These impacts are more prevalent in countries that are characterized by high vulnerability and population growth rate. Tackling climate change and its associated risks and causes is unavoidable for all countries and more specifically for developing countries like, in our case Egypt, as they are mainly relying reliance on climate-sensitive activities like agriculture, fisheries, and forestry, tied with their high-poverty levels, population growth, and poor educational level, and institutional, technical and financial capacity, economic status, lack of responsibility toward the causes of the environmental problems (Lekwot et al., 2012; Parry et al., 2007; Thorpe & Ogle, 2011; UN, 2018).

2.1 Research Importance and Motive

According to Dasgupta et al. (2009) among the Middle East and North Africa region, Egypt and its population will be affected the most by the environmental damage observed in climate change and its associated negative outcomes, and it will be among the five most impacted countries all over the world (Dasgupta et al., 2007). These findings highlight the importance of carrying out this research. Given that, acknowledging the importance of tackling the problem by applying proper solutions. Given that pre-adaption plan for climate change will be of less cost than post-event expenses (Elsharkawy et al., 2009; Thomas, 2008). Second of all, the low-economic growth and overall poor economic performance experienced by Egypt over the past decades remain unprecedented, especially that Egypt is known for abundance of natural and human resources a problem that worth understanding. Furthermore, most of the published researches cannot be generalized given the special nature of each country. Goodland and Daly (1992) argue that they need to consider the special nature of the developing countries while analyzing their economic performance. Further, some argue that economic growth is not closely attached to human welfare. Accordingly, understanding the impact of environmental changes in Egypt on Economic activities and hence citizens is vital (Nussbaum and Sen, 1993; Rosa et al., 1980; Sen, 1993).

2.2 Research Gap and Objective

Egypt, therefore, face poor economic performance and environmental degradation together as a key burden to further development. In fact, the question arises whether there is a link between the two. Hence, Egypt may consider improving economic performance on a sustainable basis as a key factor in finding a long-term resolution to both population and environmental problem. The available literature has—to the best of our knowledge—not tackled the effect of historical experience with climate change on economic growth in Egypt. Hence, this research objective is to research the nature of the paradoxical relationships between economic growth and climate change in Egypt. Through testing the following hypothesis; H1: Temperature has a long-term negative relationship with economic growth.

The generalizability of the published research analyzing developing countries, on a country like Egypt, without any consideration for its special social, environmental, and institutional nature is problematic. Most of the available literatures analyzing the Egyptian economic growth and its possible determinants. Either analyzed a limited number of economic explanatory variables, such as government expenditure, trade openness, and capital accumulation or included Egypt as one of many countries listed in the panel data of the study without adequate consideration to special nature of every country and the possible dynamics between environmental-economic factors. For example, Alhakimi and Alhagrasy (2015), Ghalwash (2014), El Hamid (2013), Nasr (2008), Kheir-El-Din and Moursi (2006), Bolbol et al. (2005), Galal (1998), and Levy (1986) This calls for further research for our case Egypt.

The approach suggested in this research is intended as a preliminary step toward constructing a better understanding of the dynamics between the environment and economic performance relative to the other driving forces in a developing country such as Egypt. This research builds on the work of Hussen (2012), Hughes (2009), Bhattarai and Hammig (2001), Stern et al., (1996), Cropper and Griffith (1994), Turner et al., (1993), Lewis (1992), Trainer (1990), Rudel (1989), Allen and Barnes (1985), Repetto and Holmes (1983), Ehrlich and Holdren (1971).

3 The Change in Climate and Agriculture Distress

One should be caution in using the term economic growth interchangeably with economic development. Given that achieving high-economic growth does not necessarily indicate development. For instance, there could be economic growth with high level of pollution or unequal income distribution (Hollanders, 2015; Sen, 1999). According to USAID (2017), the increase in the Egyptian economic activities and continued fossil fuels burns have shown a clear reflection on Egypt's anthropogenic greenhouse gases emissions (CO_2), which increased, by 133% over the period 1990–2012. Thus, it is possible to claim that the increase of anthropogenic greenhouse gases mostly stems from the uncontrolled businesses' activities and unsustainable production pattern followed. The increasing air, soil, and water pollution (Wedy, 2016), the continuous rise in anthropogenic greenhouse gases along with deforestation and the use of unsustainable techniques in the agriculture industry has led to change in climate (Gerrard, 2007; Oreskes & Conway, 2011).

Climate change as seen in the continuous increase in global temperature, the rise in sea level, and ocean acidification is putting the survival of many countries especially developing countries, coastal areas, low-lying coastal countries, and the small islands at risk (Abou-Hadid, 2006; Elsharkawy et al., 2009; Leary & Kulkarni, 2007; WHO, 2021). Climate change negative effect extends to earth natural resources that are seen as a fundamental factor of production in any given country especially in developing countries. Combine these factors together leads to nothing but intensify for the weather-related disaster impacts (IFRC, 2009).

This environmental catastrophe named change in climate has taken this dramatic turn after 1997, and it is seen to risk human lives. It is estimated that by the year 2100 an increase in temperature between around 1.8 and 4 °C will be taking place, considering the probable minimum increase (1.8 °C), it will still be larger than any variation that occurred over the last 10,000 years (Gore, 2006; Sachs, 2015). This environmental imbalance is threatening human life and all living on the planet with a degree and intensity that has never been witnessed before, it contributes to the increasing diseases, land, and asset damage which has an estimated cost of billions of US dollars (Elsharkawy et al., 2009). In the same vein, Graßl et al. (2003) note that a closer look at the developing world especially African countries would, in fact, reveal a more distressing effect now and in future because of change in climate and the projected global increase in temperature. As it affects and will continue to affect their key sectors, which are crucial factors to achieving sustainable socio-economic development, for example, agriculture, water, health, energy, and transportation (Pelling et al., 2004).

As per the World Bank, Egypt's temperature has shown an increasing trend over the last years with an average of 22.4 °C see Fig. 2, the hottest recorded year for Egypt was 2010 with an average yearly temperature of 24.8 °C.

Although, many sectors will be affected as mentioned before, the agriculture sector will be affected the most by the increasing frequency of extreme environmental events such as the increase in temperature. African countries are already exploiting agriculture land (UNEP, 2007). The anticipated reduction in crop yield, change in crops' cycle and structure has a direct impact on productivity, income, unemployment, nutritional value, and taste of some fruits and vegetables (Elsharkawy et al., 2009; UNEP, 2007). According to Lekwot et al. (2012), the continuous decrease in agriculture productivity and crop yield will cause a direct change in supply and demand pattern leading to an increase in goods prices, decrease in farming profitability, food availability and affordability, and human health problems. In addition to, the expected increase in the prices of imported goods. It is possible to argue that Egypt will suffer from food availability problems (El-Raey, 1999).

A problem that will be aggravated by the accelerating population growth, urbanization, industrial development, and irrigation intensification. Since these factors lead to a continuous increase in water demand triggering agriculture vulnerability in Egypt (Abou-Hadid, 2006). Egypt was listed as one of the most affected countries by environmental surges; an increase of 83.6% is estimated to Egypt surge zones, with the continuous change in climate, Egypt will suffer from storm surges along with the sea level rise putting cropland at risk as well (Dasgupta et al., 2009).

Eid et al. (2007) have supported this view as they estimated that the agriculture sector in Egypt will be suffering in the coming years because of a decrease in available water and subsequently irrigation water that is caused by climate change. Especially that Egypt is suffering already from water stress along with the continuous population growth that it mainly concentrated along the Nile valley and delta pressured by increasing urban demand (Leary et al., 2008). The aforementioned industries will be forced to reduce their operations and downsize employees to accommodate these

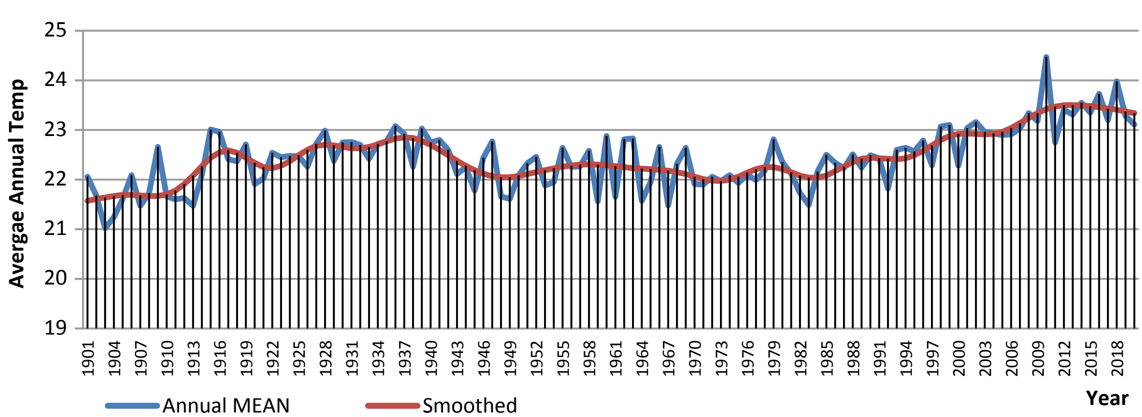

Fig. 2 Average annual temperature in Egypt 1901–2020. *Source* Climate Change Knowledge Portal World Bank (2021)

changes in the short run. However, this could be reversed in the long run if adequate measures are taken or the shutdown of major industries is projected in the medium to long run (Schubert et al., 2007).

The impact on human survival and animal livelihood is almost certainly catastrophic as plants represent the main source of energy, food production, and medical herbs. The water and food deficiency will lead to more poverty; a real example of this would be Nigeria (IFRC, 2007) and Egypt (Eid et al., 2007). The aforementioned environmental imbalances will cause a decrease in income and limit the ability to satisfy household needs' and wants' (Lekwot et al., 2012; Parry et al., 2007). Further, creates net losses, increase impoverishment (Graßl et al., 2003), unemployment and increasing environmental induced migration (Schubert et al., 2007) which will give rise to destabilization, the failure of social systems, and vicious conflicts (UNEP, 2007), ending with probable political unrest are foreseen (Elsharkawy et al., 2009). Meaning that protecting the environment is an essential element in poverty alleviation and the country's social stability (Hughes 2009; Shiva & Bandyopadhyay, 1989).

4 Methodology

This paper contests the claim that economic activities measured in annual GDP and GDP per capita have a long-term relationship with the environment measured using average annual temperature in Egypt. Economic activities are not only affecting the environment but also being affected any change in the environment. Hence, it could conceivably be hypothesized that; H1: Temperature has a long-term negative relationship with economic growth.

Accordingly, time series data from 1917 to 2015 were gathered from multiple sources such as the World Bank, Issawi (1947), Hansen (1975), Yousef (2002) and Climate Change Knowledge Portal. The data were analyzed using E-views software. A threshold model is used to determine the exact turning point for change in climate and to be able to determine the optimum level. The use of threshold models has been vastly influential in economics and evident in several different areas of statistics and not limited to time series. Generally, the empirical use of the threshold model in different economic settings is conceivable. Tong and Lim (1980) first introduced threshold autoregressive (TAR), yet it was credited to Tong and Dabas (1990) for his extensive presentation. Threshold model is based on the idea that a certain process may act in a different way when the value of the chosen variable(s) exceeds a certain threshold value. To be precise, a different model may apply when values are above the threshold value than when they are below it. It works based on the assumption that the "regime is determined by a variable qt relative to a threshold value". Threshold model is used in different fields of economics, for instance, Agricultural Economics, Macroeconomics, and Industrial Economics.

What makes the use of threshold modeling beneficial in many different ways are the recent developments that have offered distinctive methods of incorporating the non-stationarity and cointegration properties of economic data. The Threshold model offers a broader specification for the model. As for instance, when adjustment is seen symmetric in the error correction term, threshold model reduced to the standard error correction model (Balke & Fomby, 1997; Enders & Granger, 1998; Enders & Siklos, 2001; Hansen, 1997).

5 Results and Discussion

The economic activities of Egypt are not only affecting the environment but also being affected by any change in the environment. In the early 1900s, Egypt's economy was mainly agriculture-based and thus more sensitive to any change in environmental factors. Estimating threshold model shows that if GDP one year ago was less than 24%, then the impact of temperature is negative and will cause a reduction of 1%, and this result represents most of the observed sample yet is insignificant. On the other hand, if GDP is greater than 24%, the temperature impact will turn out to be bigger with almost 16%, and the final model was selected based on the robustness check. For this time period (1917–1945) given that Egyptian GDP was mainly agriculture driven by temperature has a much bigger impact if compared to an industrialized country. Hence, economic growth plans including production plans, agriculture methods, and natural resource management need to go in line with climate change policies and programs. This result goes in line with the previous empirical findings. Lopez and Mitra (2000) showed in their study that the income-environment relationship exhibits a U-curve relation supporting the environmental Kuznets curve (EKC), as initially an increase in income leads to a deterioration in the environment, up to a certain level of economic growth, at which a positive relation is witnessed between economic growth and environmental quality (Gill et al., 2018).

$$\mathrm{GDP}_t = \alpha + \begin{cases} \beta 1 \mathrm{Tempgr}_t + u_t & \text{if } \mathrm{GDP}_{t-1} < 24.6 \\ \beta 2 \mathrm{Tempgr}_t + u_t & \text{if } \mathrm{GDP}_{t-1} > 24.6 \end{cases} \quad (1)$$

Studying the economic environmental interaction over a longer time period 1917–2015 using the threshold model reveals a more interesting and unique relationship as shown in Tables 1 and 2. If the temperature is between 22.4 and 22.9 °C GDP per capita will have a positive trend while if

Table 1 Environmental-economic growth threshold model 1917–1945

Dependent variable: GDPGR				
Method: threshold regression				
Sample (adjusted): 1918 1945				
Threshold type: Bai-Perron tests of $L + 1$ versus L sequentially determined thresholds				
Threshold variables considered: GDPGR(-1) GDPGR(-2) GDPGR(-3) GDPGR(-6) GDPGR(-7) GDPGR(-8)				
Threshold variable chosen: GDPGR(-1)				
Threshold selection: trimming 0.15, Max. thresholds 5, Sig. level 0.05				
Threshold value used: 24.66636				
Variable	**Coefficient**	**Std. error**	***t*-statistic**	**Prob**
GDPGR(-1) < 24.66636 – 24 obs				
TEMPGRPR	−0.947441	0.692926	−1.367305	0.1837
24.66636 ≦ GDPGR(-1) – 4 obs				
TEMPGRPR	−15.67293	2.858535	−5.482852	0.0000
Non-threshold variables				
C	3.679790	1.861473	1.976816	0.0592
R^2	0.379256	Mean dependent var.		5.268097
Adjusted R^2	0.329597	S.D. dependent var.		11.41974
S.E. of regression	9.350276	Akaike info criterion		7.409646
Sum squared resid	2185.691	Schwarz criterion		7.552382
Log likelihood	−100.7350	Hannan-Quinn criter		7.453282
F-statistic	7.637127	Durbin-Watson stat		1.065589
Prob(*F*-statistic)	0.002579			

Table 2 Environmental-economic growth GDP per capita threshold model

Dependent variable: RGDPPC				
Method: threshold regression				
Threshold type: Bai-Perron tests of $L + 1$ versus L sequentially determined thresholds				
Threshold variable: TEMP				
Threshold selection: trimming 0.15, Max. thresholds 5, Sig. level 0.05				
Threshold values used: 22.40362, 22.90669				
HAC standard errors and covariance (Bartlett kernel, Newey-West fixed bandwidth = 4.0000)				
Variable	**Coefficient**	**Std. error**	***t*-statistic**	**Prob**
TEMP < 22.40362 − 36 obs				
TREND	−3.001981	2.925292	−1.026216	0.3078
RGDPPC(-1)	1.252926	0.028749	43.58150	0.0000
22.40362 ≦ TEMP < 22.90669 − 39 obs				
TREND	10.00091	3.303288	3.027562	0.0033
RGDPPC(-1)	1.045207	0.028916	36.14680	0.0000
22.90669 ≦ TEMP − 15 obs				
TREND	−55.35832	17.09311	−3.238634	0.0017
RGDPPC(-1)	1.389468	0.084192	16.50361	0.0000
Non-threshold variables				
C	−5.783884	1.507539	−3.836640	0.0002
R^2	0.998851	Mean dependent var.		1031.837

(continued)

Table 2 (continued)

Adjusted R^2	0.998768	S.D. dependent var.	2019.096
S.E. of regression	70.87020	Akaike info criterion	11.43416
Sum squared resid	416,874.6	Schwarz criterion	11.62859
Log likelihood	−507.5374	Hannan-Quinn criter	11.51257
F-statistic	12,026.13	Durbin-Watson stat	1.571736
Prob(F-statistic)	0.000000		

the temperature is below 22.8 °C, GDP per capita will follow a negative trend. The negative trend is bigger with a higher temperature than with the lower one. What we learn from this threshold regression is that the economy needs an "optimal" temperature, which is between 22.4 and 22.9 °C, i, in order to avoid any food shortage problem or any macroeconomic imbalances. Of course, this result is country specific and may be different for other countries. However, as far as Egypt is concerned, Egypt has an interest to limit the temperature increases to 22.9 °C. This could be challenging to achieve, thus, Egypt needs to prepare a backup plan as an alternative to the potential agriculture production loss claimed to climate change in future.

$$\mathrm{GDP}_t = \alpha + \begin{cases} \beta 1\mathrm{Trend} + \beta 2\mathrm{GDP}_{t-1} & \text{if Temp} < 22.4 \\ \beta 3\mathrm{Trend} + \beta 4\mathrm{GDP}_{t-1} & \text{if } 22.4 < \text{Temp} < 22.9 \\ \beta 5\mathrm{Trend} + \beta 6\ \mathrm{GDP}_{t-1} & \text{if Temp} \geq 22.9 \end{cases} \tag{2}$$

6 Conclusion and Implications

In conclusion, there is a consensus among economists that developing countries economy known to be fragile and unstable. On the economic level, they are largely based on agriculture activities where the environment is an important factor of production. On the social level, accelerating population growth is evident. On the institutional level, a high level of corruption or institutional failure is present. On the environmental level, they are suffering from an increase in drought, water scarcity, and soil degradation. Thus, the risk of environmental migration is projected in the coming years. The novelty of this research paper is not only represented in the impacts that it tests for but also, the country of choice and time period covered; Egypt is an interesting case to study as one of the developing countries that are at high risk of environmental damage and is simultaneously facing institutional, social, and economic challenges.

The general increase in temperature known as global warming leads to a number of environmental risks. These negative outcomes do have an impact on the country long-term developmental plan. A clear negative outcome would be a decrease in agriculture productivity, food shortage, diminishing of natural resources, health problems, increase in poverty and unemployment, in addition to environmentally induced migration. Accordingly, it is important to eliminate the source of the problem by eliminating or controlling factors such as population growth, uncontrolled economic activities, pollution, and institutional failure, as all efforts directed toward sustainable development and environmental protection could be wasted by these factors. Meaning that public policies, goals, guidelines, and developmental social and economic programs must be in line with the objectives, guidelines, and instruments of environment protection. This includes reducing emissions by using environmentally friendly production methods, infrastructure, and technology. On the micro-level adjustment to citizens, lifestyle to a more environmentally friendly life is crucial. The paper underpinned the impact of climate change on economic growth. The evidence from this threshold regression suggests that the economy needs an "optimal" temperature, which is in between 22.4 and 22.9 °C. Obviously; this result is country specific and may be different for other countries. However, as far as Egypt is concerned, Egypt has the interest to limit the temperature increases to 22.9 °C. Acknowledging the importance of tackling such a problem is done via applying proper solutions. Alternatively, Egypt might consider investing in technology where agriculture productivity is somewhat maintained despite the change in climate (increase in temperature). Given that pre-adaption plan for climate change will be of less cost than post-event expenses.

Thanks to data availability, we analyzed in the study the consequences of a specific problem, namely the change in climate for economic growth in Egypt over a long period. However, our econometric analysis to provide a more comprehensive multidimensional growth model for Egypt was at times restricted by the limited amount of data available for other plausibly relevant variables affecting the dynamics of our model. We recommend expending this research to include the role of technology, social, institutional variables that could be relevant to the growth formula of Egypt along with the environmental one.

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Preschool Children's Environmental Knowledge and the Application of Multimedia Learning for Environmental Education

Athirah Zaini, Kin Meng Cheng, Tee Chuan Ong, and Sean Calvin Shin Ching Yong

Abstract

Environmental issues are known to be caused by human activities. To overcome this, children must be exposed to environmental education from a young age. The subject of environmental issues, on the other hand, is vast, making it difficult for adults to convey and even more difficult for children to comprehend. The focus of this study is two-fold: to investigate the level of environmental knowledge amongst preschool children in Malaysia and to integrate multimedia learning in environmental education. A conclusive descriptive research design using a semi-structured interview was initiated, and the results indicated that preschool children have more awareness of common environmental issues but lack a deeper understanding of their causal relationship. The result also finds that preschool children can comprehend complex environmental issues, and there is potential to improve environmental education standards in their curriculum. Finally, this study supported the idea that multimedia learning helps preschool children understand complicated topics whilst also providing positive engagement and enjoyment.

Keywords

Environmental education • Multimedia learning • Education technology • Preschool children • Climate awareness

1 Introduction

1.1 Environmental Concerns

Civilization, technology, and the economy are continuing to evolve and advance rapidly as the human population grows. Whilst this is advantageous, our environment is constantly being remodelled to adapt and fit into the need of society. The majority of human activities, if not environmentally cautious, can cause severe impacts to the environment such as changes to the ecosystem, biodiversity, natural resources, and biophysical environments.

In Malaysia, rapid urbanisation is causing environmental degradation, and the public is fully aware of the country's environmental challenges (Cheng et al., 2022; Said et al., 2003). Malaysians generally have a good understanding of environmental issues but lack understanding of the underlying causes. In addition, the practice of environmentally responsible behaviour was not in line with the level of concern and knowledge illustrated by Malaysians (Ahmad et al., 2015; Said et al., 2003). Similar data was found in a study conducted by Neo et al. (2016) where awareness and behaviour are not consistent. This implies that having the knowledge and awareness is not sufficient—it needs to be followed by positive behaviour, attitude, and commitment. In this regard, it can be argued that these values must be instilled and nurtured from a young age to bear adults with high-environmental consciousness (Lace-Jeruma & Birzina, 2019).

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1.2 Environmental Awareness in Children

Children are being recognised in The 2030 Agenda for Sustainable Development as critical agents of change and important activists for improving the world (United Nation, 2015). However, their environmental awareness was found to be insufficient by researchers in many countries, including Malaysia. Konur and Akyol (2017) revealed that awareness of environmental issues, their causes, and solutions is lacking in children because they are in their pre-operational stage, making them unable to establish a causal relationship between environmental issues. This stage is defined as the second stage in cognitive development based on Piaget's Theory of Cognitive Development, where early childhood rationale is done in a non-logical and non-reversible manner (Huitt & Hummel, 2003). Based on Piaget's Theory of Cognitive Development, it can be debated that the concept of environmental cause and effect may be considered too complex for preschool children to comprehend, if traditional teaching methods are used.

In Malaysia, 6-year-old preschool students' knowledge, attitude, and practice about environmental sustainability were examined by Mahat et al. (2019). Results showed that they could not distinguish between recyclable and non-recyclable items. Even if a child has some knowledge of environmental sustainability, they are hardly practising it (Mahat et al., 2019). This is worrying as we can see the same pattern of behaviour in adults. This culture of indifference towards the environment is detrimental to the future of our planet.

In other parts of the world, researchers Huang and Yore (2005) did a comparative study and found that children from Canada and Taiwan both expressed positive behaviour and attitude towards the environment, possess moderate environmental knowledge, and have a high concern about environmental problems. An international study of 4 and 6-year-old children in England, Slovenia, and Greece demonstrated that the children in all three countries have a high level of accurate understanding—they can reason and make meaningful links between causes and effects of environmental problems (Palmer et al., 1999). Similarly, Strong (1998) conducted a questionnaire survey with 7 to 11-year-old children in the United Kingdom and found a high level of knowledge and understanding of environmental issues. Meanwhile, the introduction of eco-schools environmental education programme in Latvia had successfully improved students' knowledge and attitude towards the environment (Lace-Jeruma & Birzina, 2019). In addition, the knowledge of environmental issues in children of western societies was developed from parents and peers (Muldoon et al., 2019).

1.3 Integration of Technology in Learning

Today, we are living in the fourth industrial revolution where the Internet of things (IoT), virtual reality (VR), robotics, and artificial intelligence (AI) are revolutionising the way we live, learn, work, and play. Many smart technologies are apparent in our homes, offices, public places, and schools (McGrath, 2022). To escape from this paradigm of technologies would be inevitable, as these advancements are also affecting the way we learn and educate. Electronic media is prevalent amongst children as they are brought up or developed through learning in a digital world of interactive media.

Integration of digital tools in teaching refers to the process of using technology as a medium to assist and support educational practices. Hudson (2001) pointed out that environmental education must constantly adjust and adapt to the ever-changing sociological and technological aspects. Besides, modern technology-based teaching materials could enhance children's cognitive abilities and attentiveness and provide them with an understanding of a subject from multiple angles (Barkhaya & Halim, 2017; Gaybullaevna, 2022). Additionally, this form of teaching also encourages social engagement between children and adults, as well as putting young children in a more active and creative role (National Association for the Education of Young Children, 2012). Children are more likely to have greater visual attention and be motivated to understand words and phrases when a video element is added to their learning (Verhallen & Bus, 2009). In Mayer's cognitive theory of multimedia learning, the presence of animation together with narration will help boost children's memory recall and comprehension of the storeyline (Bus et al., 2015; Mayer, 2005). Motion and zoom shots used in a study by Sung and Chen (2019) suggest that animation coinciding with the storey helps promote preschool children's storey comprehension. This is aligned with the attention-guiding principle by Bétrancourt (2005) and with the study by Bus et al. (2015), which states that motion and camerawork help to guide children to select important elements in a storey. This allows children to acquire storey messages without being distracted by the animation (De Jong & Bus, 2004). Children who participated in Sung and Chen's study claimed that the movements and sounds in multimedia storeys are interesting (Sung & Chen, 2019). By holding the children's interest, we can instil knowledge and positive behaviour towards the environment.

Educating and nurturing our children to be environmentally cautious from a young age certainly has innumerable positive benefits. Furthermore, Zhuang and Qiao (2019) pointed out that environmental sensitivity and behaviours can be cultivated by the implementation of digital multimedia technology. Therefore, this research aims to investigate and understand preschool children's knowledge, and their level of awareness and understanding of environmental issues, before producing a series of short multimedia animations for their learning.

1.4 Children's Concern for the Environment

Research conducted by Strong (1998) aimed to understand and investigate children's knowledge and awareness of environmental concerns gained through their primary school education, and the implication of environmental education towards children. Strong (1998) analysed the data and illustrated how children think the environment could be protected through three segments. The first is conscious decision-making as a customer in a local environment, such as using non-CFC products, practising recycling, and reducing unnecessary transportation usage. Secondly, the common-sense actions as a citizen in a local environment, for example, taking care not to litter or cause damage to trees. And lastly, the common-sense actions as a citizen in a global environment, such as organisation or people not damaging the ocean and river.

Furthermore, Strong (1998) demonstrated children's focussed concern towards wildlife, plants, and trees, and a broader concern for the future of nature, the ozone layer, rivers, the sea, and pollution. The matrix table as shown in Fig. 1 is relevant to the objective of this study and was used as a base method to gather data about Malaysian's children concerns.

A matrix of children's concern for the environment

	Out of children's immediate control	Actions which can be controlled by children themselves
Focused	Concern for Wildlife	Concern for plants and trees
Broad Scope	Concern for the future of nature and seas e.g. oil spillage	Concern about pollution

Fig. 1 Matrix table constructed by Strong (1998)

1.5 Cognitive Theory of Multimedia Learning

To achieve the research objective, it is necessary to understand the learning process involved. Multimedia has a great potential to promote a deeper understanding of the learning process. Based on the cognitive theory of multimedia learning by Mayer (2005), "people learn more deeply from words and pictures than from words alone". However, it should be understood that this does not mean just adding words to pictures, but rather, the brain processes a host of stimuli (e.g. words, pictures, audio) together, by shifting, selecting, organising, and associating, to make sense of something (Fig. 2). As a result, the implementation of multimedia in learning is much more effective than single-medium-based learning (Hidayat & Suroto, 2022; Mayer & Moreno, 2002).

1.6 Design Principle for Instructional Animation

An example of a multimedia instructional message is when a multimedia presentation is used to explain something to a learner. There are two key characteristics in multimedia learning which stands out: animated graphics and user interactivity (Bétrancourt, 2005). Besides, Bétrancourt (2005) also stated that animated graphics can improve learning by supporting the visualisation and mental representation process, producing an animation of cognitive conflict for learning purposes, and enabling learners to explore a phenomenon through a discovery approach. In other words, animation assists children in visualising a situation they may not be able to visualise on their own, due to their limited imaginative capabilities.

Carefully designing the multimedia instructional message will ensure that learners are viewing the animated graphics in an actively engaged process. Bétrancourt (2005) listed five principles as a guideline to design an instructional animation. The first principle is apprehension, which means that graphical elements in animation should be the same as the initial domain, and any cosmetic feature that is not related should be removed. The second principle is congruence, which means, to help understand a certain phenomenon—the level of realism can be altered. The third principle, which is interactivity, states that learners can understand information better if they have control over the pacing of the animation. The fourth principle, which is attention-guiding, is that the presentation should guide and direct learners' attention on how to process the information displayed. Lastly, the fifth principle of flexibility states that allowances should be made for learners' different levels of knowledge, so any multimedia instructional material should include an option to activate the animation. Then, the information provided in the animation should be described as such to

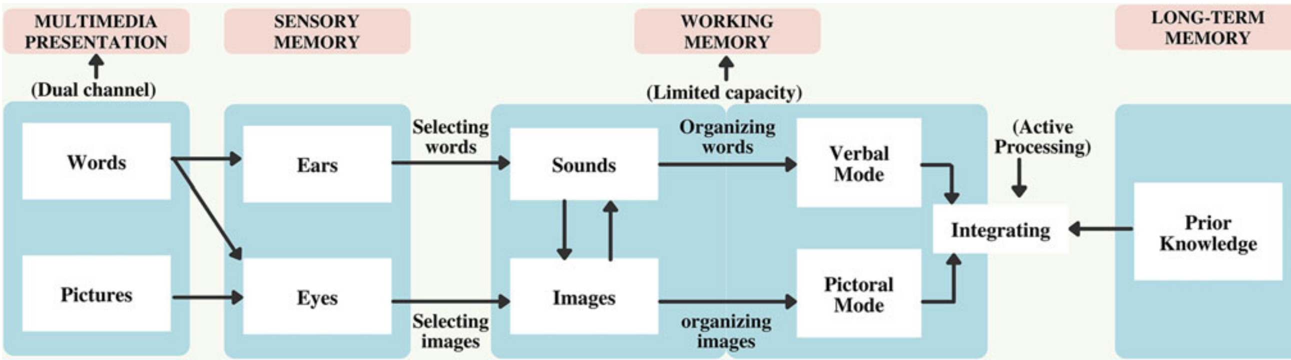

Fig. 2 Cognitive theory of multimedia learning by Mayer (2005)

avoid redundancy between static and animated visual materials. Bétrancourt's design principle for instructional animation is important for this study's objective as it guides the creation of multimedia animation for environmental learning.

2 Methodology

2.1 Research Design

A conclusive descriptive research design was conducted to understand the level of children's knowledge of environmental issues, their relationship, and subsequently, the children's environmental concerns. A qualitative method was conducted in three phases, starting with a semi-structured interview with a school teacher to understand the preschool level of academic background and syllabus. Next, a semi-structured interview using flash cards was conducted individually amongst 11 preschool children, and lastly, an online questionnaire with 29 children. Data collected were analysed using a content analysis approach based on the meaning of words, phrases, keywords, and sentences. The results helped in understanding children's perspectives and the creation of short animation series that covers on environmental issues. A summary of the research activity workflow can be seen in Fig. 3.

2.2 Research Procedure

The main aim of phase-one was to obtain preliminary identification on the curriculum of environmental education at the preschool level and gauge preschool children's comprehension levels based on a teacher's input. In phase two, 11 children were asked open-ended questions using visual flash cards. Questions like "what do you see in this picture"? and "what do you think happened"? allowed them to answer freely based on their knowledge, understanding, and feelings. This process was done face-to-face to observe the participants' understanding of the interview questions and to ensure that they can comprehend the flash cards that were presented. Due to the participants' age, it is difficult to formulate simple yet standardised questions because each participant has different levels of comprehension, which was why flash cards were used in this study. The images were carefully selected from various online sources and did not contain any secondary elements such as humans or animals to eliminate biased in the participants' answers. This method of using images, forms, and structures is classified by Polonsky and Waller (2018) and Schindel et al. (2022) as qualitative data collection.

The ease and familiarity of the children with their teacher were considered during the formulation of the interview process. Participants were more inclined to answer honestly when talking to someone they were comfortable with. The

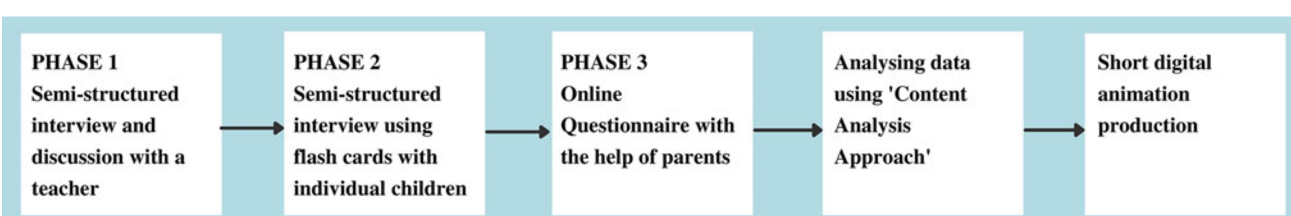

Fig. 3 Research activity workflow

teacher was instructed to ask a specific set of questions. The questions can be rephrased or translated into a different language, but the teacher was not to mention any key words that might cause bias or reveal the intention of the questions. If the children have been taught or exposed to the issue, they will be able to answer correctly. However, the main objective was not to answer correctly, but to observe whether they were familiar with the environmental issues shown to them.

Each child had to answer five sets of questions, with three questions in each set. They were asked to look at the flash cards, describe the problem, and explain the causal relationship. This method was repeated in Phase 3 using an online questionnaire, which had a total of 29 responses. Accumulatively, there were a total of 40 preschool children who participated in this study.

Figure 4 was done repeatedly with 5 environmental issues flash cards. The issues were water pollution, air pollution, deforestation, global warming, and waste increment. With this method, it can be identified whether children know about environmental problems, their causal relationship, and any concern which is expressed by the children.

2.3 Data Collection Method

Children's responses to words were analysed using a content analysis approach, and a simple matrix table (Fig. 5) was used as data categorisation. The correct answers are labelled in green and the wrong answers in red. Additionally, the children's concerns can be detected in their sentences, if any.

3 Results and Discussion

3.1 Key Findings and Interpretations

Data from the semi-structured interview and online questionnaire were collected and analysed together. The pie chart below (Fig. 6) comprises all five environmental issues where the participants (preschool children) exhibited the most significant understanding of water pollution issues, whilst

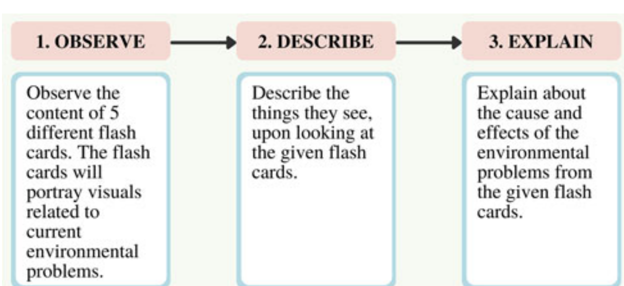

Fig. 4 Semi-structured individual interview method using a flash card

their lowest understanding fell on global warming issues. The second greatest would be air pollution, followed by waste increment. In addition, deforestation issues took fourth place before global warming.

The data in Fig. 7 showed that the participants' environmental knowledge varies between topics. Furthermore, the children scored highest in identifying environmental problems but scored lower on the cause and effects. For air pollution and deforestation issues, the children are less aware of the problem's cause than its effects. Global warming and waste issues received the same amount of data for both cause and effects, whilst slightly more children know about the cause than the effects of water pollution. It can be seen that preschool children are aware of environmental issues that are direct, simpler to comprehend, and hit closer to home such as water pollution and air pollution. On the contrary, global warming and deforestation do not directly affect them. This result is in line with the research done by Demirbaş and Pektaş (2009) that explored students' awareness and knowledge of environmental issues.

In this study, participants who answered correctly about water pollution stated the cause as throwing rubbish in water, instead of viewing it from broader scope such as oil spillage and industrial waste dumping. Additionally, they thought that waste increment was due to a huge amount of trash being thrown out. There was no mention of issues such as consumerism, consumption, single-use-plastic, and recycling. This is aligned with the study by Doğan et al. (2017) where students believed that environmental issues are the result of throwing garbage on the ground, without mentioning other causes. It is clear that preschool children are aware that environmental issues exist, yet only a few answered correctly when asked about the causal relationship. This could be due to a lack of exposure to such topics. Tan et al. (2014) stated that environmental topics in Malaysia's preschool curriculum are still limited in scope and quantity. Konur and Akyol (2017) discussed the complex issues such as global warming and greenhouse effects as not being mentioned enough in the children's environmental education, whilst research by Doğan et al. (2017) also revealed that even up until middle school, students have limited awareness of environmental issues.

Despite the low numbers, the data still prove that preschool children can comprehend a causal relationship. It can also be thought that young children cannot internalise complex ideas such as the notion of global warming. However, this can be proven wrong since seven out of forty children unexpectedly answered all questions related to global warming correctly. Although the number is small, it proved the possibility of young children's intelligibility in complex environmental issues.

Based on the four-categorisation concerns acquired from Strong (1998), Malaysian children's environmental concerns

CHILD 1				
	PROBLEM	CAUSE	EFFECT	CONCERN
ISSUE 1	• Rubbish	• People throw it into the water	• Smelly, dirty	• Pollution
ISSUE 2	• Haze	• From fire	• Cough	• Health
ISSUE 3	• Trees	• People cut it down	• Animals will have no place to live	• Animal
ISSUE 4	• Ice	• Hot	• No place for penguin	• Animal
ISSUE 5	• Landfill	• People dump it	• Smelly	• pollution

Fig. 5 Data collection and categorisation

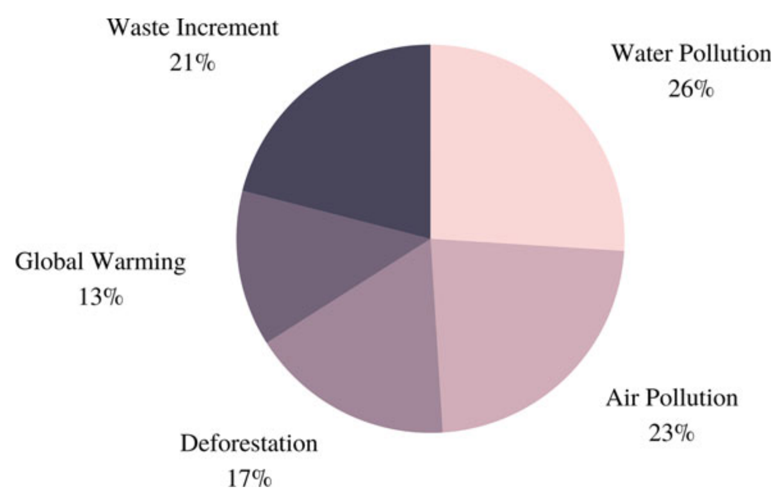

Fig. 6 Percentage of preschool children's knowledge and understanding

in this study can be observed through six categories in Fig. 8. Children were mainly concerned about pollution and human health compared to nature, trees, wildlife, and the ocean.

The children's concerns are possibly based on their current level of knowledge. For instance, a picture of rubbish in water was used in the flash card with no indication of location nor any living factors present. Hence, the children are free to show concern without any visual biases towards humans, animals, or plants. On the other hand, the "global warming" flash card depicted external factors of geological context. Therefore, when the children saw a picture of ice breaking and did not show any concern for "plants and trees", it is a simply common-sense reaction to the presented situation. Although the data in Table 1 showed no significant pattern, it is an arguable assumption that the children's concerns are related to matters closer to home. A predominant reaction to air pollution is the burning of fire and rubbish. This is because open burning can be commonly seen around older neighbourhood areas in Malaysia. The environmental problems recognised by Malaysians are pollution, waste, deforestation, flash flood, land degradation, and open burning (Said et al., 2003). Further research is needed to determine the conditions that prompted the children to

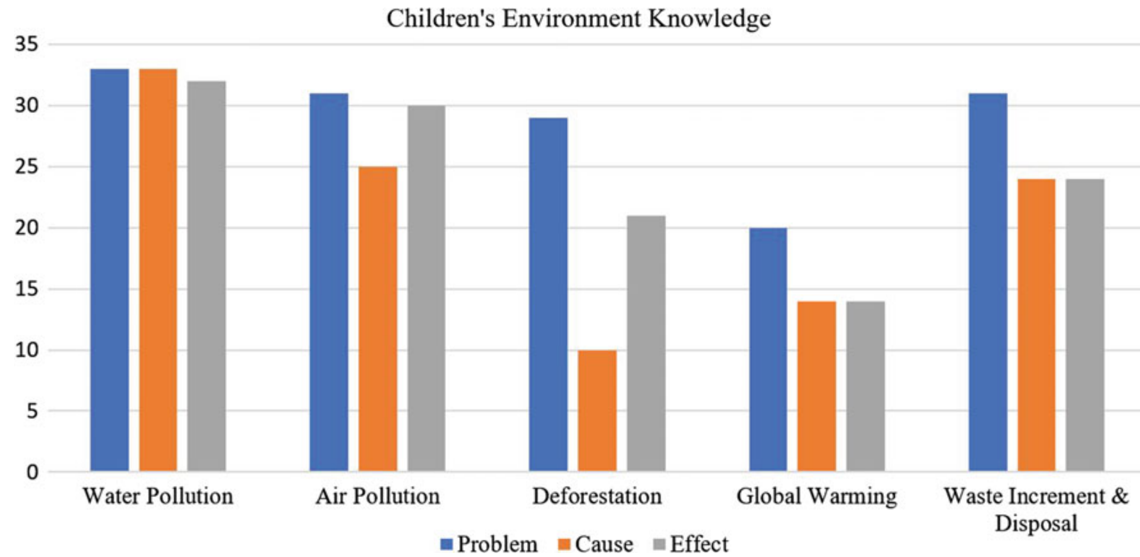

Fig. 7 Children’s understanding of environmental problems and its causal relationship

Fig. 8 Identified concerns of Malaysian children

	Out of children’s immediate control	Actions which can be controlled by children themselves
Focused	• Concern for animals and wildlife	• Concern for human health and injury • Concern for plants and trees • Concern for water and ocean
Broader scope	• Concern for the future of nature and natural disaster	• Concern about pollution

Table 1 Children’s concern based on each environmental effects

Environmental effect/concern	Animals and wildlife	Human health and injury	Plants and trees	Water and ocean	Future of nature and natural disaster	Pollution
Water pollution	11	5		8		11
Air pollution		22				10
Deforestation	1	2	15		3	
Global warming	1	1			13	
Waste increment						24

display these concerns as there are no significant patterns in their answers.

Within the answers, it is particularly striking that there is an ethical response about how children think the environment should be treated. One child answered, “human is not being responsible”. For them, it is the behaviour and the result of human activities that caused our environment to degrade. Even without fully describing the environmental situation, the children could recognise that the circumstances are wrong and threatening to the earth.

3.2 Implications

This study presented a clearer understanding of Malaysian preschool children’s knowledge on environmental issues and reinforced the study by Mahat et al. (2019), which states that preschool children do not have solid environmental knowledge. Similarly, Konur and Akyol (2017) stated that children from turkey are lacking in environmental awareness.

In stark comparison, children from countries such as Canada, Taiwan, the United Kingdom, England, Slovenia, Greece, and Latvia demonstrated positive behaviour and good knowledge about the environment (Huang & Yore, 2005; Lace-Jeruma & Birzina, 2019; Palmer et al., 1999; Strong, 1998). This implies that children can comprehend the environmental issue, and there is potential to improve the unsatisfactory standard of environmental education in countries like Malaysia, and other countries that are lacking in that aspect too. Additionally, the result of this study provides valuable insight in creating and developing new multimedia-based learning material to elevate preschool children's environmental education and potentially overcome future issues regarding environmental degradation.

3.3 Design Output

Digital technology brings various positive effects in supporting a child's teaching and learning. The objective is to design a medium that increases environmental awareness and encourages social engagement between children and adults, as was promoted by The National Association for the Education of Young Children (2012). Hence, a series of short animations titled "What Do You See"? was created (Zaini et al., 2021). The concept of "What Do You See" is based on the impression of wanting the children to carefully observe the surrounding environment with their own eyes, whilst gradually noticing the unhealthy damages on our planet Earth (Fig. 9).

The animation series was created by using several software, namely Procreate to create brush effect drawings, Adobe Photoshop to create 2D images, Adobe After Effects to animate, and Adobe Premiere Pro to compose the sound design. Examples of the concept and animation process can be seen in Figs. 10, 11, and 12.

The animation series is playable on mobile devices by scanning the provided QR codes in Fig. 13. It is hoped that by having the digital animations, teachers, and parents will find it easier to teach and explain about environmental issues, as it is accompanied by enjoyment and visualisation of related graphics or elements that children cannot experience in person (Zaini et al., 2021). In the future, the authors hope to add more short videos to the collection.

4 Conclusion

This research aimed to identify preschool children's environmental knowledge and share evidence of the importance of multimedia learning in environmental education. Based on

Fig. 9 "What Do You See" poster design

Fig. 10. 2D asset creation before the animation process

Fig. 11 Colour scheme used in the animation

Fig. 12 Example of the animation technical process in Adobe after effects

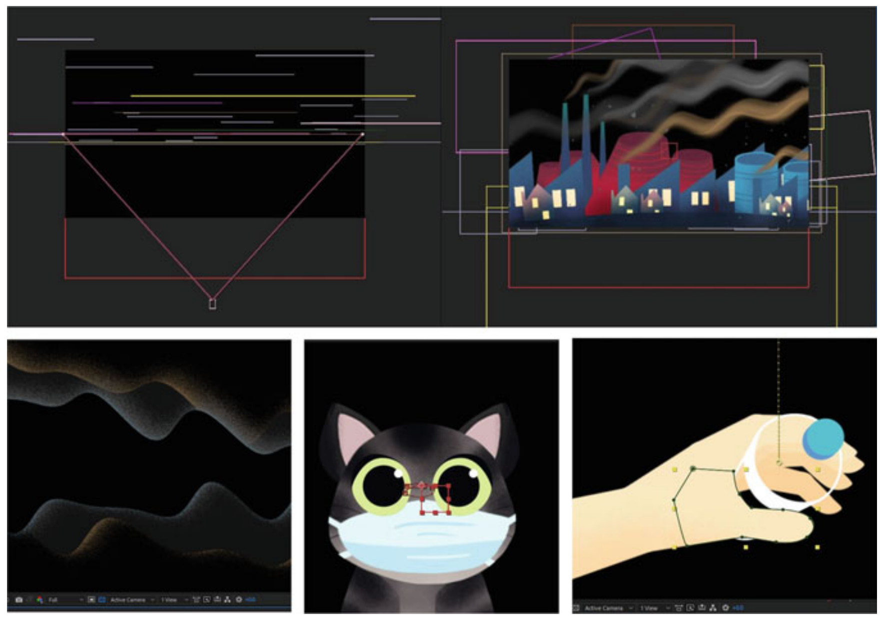

Fig. 13 QR Codes to watch the preview and process of the animated videos

Deforestation, Air Pollution, and Ocean/Water/Plastic Pollution

Process Video

the data analysed and shown in Fig. 13, it can be concluded that preschool children have adequate environmental knowledge. However, that knowledge is limited to an alarming small scope. There is a need to understand broader environmental topics on a global scale, rather than just the local issues surrounding the children. Awareness of environmental causes and effects are also limited in scope. Children must understand the impact of seemingly little actions and how they can result in far-reaching repercussions. Based on the findings, children who participated in the research did not mention about consumerism and consumption behaviours. These topics might seem heavy, but early exposure is necessary, and the research data showed that children can grasp complex environmental issues if given a chance to learn. The findings from this research reinforced Tan et al.'s study, which claimed that Malaysia's preschool environmental curriculum is still limited in scope and quantity (Tan et al., 2014). Children do not know about issues such as global warming, greenhouse effects, and deforestation, because it is not mentioned enough in the children's environmental education syllabus (Doğan et al., 2017; Konur & Akyol, 2017). Nevertheless, the results provided new insight for areas that needed more exposure and improvement. In addition, it was found that Malaysian children's environmental concerns can be observed through six categories (Fig. 8 and Table 1). Concerns for animals and wildlife, human health and injury, plants and trees, water and ocean, future of nature and natural disaster, and pollution were identified. By knowing children's concerns, teaching materials can be structured to align with these interests.

The use of a multimedia tool in teaching and learning was revealed in literature to have innumerous benefits (Barkhaya & Halim, 2017; Bus et al., 2015; De Jong & Bus, 2004; Gaybullaevna, 2022; Mayer, 2005; National Association for the Education of Young Children, 2012; Sung & Chen, 2019; Verhallen & Bus, 2009; Zhuang & Qiao, 2019). Based on this revelation, the implementation of multimedia tools into teaching materials should be considered by educators and parents. The efficiency of learning with integrated modern multimedia learning is important as an up-to-date education format. Therefore, children will be more aware and optimistic about the future of a clean and sustainable environment.

In conclusion, implementation of multimedia-based teaching material must be done to help ease the teaching and learning process and improve the standard of environmental education. Additionally, parents' and teachers' involvement are crucial in children's environmental education, as adapting to an environmentally conscious lifestyle cannot be achieved in a short period of time—shaping the values, attitude, and commitment of future generations begin at an early age.

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Green Architecture for Sustainability Development in Algeria: Limitations and Visions

Ibrahim Zakarya Kaddour and Tarek Teba

Abstract

Sustainability development aims to promote cities that can respond to different climatic, social and economic challenges. In the discipline of architecture and urban design, green architecture is one of the key aims that sustainability development aspires to achieve by bringing frameworks that support the architecture profession and architects in developing environmentally friendly buildings and cities that meet the triple bottom line of sustainability development (economic, social and environmental pillars). Algeria is a North African Mediterranean country that covers different climatic zones. There have been different attempts to develop green architecture practices. However, these attempts have not contributed yet to a holistic solution that feeds into the architecture and urban design professions in this regard, and there is no framework that can manage the development of green architecture practices in the country. Therefore, this article explores the question of why environmental assessment methods are essential to promote the green architectural practices in the country's different climatic zones. This is done through discussing the sustainability development pillars and critically analysing and evaluating previous sustainability development approaches in Algeria, reflecting by doing so on their positive and negative attributes and highlighting the limitations that push the sustainable and green architecture practices backward. In addition, these limitations are used to develop the discussion around the sufficiency of an environmental assessment method in responding to these short comes. By analysing relevant precedence (Environmental Assessment methods) which highlights critical gaps in current assessment methods and informs the construction of an opening statement to the importance of geographically, environmentally and socially routed assessment methods to develop the culture of green architecture in the country.

Keywords

Sustainability development • Environmental assessment methods • Algeria

1 Introduction

The built environment is where an individual lives, learns, explores and contributes to society (Rzin & Alhalabi, 2017). It is also considered as a base from which all things come to life and exist (Razin & Alhalabi, 2017). In addition, architecture plays a vital role to the functioning of human daily life, such as productivity, happiness and entertainment. Yet, the current situation of the world faced by global warming and climate change is considered as a real threat to the present and future generations. As a result, the environment becomes unsafe for human well-being, and uncomfortable for their day-to-day activities. The recent flooding around the world and massive wildfires in Greece, Turkey, Algeria and Austrian forests, the rise of sea level and water shortage in many countries are evidence of the disaster (Gannon & Steinberg, 2021). Therefore, the architecture has yet to consider new approaches and solutions to adapt for the present and the future.

According to many academic and research findings, global warming is mainly due to the greenhouse gases emissions (GHEs) which is considered as a major factor for climate change (Iyer-Raniga & Kashyap, 2021), such as carbon dioxide emissions which is estimated at 65%; not only from vehicle gas emissions, but also from electricity and heat production, manufacturing, transportation for building and construction industry that counts 66% of the

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GHE (Iyer-Raniga & Kashyap, 2021). Another reason is the rapid demographic growth and the expansion of major cities that hold half of the world's population (Shamseldin, 2017), which is expected to exceed 70% by 2050 (Shamseldin, 2017); cities energy consumption has escalated to a very high level in order to build, operate, maintain and manage different buildings such as office buildings and institutional and industrial structures. These cities are continuing to consume as much as 40% of the total energy consumption globally. As a result, not only the construction process but also the building industry is considered harmful to the environment on a longer term after construction (Iyer-Raniga & Kashyap, 2021).

This paper therefore will investigate sustainability and sustainable development and its triple bottom-line dimensions (environment, social and economic) within the context of architecture and built environment. It will then explore the architecture and built environment attempts to address these aspects in Algeria highlighting the gap and the need for a new bespoke environmental assessment method for the country. The current major environmental assessment methods will then be analysed in order to highlight certain shortcomes that need to be considered when designing a bespoke multi-climate environmental assessment method for the context of Algeria.

2 Sustainability, and Sustainable Development

The sustainability movement has been created to meet the present needs; and at the same time preserves the resources for future generations by implementing changes in policies, laws and regulations. It is also meant to support the human well-being, healthy environment, smart growth and to reduce the impact of each phase of the project life cycle on the environment. Therefore, it is important to highlight how the concept of sustainable development has emerged and implemented in the architecture discipline.

This definition of sustainability, as indicated above, by World Summit on Sustainable Development, Agenda 21, and Brundtland (WCED, 1987) is the most referred to, and strongly dominant in the academic literature (Moldan et al., 2012; Purvis et al., 2018). Furthermore, Purvis et al. (2018) present arguments to emphasise further and add to the definition of sustainability development by the noun from which its adjective is "sustainable" and indicates that it is something bearable and capable of conserving its condition for an extended period of time. Dempsey et al. (2011) and Hedrén (2009), additionally comment that sustainability is the different processes and actions by which human beings preserve natural resources for the purpose of a balanced society. Christie et al. (2019) further explain that the built environment is sustainable on the off chance that it doesn't harm the environment, society and the economy.

Sustainability has emerged in the work of the United Nations' World Commission on Environment and Development, and in 1987s report of Brundtland, a former prime minister of Norway first introduced the concept and the three pillars of sustainable development in his report titled "*Our Common Future*." However, Portney (2015) identifies the pillars of Sustainability as "*It has become defined by the pursuit of the three co-equal elements: economy, environment, and equity.*" (p. 56). Moreover, it can be seen that Brown et al. (1987) have tried to root the general design of the concept of sustainability by comparing six different meanings of sustainability which they have suggested into two major categories: one emphasises ecology, and other emphasises economics.

These six meanings, according to Brown et al. (1987), represent the necessary potentials that have to be sustained such as "sustainable biological resources use," which is concerned about the natural systems and what all flora and fauna cover, to keep them at a balanced state between their level of productivity and harvestability. This balance between harvesting and producing is at the same aim in "sustainable agriculture." Whereas "carrying capacity" is concerned about the whole world being at a certain balance between the number of people living on a surface area and the capacity of supportability of this area in order to avoid species collapsing. Due to the fact that there are concerns about running out of fossil fuel and natural resources, "Sustainable energy," seeks alternative sources for producing energy such as electricity and powering machinery, at the same time that do not harm the environment. "Sustainable society and sustainable economy," have a relation with "carrying capacity" where the social conditions and economic, as well as the human well-being, are the epicentre concern of these meanings. Brown et al. (1987), predict that the economy will be overwhelmed by the population growth of the planet even to an extent that the natural resources will follow this collapse too.

The last but not least meaning of sustainability according to Brown et al. (1987) is "sustainable development (SD)" which seeks a trade-off relationship or win–win situation between the economic growth and the preservation of the environment, notwithstanding that both have positive or negative impacts on the society. For instance, the world's leading developing countries such as China and India have augmented their massive productivity to grow their economy. This has led to a rise in the carbon emission in the atmosphere and contributed to climate change, and thus, many islands, nations and citizens now are in danger of being sunk due to the rise of sea level. Brown et al. (1987) consider the environment, economic and social dimensions as the triple bottom line of sustainability development (SD).

Mieg et al. (2012) reinforce this composition and recognise these aspects as the three fundamental dimensional pillars of SD; the ethos of these pillars is to improve and fulfil real needs of the current generation without imperilling the potential and capacity of people in the future to meet their requirements in accessing and utilising social, financial and natural assets. In this way, sustainability development ensures a satisfactory harmony between financial development, care for the climate and social prosperity which confirms Moldan et al. (2012) and Purvis et al. (2018) arguments.

3 Triple Bottom-Line Dimensions: Environment, Social and Economic

Loviscek (2021) states that these three bottom-line elements of sustainable development have been initiated in "*Cannibals with forks: the triple bottom line 21st century business*," in which Elkington (1997) suggests alternative components of sustainable development; they are people, planet and profit, also known as the 3 Ps. Loviscek (2021) has reviewed 575 articles based on two major databases (Web of Science and Scopus) for the last 21 year starting from 1998. However, Loviscek's research methodology has missed what has been reported by Purvis et al. (2018) from the 1960s and onwards. In addition, Portney (2015) explains that the true meaning of sustainability relies on the contexts and the disciplines where it is implemented. Indeed, Kidd (1992) further indicates that this diversity in the fundamental bases of sustainable development is rooted in different schools of thought. These schools that have acquired the notion of sustainability justifies the change in the triple bottom-line conception (Clune & Zehnder, 2020; Purvis et al., 2018). Kidd is amongst many researchers and academics who deeply historically rooted the origin of sustainable development's triple pillars of economy, society, and environment. He explains that sustainable development pillars are a natural extension of the Brundtland report by the combination and creation of the feasibility and liveability space for humankind taking into account their environmental protection and ecological objectives (Clune & Zehnder, 2020; Purvis et al., 2018). This triple bottom-line dimensions have been further developed following the Rio+20 summit in form of sustainable development goals (SDGs) and the Millennium Development Goals (MDGs), suggesting solutions for the ecological and social problems by the implementation and the development of the economy (Loviscek, 2021; Purvis et al., 2018).

The triple-dimension pillars are an applied and solutions-oriented approach to sustainable development (Clune & Zehnder, 2020). They have effectively helped its application and execution at scale and speed explicit supportability arrangements going from theories to practice. As a result, many techniques, methods and approaches have been created to make their performance better effectively in the architecture discipline at its best (Clune & Zehnder, 2020).

Iyer-Raniga and Kashyap (2021) argue that the architecture discipline has adopted these three sustainability dimension objectives since their appearance to tackle the climate change crisis through mitigating GHGs that are released in the atmosphere. Iyer-Raniga and Kashyap (2021) note that environmental dimension aims at seeking and exploring new solutions, approaches and strategies to improve buildings' efficiency in using energy and water, as well as in decreasing waste through using renewable energies and being environmentally friendly. Therefore, assessing buildings' environmental impact on the environment is a first step that indicates the level of this building's energy performance as well as its carbon footprint. It is well proved that thermal comfort, indoor air and lighting quality are amongst all indicators for a better indoor environmental improvement that has either a positive or negative impact on users' satisfaction and at the same time on the environment (Brown & Cole, 2009; Brownbill, 2019; Gowri, 2004).

Park et al. (2017) additionally comment that the environmental aspect craves at protecting and enhancing the environment conditions. They have indicated that the "Ecology, Energy and Resources" are critical success factors for reducing negative impact on the environment, such as toxic materials and urban heat island, effectively selecting energy saving materials and appliances, respectively, are amongst others to be taken into consideration.

Concerning economic dimension, Iyer-Raniga and Kashyap (2021) advocate the view that there is a potential opportunity of return investment in energy saving, maintenance and operational costs if the overall building design has been well exploited. Park et al. (2017) support studying economic factors by indicating three major opportunities: "Life cycle Cost, Durability and Adaptability," through which a good economic saving can be achieved. Due to the fact that all buildings have a life cycle similar to living creatures—development, introduction/construction, growth and maturity, and then decline and demolition—they suggest that in each stage of the project life cycle, durable and environmentally friendly materials are encouraged to be implemented amongst other products if this building would be considered sustainable.

Finally, social dimension has been getting more attention by academia, organisations and stakeholders from different fields in the last few years (Iyer-Raniga & Kashyap, 2021). This is because of sociopsychological and psychosocial well-being, comfort of the occupants and employees. Additionally, any business productivity or projects' profit (economic) may well be affected if building-occupant interaction, behaviour and attitude are not taken into consideration (Wu et al., 2016). Mensah (2021) and Park et al. (2017) strengthen the idea and emphasise the importance of the social dimension as any project or business success' is relying on the supply chain that is in turn run by people. Therefore, the importance of the safety, health and well-being including equity, justice and diversity, as well as transparency in product consumer's ingredients/components significantly cannot be stressed more. They are vital for the growth of profitability (Arora et al., 2016).

Since the appearance of sustainable development and its triple bottom line, the architecture disciple has widely integrated and implemented this strategy. This has led to the emergence and development of many specialties and fields such as "Green Architecture," "Green Building Movement" and "Sustainable Architecture and Design," in order to contribute to sustainable development. However, building's evaluation methods are still very important to better rank those buildings according to the sustainability development requirements. Hence, there was a creation and development of (1) "Life cycle" assessment-based methods such as Athena Environmental assessment tool and (2) "Building Environment or Green Building" assessment method based such as the British Research Establishment Environmental Assessment Method (BREEAM) in the UK in the 1990s as the first assessment methods ever created, followed by the Leadership in Energy and Environmental Design (LEED) in the USA.

3.1 The Life Cycle Assessment Tools Base

As Iyer-Raniga and Kashyap (2021) explain that any building or project has a life cycle similar to living species, creation and development, maturity and then decline. Its impact on the environment is also related to these three stages. Therefore, the assessment should be taken into consideration during the construction process, during the operation and then deconstruction and recycling phase too. This cannot be well achieved only if the design process has seriously planned for the whole project life cycle. Hence, Cole (1999) defines life cycle tools with techniques that predict, estimate and calculate different environmental considerations of a project's phase. These project phases consist of the acquisition and production of building components, the exploitation and operation of these products and finally the disposal and demolition of the building. Life cycle assessment tools take into consideration the impact of each phase on the environment and assess the design performance to mitigate the impacts on natural systems (Cole, 1999).

3.2 Pure Criteria Methods Base

Unlike life cycle assessment tools, criteria-based methods classify a selected number of environmental performance criteria with certain weighting and points in order to measure the impact of the building on the environment and its users (Iyer-Raniga & Kashyap, 2021). These methods use assessment as a core function in their approach and a third party for the verification of the results before issuing their final certification (Cole, 1999).

According to Gowri (2004, p. 58) green design is "…*one that is aware of and respects nature and the natural order of things; it is a design that minimizes the negative human impacts on the natural surroundings, materials, resources, and processes that prevail in nature*." It is therefore the aim of green building rating systems to achieve these design goals through a set of performance criteria whilst assessing the entire design. Certainly, all popular green building assessment methods rank the progression of different buildings according to their environment performance in regard to current typical practice requirements (Iyer-Raniga & Kashyap, 2021).

Lee et al. (2013) and Toroghi et al. (2016) additionally comment that green buildings assessment methods whether has been developed by a construction authority, private, public, or international organisation, all assess and verifies buildings' compliance to the sustainability and green development. Mattoni et al. (2018), Wu et al. (2017), Shan and Hwang (2018) indicate that in order to recognise a building green, each of the economic, environmental and social aspects must be implemented in the building design.

Gowri (2004) indicates the five categories that green building systems take into consideration throughout the assessment process. Those categories are, site, water, energy, materials and indoor environment that weather or not consider a building green. Each category has a specific design and performance criteria assigned. These criteria are prerequisite for the achievement of the underline categories. For instance, Table 1 shows a breakdown of LEED rating system categories and their available credits. It is mandatory to meet all the existing prerequisites to be eligible for certification.

Design guidelines are organised to offer heading on the most proficient method to develop current plan rehearses and just certainly recognise its sustainability (Cole, 1999). The assumption that persistent working on the natural presentation of individual structures, the aggregate decrease in asset use and ecological loadings by the structure business will be adequate to completely address the environmental agenda. The decision of the expression "green building assessment" is viewed as a helpful term to pass on this message (Shan & Hwang, 2018). These methods educate individuals how

Table 1 Structure of the LEED rating system

No.	LEED categories	Number of prerequisites	Number of credits	Maximum number of points
1	Sustainable sites	1	8	14
2	Water efficiency	–	3	5
3	Energy and atmosphere	3	6	17
4	Materials and resources	1	7	13
5	Indoor environmental quality	2	8	15
6	Innovation and design process	–	2	5
	Total	7	34	69

From Gowri (2004, p. 58)

eco-friendly and ecological buildings can be and distinguish the economical standards and practices that have been utilised (Kubba, 2010; Pearce & Ahn, 2017).

4 Sustainable Development in Algeria

Algeria is a northern African country looking over at the Mediterranean Sea. The country covers an area over 2 million km^2. This huge area hosts three different climatic zones. From Fig. 1, only, 4% of the total area represents the coastal area with the mild Mediterranean climate of the coast. 10% of the total area represents the high plains in the country with the transactional climate of the northern hills and mountains. Finally, more than three quarters of the total area of the country represent the Sahara extended on 86% represents the desert climate.

Despite the fact that Algeria has a huge potential for the solar radiation to produce solar energy (heat or electricity), the exploitation of the renewable energies in the country is still late and undeveloped. Algeria is one of the three main contributors to CO_2 emission in Africa alongside South Africa and Egypt (Bouraiou et al., 2020). Belkacem et al. (2017) indicate that the CO_2 emission of any building is an indicator of its design and thermal quality. Thus, it could be argued that Algerian's buildings have a poor quality of design and thermal quality, based on the high amount of CO_2 gas emission indicated by Belkacem and et al. (2017). In addition, Kacher and Zermout (2016) also have compared GHGs emissions and energy performance of an ecological house to a house in Tlemcen, one of the cities in north-west Algeria. They have concluded that the emission of the house in Algeria is seven times greater than the ecologic house.

In fact, Algeria is located in the so-called Sunbelt area with a high concentration and potential of solar radiation (Abdelhamid et al., 2011). By taking into consideration the geographical location, Algeria has an important advantage for welcoming renewable energy, like the exploitation of solar energy due to the highest value of solar radiation that cover 80% of the total area of Algeria, wind turbines or wind energy conversion systems, hydro energy, biomass and geothermal energy (Blal et al., 2018; Najjar et al., 2019). From Fig. 2 and Table 2, the daily potential of energy is 16 K TWh, where 98% of it comes from the desert Sahara of Algeria. Yet, more than 99% of electricity production comes from fossil fuel (Nachmany et al., 2015). Sahnoune et al. (2016) and Nachmany et al. (2015) have indicated the significance of the rise in the electricity consumption during the last 12 years starting from 2000. Initially, the electricity consumption escalated from 25 TWh in 2000 to 40 TWh during 2008, and reaching up to 56 TWh in 2012 (Sahnoune et al., 2016). The national electricity power installation is forecasted to reach 30 GW by 2030 (Sahnoune et al., 2016). Kacher and Zermout (2016) confirm that Algeria is very late in regard to the sustainable development and the performance of the impacts of the building on the environment than in Europe in recent years.

Nachmany et al. (2015) and Sahnoune et al. (2016) estimate between 69 and 75% of the global GHG emission in Algeria are mainly from the electricity production. This electricity is primarily used for the heating and air-conditioning in general buildings in Algeria (Boudghene Stambouli, 2007). Thus, the government has put in charge the responsibility of policy advisement, the initiation and facilitation of the implementation of energy efficiency programme and promotion of renewable energy to the National Agency for the Promotion and Rationalisation of the Use of Energy (APRUE) in Algeria during 1997 (Sahnoune et al., 2016). In fact, APRUE is an Algerian public industrial and commercial firm, created in 1985, for the purpose of implementing the promotion of energy efficiency and aiming for the execution of the national energy management policy as a contribution towards the sustainable development in the

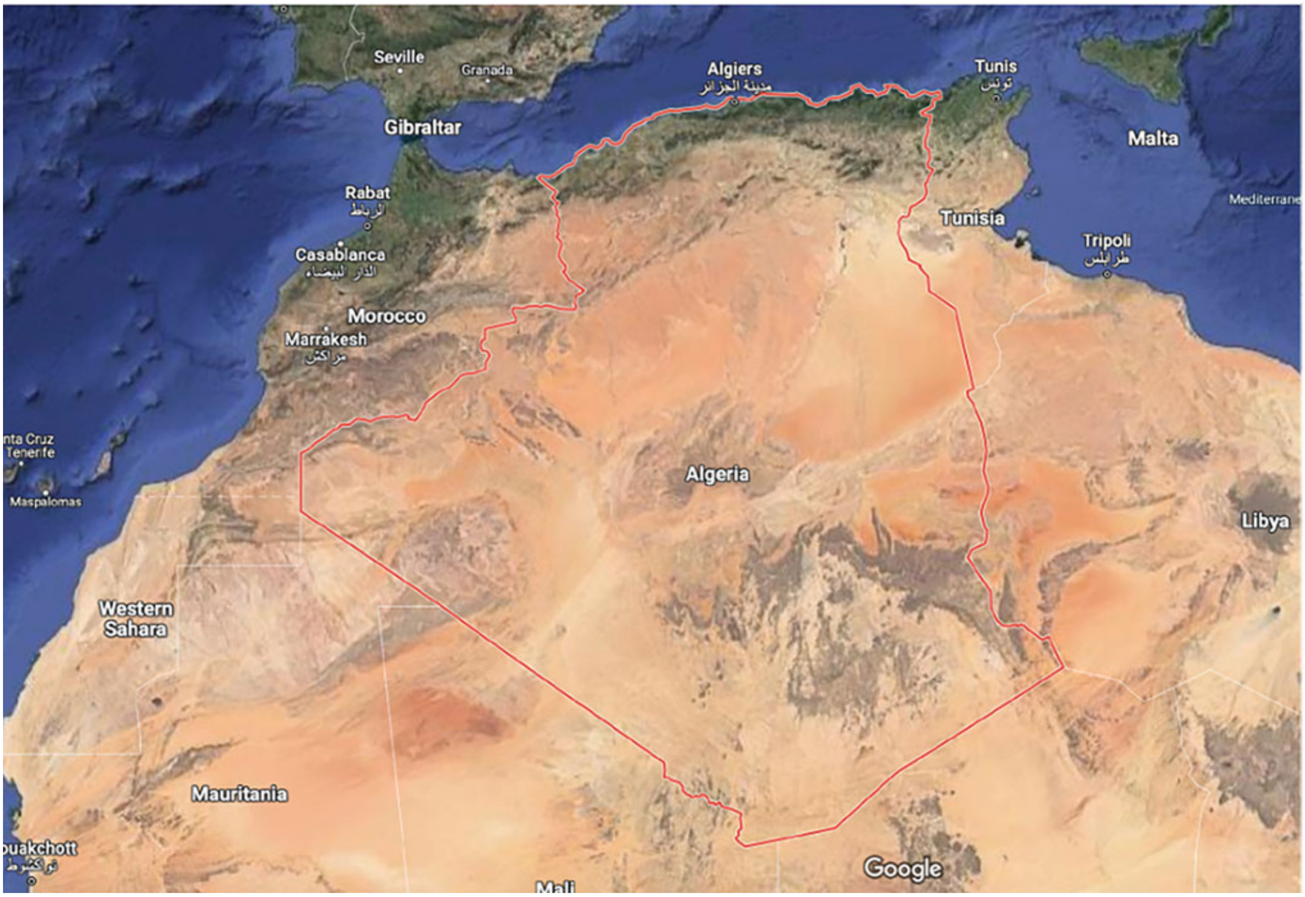

Fig. 1 Algeria satellite view. From Google Maps

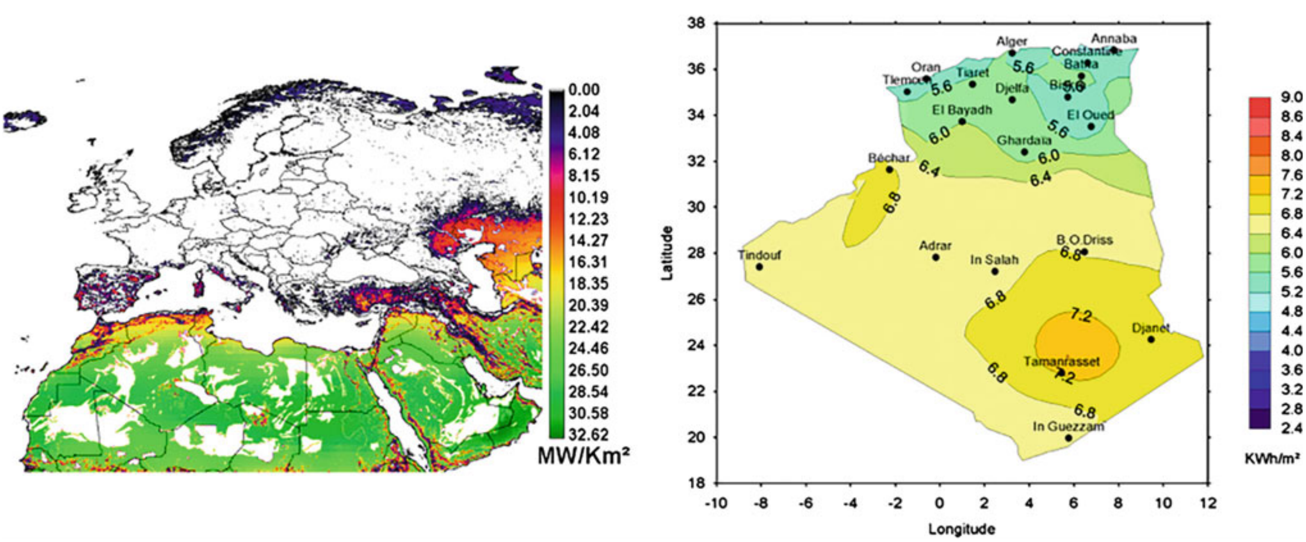

Fig. 2 Potential sites for solar electricity in Algeria. From Stambouli et al. (2012, p. 4449)

country. Its main objectives consist of advance energy reserve funds in all areas of movement, activate different entertainers around the issues and difficulties identified with energy proficiency, advance organisation in setting up energy efficiency projects, offering perceivability to likely financial backers, add to the development of a feasible energy effectiveness and improve and fortify the limits of partners in the field.

Table 2 Solar potential in Algeria

Areas	Coastal area	High Plains	Sahara	Total
Surface (%)	4	10	86	100
Area (km^2)	95,270	238,174	2,048,297	2,381,741
Mean daily sunshine duration (h)	7.26	8.22	9.59	
Average duration of sunshine (h/year)	2650	3000	3500	
Received average energy (kwh/m^2/year)	1700	1900	2650	
Solar daily energy density (kwh/m^2)	4.66	5.21	7.26	
Potential daily energy (TWh)	443.96	1240.89	14,870.63	16,55.48

From Stambouli et al. (2012, p. 4450)

Meanwhile, Algeria has joined MEDENER. The Mediterranean Association of National Agencies for Energy Management was established in Tunis in 1997 as a global non-benefit association for this reason. It unites organisations in the Mediterranean locale accountable for energy productivity and the advancement of environmentally friendly power sources, two critical success factors for the realisation of the energy progress programme. The association is enrolled in Madrid at the base camp of the organisation IDAE (Spain). The secretariat is right now dealt with by its individuals, which hold the administration on a turning premise.

Yet, it unites 11 national public organisations from the northern and southern banks of the Mediterranean:

- The French agency for ecological transition (ADEME) in France, it is a merge between AFME (French Energy Management Agency), ANRED (National Waste Agency) and AQUA (National Air Quality Agency) during 1992, is responsible for carrying out open approaches in the space of the climate, energy, economy and supportable turn of events.
- The Portuguese Energy Agency (ADENE), created in 2000 in Portugal with the mission to create and uphold exercises under open arrangements, to advance the effective utilisation of energy and water, by all and consistently, adding to a more balanced society.
- The Institute for Energy Diversification and Saving (IDAE) established in 1986 in Spain, it works in the space of energy proficiency, sustainable power sources and transport. It instructs the service on the execution with respect to energy arrangements.
- The National Agency for New Technologies, Energy and Sustainable Economy Development (ENEA), founded in Italy in 1960s for the purpose of the development of energy innovations, for which the agency is likewise the facilitator of the Energy National Technology Cluster, energy productivity, environmental change and many more. Since October 2017, ENEA (Italy) is dealing with administration for a two-year term, prevailing to ANME (Tunisia) from the year 2014 to 2016 and ADEME (France) which held the job for two years starting from 2012.
- The Centre for Renewable Energy Sources and Saving in Greece in 1987, its principal objective is to advance innovative applications in the spaces of sources of renewable energy (SRE), rational use of energy (RUE) and energy savings (ES), both at public and global level.
- The Lebanese Energy Management and Environment Association (ALMEE) founded in Lebanon in 1993, engaged with a wide scope of exercises connected to feasible practices and natural issues. This politically autonomous non-benefit affiliation works for better administration of activities and advancements connected to energy and the climate, in Lebanon as well as in the Mediterranean Basin and the remainder of the world.
- The Palestinian Energy and Environment Research Centre (PCE), created in 1993 in Palestine, aims at coordinating of all viewpoints identified with the advancement of environmentally friendly power sources, energy economies and security of the environment in Palestine.
- The National Energy and Research System (NERC) is a Jordanian non-profit organisation created in 1998 for the motivations behind research, improvement, preparation in the fields of new and environmentally friendly energy and increasing the expectations of energy use in the various areas and to advance the usage of sustainable resources in Jordan.
- The National Agency for Energy Management (ANME) created in Tunisia in 1985 aims at implementing the energy management strategies and governmental guidance by discovering alternative energy sources that may be used for a long period in order to ameliorate the energy efficiency.
- The Moroccan Agency for Energy Efficiency (AMEE) was created in 2016 in Morocco for the purpose of promoting and developing the national energy efficiency programme.
- And of course, The National Agency for the Promotion and Rationalisation of Energy Use (APRUE) in Algeria.

During the 1997, CNERIB (the National Centre for Studies and Integrated Research of Building) under Housing and Urban Planning Ministry tutelage has developed the National Regulatory Technical Documents (DTR) unfolded into three sub-documents (Djebbar et al., 2018):

- The DTR C3-2 created on 10/12/1997 that indicates the calculation of Winter Calorific Losses Rules for Housing Buildings.
- The DTR C3-4 created on 18/08/1998 that indicates the Calculations of Summer season Calorific Gain for Buildings.
- The DTR C3-31 created on 12/04/2006 indicating the Natural Ventilation of Housing Usage Areas.

After that, APRUE established a national organisation system for controlling the energy following the 28th of July 1999 law of the energy control. This National Energy Control Programme (PNME) was established on the basis of the main orientations of the government's economic and social development policy as well as energy prospective studies in medium and long term allowing the definition of the challenges and energy management potentials for each sector's economic activities. The PNME defines the orientations, objectives and the means of its implementation; it establishes the framework in which the partnerships between economic and social actors as well as public and private operators. In addition, another key player of the organisation system is the National Energy Control fund (FNME) is responsible for the continuity of the means of this policy from where the tax assigned is the main source. Hence, it is independent of the country's budget.

However, in order to maintain the success of this system, there is a need for a systematic and permanent partnership. Therefore, the Inter-sectoral Committee on Energy Control (CIME) has been created with the strategy to control and manage stakeholders involved in energy control programmes. It is therefore an advisory body placed with the Minister of Energy responsible for organising consultation and the development of public/private partnership lawful to change any policy or resources related to the energy management programme, as well as developing, implementing and monitoring it.

On the 14th of August 2004, the Algerian Government has announced law No. 04-09 relative to Renewable Energy Promotion in the Framework of Sustainable Development followed by another law on Renewable Energy and Energy Efficiency Development Plan 2011–2030 on February 2011 (Nachmany et al., 2015). Boukarta and Berezowska-Azzag (2018), Hamiche et al. (2015), Himri et al. (2009), and Sénit (2008) summarise these two laws into six main strategies that they are considered as the main pillars for the achievement towards the sustainable development according to the Algeria government.

The first strategy of intervention is a project created in 2015 in collaboration with APRUE and GIZ (The Deutsche Gesellschaft für Internationale Zusammenarbeit GmbH, a development agency based in Bonn, Germany that provides international development cooperation and international education work services) folded into two steps:

- The first step is concerned about educating and training architects and engineers and the assessment of the building's energy demand in different education levels such as universities, institutes and schools. This guidebook presents insights of how to protect the environment by using alternative sources of energy, for instance renewable energies and making effective use of them. Algeria's main and only source of energy consumption is based on fossil fuels. Despite the fact that there is a huge opportunity for the exploitation of renewable energies in the country, Algeria has no experience in this discipline. Thus, GIZ partnership aims to support the national government project 2030 using the German experience and know-how for the installation of solar and wind energy farms with the capacity of 5.5 GW.
- The second step is the application of the Document Thermal Regulation (DTR C3-2, C3-4, C3-31). However, for the efficiency running of the use of both DTR C3-2 and C3-4, the Renewable Energy Development Centre (CDER) in Algeria has developed a software called RETA, accessible from an open platform site web (reta.cder.dz), available for the use of architects and engineering, etc., for the purpose of verifying their different building's components as well as the whole project's compliance in both climatic periods' regulations of DTR.

The second strategy is the development of solar water heaters, also known as the Alsol programme. This programme aims for the encouragement of the use of sustainable energy by citizens in order to reduce the rise of energy consumption by 40%. In parallel, it contributes to the mitigation of carbon emissions by 27%. Therefore, the Algerian authorities are supporting this project by a grant scheme of 50% in each installation.

The third strategy is another solution for the promotion of energy use through the improvement of insulation in houses; 100,000 houses per year are the target set by the government in this programme as well as keeping the awareness of consumers the wise use of their energy (cooling or heating) and diminishing energy wastage.

The fourth strategy is the improvement of energy efficiency in public lighting use; this programme aims at the replacement of the mercury lamps with high-pressure sodium ones. This will save one million Tonnes of Oil Equivalent (TOE) projected by 2030. In addition, the government has forbidden the use of any incandescent lamps instead the government encourages the local production of energy efficient lamps as well as the partnership of foreign products.

The fifth strategy is about the promotion of liquefied petroleum gas fuel (LPG/C) and natural gas fuel (CNG); this will help the mitigation of carbon dioxide emission from vehicles as well as individual and collective transport to preserve a clean environment and reducing air pollution for the improvement of human well-being and towards sustainable development aspects.

The sixth and last strategy considers saving energy through the improvement of household appliance, for instance encouraging the consumers to buy very high energy efficient when it comes to refrigerators and freezers, washing machines, driers, ovens, dishwashers, air-conditioning appliances, boilers, etc.; by doing so, the government has required suppliers to display energy labelling on their products in order to overcome the lack of information of consumers about the performance of what they are purchasing whether it is cost benefits and environmentally friendly or not.

All these six strategies have not contributed to the development of sustainability in the country or even promoted the green buildings; this is because strategies two to six have not been very well supported by the government and have not been well podcasted through the local media amongst the citizens (Boukarta & Berezowska-Azzag, 2018; Kacher & Zermout, 2016). However, the first strategy interpreted into two steps; DTR and GIZ guidebook cannot be the main solution for the development of sustainability. The only reason is that both DTR and GIZ are physical and mathematical calculations of the thermal regulations. Whereas, the development of sustainability and green building should be considered and tailored according to climate conditions of the country as well as the consideration of the triple bottom-line dimensions equally in a bespoke assessment method (Tebbouche et al., 2017).

Although these laws and plans have been set up to contribute to the mitigation of GHG and promote the development of sustainability development and green architecture, it can be seen that the global GHG emissions in Algeria has dramatically augmented from 137.01 MT CO_2 eq in 2008 to 152.89 MT CO_2 eq in 2012 (Nachmany et al., 2015). In addition, data in Figs. 3 and 4 are showing even more augmentation of 156.22 MT of fossil CO_2 emission in 2016 and more than 200 MT CO_2 eq in 2015 (Macrotrends.net). In turn, Fig. 5 reflects CO_2 emissions by the rise of GHGs emissions (Ainouche & Malek, 2005). Remarkably, Fig. 6 justifies Algeria's GHG emission increase by the decrease in the percentage of the exploitation of energy from renewable sources which in turn reflects the lack of APRUE's and CNERIB's strategies in the contribution to the development of sustainability in the country or even promoted the green buildings. The reason why is because strategy two to six has not been very well supported by the government and has not been well podcasted through the local media amongst the citizens (Boukarta & Berezowska-Azzag, 2018; Kacher & Zermout, 2016). However, the first strategy interpreted into two steps; DTR and GIZ guidebook cannot be the main solution for the development of sustainability. The only reason is that both DTR and GIZ are physical and mathematical calculations of the thermal regulations. Whereas, the development of sustainability and green building should be considered and tailored according to climate conditions of the country as well as the consideration of the triple bottom-line dimensions equally in a bespoke assessment method (Tebbouche et al., 2017).

Whereas, a recent research study conducted by Amraoui et al. (2021) on two existing residential buildings located in El-Oued, capital of the Souf region in the desert Sahara of Algeria. Amraoui et al. (2021) indicate that one of these two buildings are considered as a typical unit in the region, and the other one represent the neo-vernacular building. Both buildings are situated in a hot climate zone which is considered the dominant climate in Algeria (Daraf et al., 2016). The research results show that such passive design strategies implemented in those kinds of buildings require no air-conditioning to maintain the thermal comfort required and operate with less energy (Amraoui et al., 2021; Alrashed et al., 2017; Leo Samuel et al., 2017; Al-Sallal & Rahmani, 2019).

Amraoui et al. (2021) indicate that the vernacular architecture has a great potential for sustainability and is considered as climate responsive design to the local contexts without any use of mechanical cooling/heating. As a result, there is no energy consumption for maintaining the indoor thermal comfort. Additionally, Amraoui et al. (2021) consider this neo-vernacular architecture as a green strategy. Such climatic responsive design is recognised as sustainable building design that reflects the local culture and environmental context (Amraoui et al., 2021). Using these proposed strategies such as the dome that replace the common flat roofs, a local material used as a brick called "Tufla," narrow opening and windows, central interior patio for passive cooling and implementations of arches and vaults in a modern mode of vernacular architecture (Amraoui et al., 2021). As a result, a reduction of 23–89% in energy consumption for cooling needs (Dubois, 2001) will be more realistic to achieve sustainable development. This can be an alternative solution, especially in a country like Algeria that is lacking standard and regulation on energy saving (Amraoui et al., 2021) regardless of the plan set by APRUE and CNERIB.

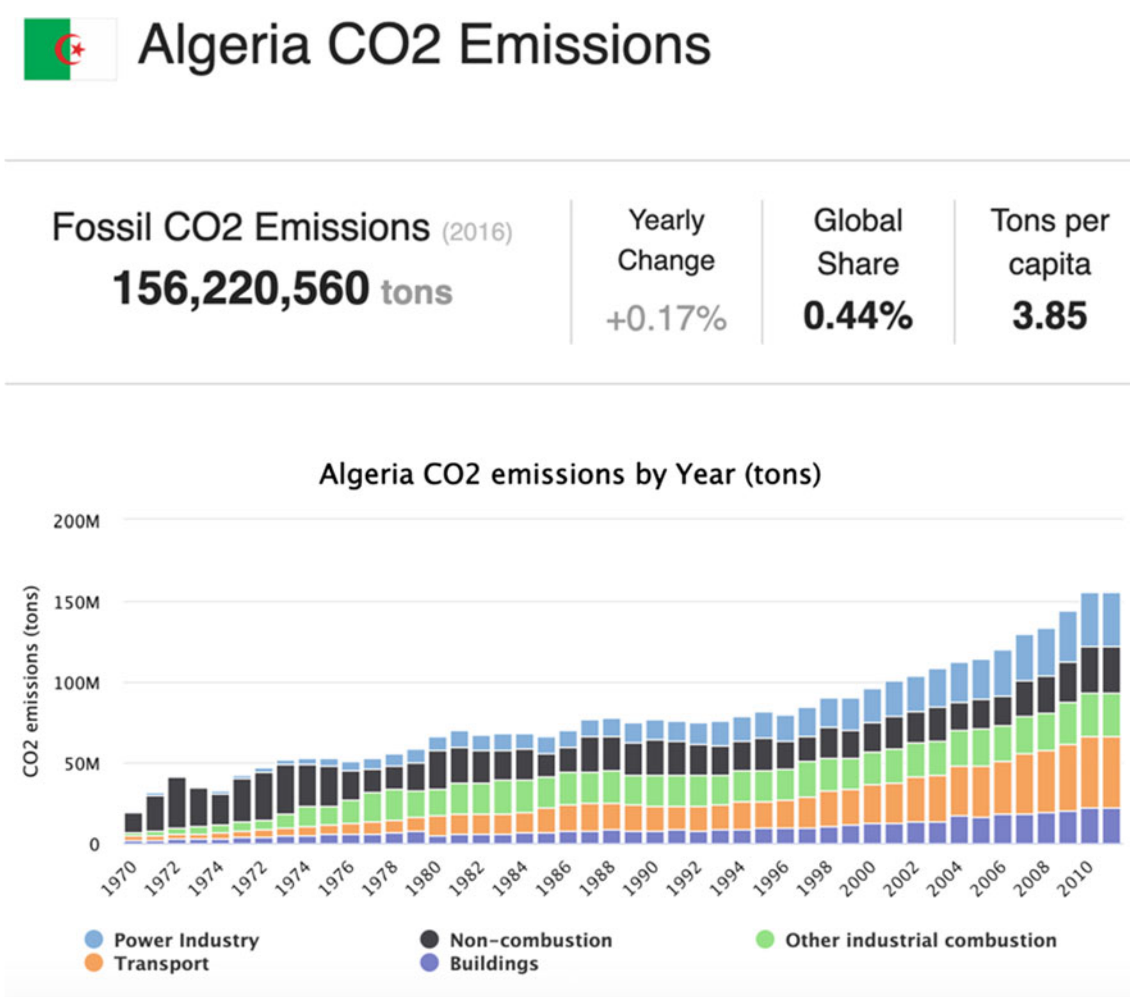

Fig. 3 Algeria CO_2 emissions 1970–2016. From worldometer.info

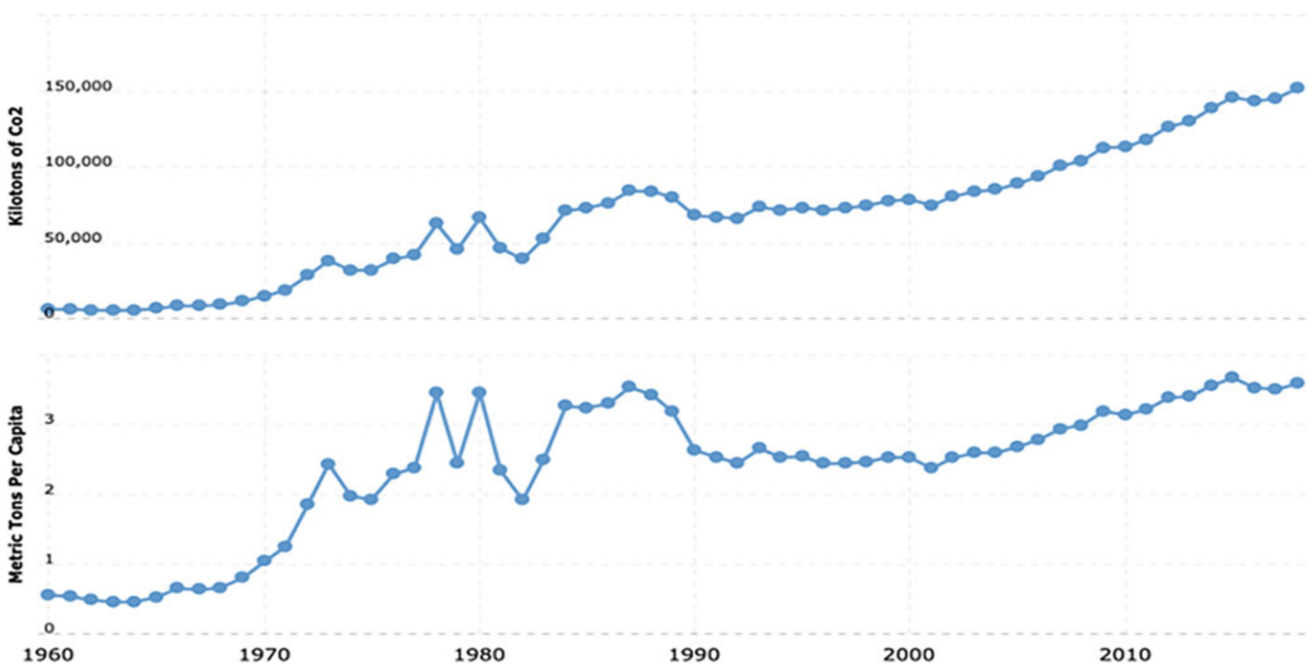

Fig. 4 Algeria carbon CO_2 emissions 1960–2022

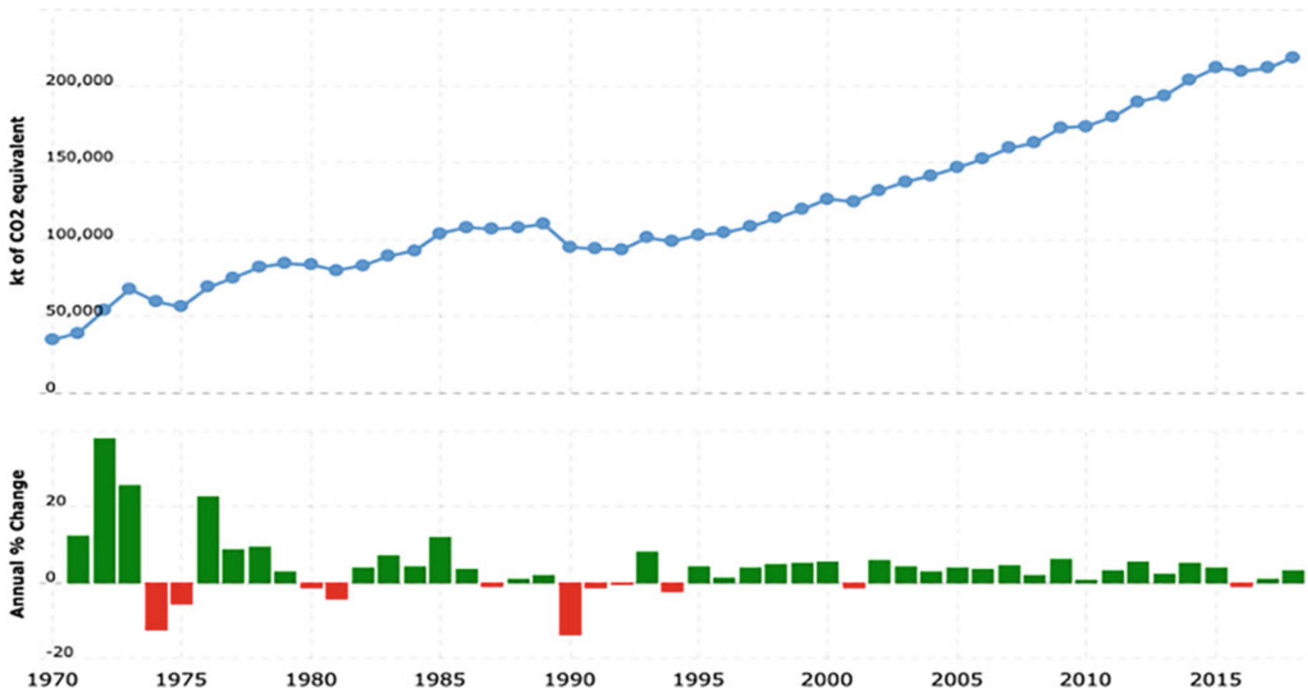

Fig. 5 Algeria greenhouse gas (GHG) emissions 1970–2022. From macrotrends.net

Fig. 6 Algeria renewable energy 1990–2020. From macrotrends.net

It is therefore worth mentioning that the importance and urge of the development of an environment assessment method for the Algerian context cannot be stressed more. The first critical step for mitigation of GHG and the development of green building in the country requires the identification and assessment of the existing and future built environment on how their green performance is doing. Afterwards, proper solutions and techniques will be implemented to upgrade building performance within a proper framework. This framework will then help the implementation and promotion of sustainability development in the country.

5 Lack of Environmental Assessment Method in Algeria

Even though many environmental assessment methods have been developed across the world, Algeria still does not develop its own method (Tebbouche et al., 2017). Many countries have contributed to the design and construction of environmentally friendly buildings, sustainable development and green buildings using alternative guidelines and principles for building construction (Suzer, 2015). These guidelines and principles have the potential to reduce resource consumption during construction, use and building operation as well as reducing negative impact to the environment through the emission, pollution and waste of its components (Ragheb et al., 2016). Thus, environmental assessment methods have been created to meet the required needs (Riascos et al., 2015) with the objective of providing guidelines or criteria to evaluate the green performance of buildings (Cole, 2005). Moreover, Cole (2005) confirms that the environmental assessment methods have provided a considerable theoretical and practical contribution to sustainable development, arguing by their facilitation of the communication between the stakeholders and their changing of the culture of the building industry. Suzer (2015) and Cole (2005) hold the position that environmental assessment methods have become very popular and on demand in the market in relation to the context of the green building. As a result, their positive impact on the performance of the buildings has grown remarkably. Indeed, Cole (2005) points out that building environmental assessment methods have widely contributed to the improvement of the performance of buildings because these methods aim to enhance the use of natural resources to improve indoor environment quality (Riascos et al., 2015). Consequently, these assessment methods stimulated the demand for sustainable certified buildings in developed countries.

Riascos et al. (2015) present arguments to emphasise that the development of sustainability has a positive impact not only on the growing economic but also the social improvement, which means that Algeria main economic on oil and gas will be exchanged by this development (Bouraiou et al., 2020) and the improvement of the social buildings to be environmentally friendly. That means an environmental assessment method must be developed in Algeria because it will generate a green building certificate, which will motivate the use of techniques and material of sustainable buildings in the country. This could lead to the design and building of green in Algeria as well as promote the growth of the economy to reduce the CO_2 emission and the contribution in the eco-friendly buildings.

Tebbouche et al. (2017) indicate that the real question that we need to stress in regard to the sustainable development in Algeria is, "[W]hat strategy should be developed for sustainable building in Algeria?;" they claim that the central issue of the environmental quality of the buildings in Algeria and the renewable energy remains on the development of "Sustainability" and "Green Buildings Assessment Methods," rather than imposing to the architects and engineers to implement the Document Thermal Regulation (DTR) and GIZ guidebook in every project and consider it as a solution for the development of sustainability in the country by these mathematical calculation (Boukarta & Berezowska-Azzag, 2018), nor by importing or adapting existing methods in order to avoid the challenges identified by Sev (2011) and Ding (2008) above. It is true that both DTR and GIZ guidebooks may help reduce energy consumption. But, they need to be integrate into a bespoke environmental assessment method for the country that has a set of criteria that meets all the three pillars of sustainability requirements. Whereas, DTR and GIZ guidebooks are more effective when it comes to achieving a better project's compliance to the criteria set by the environmental performance assessment methods in order to have higher rating in regards the sustainable development as an overall mark assigned to each project.

BREEAM and LEED are considered as the first worldwide assessment methods ever created and are both life cycle and green building-based methods (Shan & Hwang, 2018). These two methods have also contributed to the development and promotion to sustainability development globally (Iyer-Raniga & Kashyap, 2021). Considering the achievements of these two methods, it is necessary to develop Algerian GBRS. Having that said, it is really important to bear in mind that these methods have limitations and gaps that must be considered in order to build a successful bespoke EAM that can work within a multi-climatic country such as Algeria. The section below is critically exploring these gaps and limitations.

6 EAMs' Gaps and Limitations

It is undeniable that environmental assessment methods have widely contributed to the development and promotion of green architecture. During the last two decade, these methods they have gained more popularity, not to mention the economic improvement through creation of many jobs opportunities as well as adding to the credibility of building by initiating the green labels reflecting the environmental performance and its contribution to the mitigation of GHGs emissions (Chen, 2018; Gagnon et al., 1993; Zainine et al., 2021; Zeynalova, 2011). In fact, both studies conducted by Nwodo and Anumba (2019) and Fonseca et al. (2017) show the social, economic and environmental benefits of EAMs.

Many cities have witnessed dramatic growth in their economy when they have implemented and used EAMs by governmental organisations or non-governmental organisations projects.

For instance, take a look at the dramatic growth in the economics of Egypt, especially in the construction industry. The investments tripled during the year from 2015 and 2016 compared to the previous year and jumped from 43.2 to 198.6% in number of investments (Barakat et al., 2017). The construction and building sector witnessed an economic growth rate from 9.7% in the year between 2014 and 2015 to 11.2% in the following year (CBE, 2016). As a consequence, the construction industry contributes 5% of the total Egyptian's GDP and employs more than 11% of the total citizens in Egypt (Esam & Ehab, 2015). This is mainly due to the implementation of the Green Pyramid Rating System (GPRS) in the country. Given the fact that the construction industry is considered a wasteful sector (Daoud et al., 2018), especially during the project construction life cycle. As such, this waste will generates pollution and harm the environment on top of the high costs of construction materials (Azis et al., 2012). Thus, GPRS encourages the implementation and use of environmentally friendly and durable materials that generate less pollution and waste as well as are high cost rentability (Daoud et al., 2018). As a result, more savings from the maintenance and waste, and less overall project's cost.

On the other hand, there is evidence (Awadh, 2017; Cole, 2005; Ding, 2008; López et al., 2019; Shamseldin, 2017; Shan & Hwang, 2018; Suzer, 2015; Zainine et al., 2021) and from many research papers indicating limitations in these methods and their contribution regarding the sustainability development and its pillars from a different perspective. This is mainly due to the importability and the worldwide usage of these methods without taking in consideration the geographical, cultural, social and economic factors on their adaptability by many organisations and methodological developers (Suzer, 2015; Zainine et al., 2021). In addition, it seems like the major challenges identified in the lacks of adaptability present only in LOTUS, Vietnam environmental assessment method, by Nguyen et al. (2017) are very similar to the challenges faced by Green Start in Australia represented by social and cognitive, economic and cost, legislative and institutional, suggested by Chen et al. (2015). It can be argued that both the Lotus and Green Start have been developed based on BREEAM and LEED. Doan et al. (2017) study shows that Green Star New Zealand's, which is also based developed from BREEAM, suffer from complex administration issue related to the cost perception, client demand and benchmarks project, all of which have a relation to the economy (Zainine et al., 2021).

Moreover, many research findings (Awadh, 2017; Ding, 2008; Shamseldin, 2017; Shan & Hwang, 2018) present arguments to emphasise that several countries have not developed their own assessment methods and that there is imbalance weighting in the existing EAMs which was not adapted in the new created methods. The new methods, instead, have completely relied on other earlier methods by importing them directly or requested a modified version by simply adding or eliminating few criteria and changing their weighting and components required in the building without critical evaluation of the possible consequences (Awadh, 2017; Ding, 2008; Shamseldin, 2017; Shan & Hwang, 2018). As a result, the most significant and primary criterion in all assessment methods is the "energy" that belongs to the environmental criteria, followed by "site" and "indoor environment." It is obvious that the most well spread and used assessment methods are BREEAM and LEED: more than half million and quarter million certificates and buildings have been registered under these two methods, respectively. These two methods are also recognised as the oldest one (Shan & Hwang, 2018). Not surprisingly, each of these methods tend to focus on the energy and environment criteria in their weighting system, followed by the site and indoor environmental quality which justifies the hypothesis of Awadh (2017), Ding (2008), Shamseldin (2017), and Shan and Hwang (2018) that more than 70% of existing EAMs arise from the predominant international systems. It can be argued the lacks initiated in BREEAM and LEED have mutated in most of the other developed EAMs for many decades.

Chen et al. (2015) explain that EAMs challenges are frequently grouped under four major factors, technical and design, economic, sociocultural and institutional factors. For instance, they do not take into consideration the different climatic zoning; also, they give more importance to the environment than the economy and society dimensions. For instance, recent research conducted by Alyami (2019) on three different houses situated in different climatic zones in Saudi Arabia. These three houses in Riyadh, Jeddah and Al-Baha are located in hot arid climate, hot humid climate and mild hot mountainous climate, respectively. Through this experience, Alyami (2019) aims to confirm that BREEAM and LEED are unsuitable for the assessment of the built environment in Saudi Arabia. In contrast, he initiated the exploration of the first Saudi Environmental Assessment Method (SEAM) in 2011 at the University of Cardiff as an alternative or a bespoke assessment method for the purpose of this context.

Alyami (2019) used an IES-VE plotting tool for the simulation of the energy consumption in each house for one year. He then equipped each house with 50 m^2 of PV panels. Afterwards, he counted the energy savings for each house. The Al-Baha's house has the most saving percentage of 42.7% with a peak saving of 70.7% during February. Followed by the Riyadh's house with a 30% energy saving per annum and 65% as a highest percentage during February and

March. Finally, Jeddah's house with 25% overall saving percentage and 36.1% as a peak saving in February. For the reliability and accuracy of these results, Alyami has expanded the scale of his experiment by adding nine more houses from each region, and the results remained the same. These research findings are very critical when it comes to assessing environmental performance of these houses from the same country where there is a risk of applying the same grading system, despite the climatic difference. It is clear that the energy saving is different from one climate zone to another even though using the same PV surface of 50 m^2. Therefore, the requirements to maintain the same comfort level are not the same. This means, in order to obtain the same percentage of energy saving, PV panels area has to be extended in the case of Riyadh and Jeddah's houses, or more fossil fuel has to be burned to supply the energy needed, adding more cost in both cases. As a result, an increase in the CO_2 emissions and air pollution, affecting both the economy and the environmental dimensions of sustainability, can happen to maintain the indoor quality in this case.

Unfortunately, there are no existing EAMs that consider the supplement cost added to maintain the same comfort, not the realisation of the extra CO_2 emission. Hence, EAMs are not addressing equally sustainable development pillars which is a fundamental starting point. Alyami (2019) states that it is unfair to adapt or directly use any existing environmental assessment method without taking into consideration the external factors as important as the weather conditions such as Saudi Arabia's. Achieving a certain comfort level in Al-Baha is an easy task compared to Riyadh and Jeddah. It is therefore fair to consider this exertion when assessing any building in regard to their climatic conditions.

A similar study conducted by Shamseldin (2017) for the purpose of discovering the widespread use of LEED in her country Egypt instead of Green Pyramid Rating System (GPRS). She argues that regardless many countries; such as Canada, India, UAE and Malaysia have indeed modified LEED to adapt its use in their country (Whitehead et al., 2015). In fact, it is unreliable to exchange the use of GPRS with LEED for the assessment of building's energy efficiency weather in those countries, or in Egypt. Because the different climatic conditions and zones that LEED takes into consideration on its assessment criteria is very different and not similar to the Egyptian's climatic zones that GPRS has exploited. Whereas, Green Star is a more reasonable methodology and very similar to GPRS just in case of using an alternative assessment method (Shamseldin, 2017). In addition, Awadh (2017) analysed four well spread EAMs (BREEAM, LEED, GSAS, Estidama) in regard to their contribution to the sustainable development pillars; he concludes that all of the four EAMs tend to give more importance to the environmental pillar, whilst the social and economy are the least important. López et al. (2019) have found similar results on analysing 101 methods bundled under three groups. They have concluded that energy and indoor environmental quality which belongs to environmental criteria has a strong presence in all three groups. This can result in disbalanced SD pillars.

It can be argued that social sustainability is of equal importance as the environment and the economy that many EAMs neglect. Mhalla (2020) notes that the Novel Coronavirus appeared in late 2019 in China from a wet market in Wuhan has invaded the globe and become a real threat to the government, citizens and business. This virus has impacted the world economy, air lines, oil industry, many worldwide businesses fell to their knees due to the ill-equipped national health organisations in different countries, as well as its rapid infection that overwhelmed health services globally. There was no alternative solution except staying at home where possible and forced lockdown to the nation. Mhalla (2020) indicates that health conditions have a direct relation to social issues, and social distancing has deeply impacted the stability of economy and environment sustainability; therefore, their performance cannot be promoted unless in a safe society. Hence, the social sustainability relevance cannot be more underestimated.

Sev (2011) and Ding (2008) truly identified most of the challenges faced by Building Environmental Assessment Methods (BEAMs) when they are directly being used or imported with modification to another country or region which is the fact of many existing methods. They indicated six major issues related to the cause of this problematic:

- This building's environmental assessment methods must take into consideration the economic, social and environmental sustainability equally. Cole (2005) was the first who initially observed that the average living conditions in developing countries are much lower than the developed one. Therefore, developed countries have more intentions to reduce building's impact on the environment by keeping the same living conditions. At the same time, building environmental assessment methods are mandatory for the development and promotion of green architecture in those countries.
- For a proper use and recallability of the BEAMs, the criteria and sub-criteria must reflect national, regional and cultural diversity.
- There is a lack of consideration of the historic environment and its protection by many BEAMs. The existing EAM has no criteria that preserve the cultural or historical environment that is critical for social sustainability.
- Many of the existing EAMs are considered as a design guideline. Their assessment process is frequently implemented during the last stage of the final project design;

this will lead to the appearance of many issues in the design that have been already established. Therefore, EAMs implementation has to be as early as possible for allowing a collaboration between the design team and the assessment. Hence, more consideration for the development of appropriate design tools.

- Many EAMs such as BREEAM, LEED, BEPAC and HK-BREAM just to mention a few, they do not include the financial aspect. Therefore, the economic dimension is underestimated. Hence, the sustainability pillars are imbalanced by these EAMs, and projects are less attractive by investors which explain the lack of development of green architecture in many countries.
- Complexity is another issue faced by EAMs, GBTool is recognised as the international assessment method that can be applied in any country. Yet, its simplicity of use is far more considered compared by its 120 assessment criteria. Cole (1999), Larsson, (1999), and Ding (2008) additionally indicate that simplicity of use is a critical successful factor for the effectiveness and efficient adaptation for any development of EAMs. They argue that the number of assessment criteria must be carefully selected. Many sustainable strategies for the reduction of carbon emission include other improvements which their assessment is inevitable. For instance, physical and non-physical indicators can be grouped under the carbon emission assessment umbrella. Similarly, the effectiveness of land use can be linked to overharvesting. Jadhav et al. (2020) indicate in her comparative research of LEED and GRIHA (Indian's EAM) the complexity of using those methods in order to obtain an accurate result of buildings' performance in most of the country on top of their different overall rating of the same building that may cause a confusion in decision-making.

Furthermore, Zainine et al. (2021) explain the relevance of presenting the qualitative and qualitative data separately. This will improve the interpretation of the user to hinge each target to its required level of performance as well as better positioning of the building with respect to its performance (Cole, 1999; Haapio & Viitaniemi, 2008). Whereas, a bad results presentation may lead to a misevaluation and loss of the credibility of the building. In addition, Hossain and Ng (2020) present arguments to highlight the difficulty, if not impossible, to compare between EAMs' results that has a negative impact on decision-making due to the lack of a standardised data base, which is another issue present in EAMs.

Moreover, given the fact that many components are included during the building construction and operation phase, Whitehead et al. (2015) explain that these components such as Information Communication Technology (ICT), batteries and building services are frequently replaced every three to twenty years at least. Many EAMs neglect the assessment of these components which affect the overall environment performance of this particular building. It is therefore important to consider life cycle assessment to data centres in EAMs to improve the accuracy of the level of building's performance (Andrae, 2010).

Clune and Zehnder (2020) confirm the only way that sustainability solutions are effective, and successful is the cooperation of all three dimensions of sustainability development. They continue that through many examples it can be concluded that a sustainable project's failure is always related to a collusion between one or two pillars of the development. The shift from theory to action is inevitable without a sustainable solution and without implementing all its pillars equally. Whereas, Loviscek (2021) holds the position that this shift from theory to action is still unachievable at the present time due the need for additional conditions or characteristics that would help the transaction. Yet, Doan et al. (2017) support the idea and stress that the fourth pillar of sustainability should be the "Institutional Dimension." They argue that this suggestion on the concept dates back to 1995 when first introduced by the Commission on Sustainable Development. Ameen et al. (2015) and Doan et al. (2017) further anticipate that the next future dimension of the development is "cultural dimension" and "Epistemology dimension" based on cities and government's (2010), Redclift (1991)'s assumptions, respectively.

7 Conclusion

Environmental assessment methods are essential to promote green architecture practices in countries with different climatic zones, such as Algeria. These tools/methods should aim to inform sustainable development through seeking a win–win situation between economic growth and the preservation of the environment. The social dimension is no less important than the other two pillars and has to be taken into consideration. Thus, to preserve the natural resources for the present and future generation, it is important to achieve a rationalised balance between the three pillars of sustainable development. Although green architecture practice has witnessed a dramatic evolution around the world especially after the development of environmental assessment methods, Algeria has not created its own assessment method nor contributed to the sustainability development in a proper way. Algeria has instead followed a six-step approach for the development and promotion of sustainability in the country. The DTR document and GIZ guidebook are the most significant solutions in the programme. It is argued that thermal regulations and mathematical calculation that were introduced in Algeria cannot be considered as a tipping point for the development and promotion of green architecture practice. Thus, it is important to critically recognise the success factors for the development of green architecture in a country like Algeria and how the development of a bespoke environmental assessment method could contribute to the country's sustainable development and green buildings. In addition, it is worth noting that the gap does not exist only within the country's capacity and experience; it is clear that existing EAMs have their limitations and adaptability problems, particularly across different cultural and environmental contexts. In summary, the development of green architecture in Algeria, as a country with a great potential as a source of solar and wind energy, requires developing a sufficient and context-routed environmental assessment method that considers the different characteristics of each climatic zone of the country and tap onto the natural and renewable resources. Therefore, a critical exploration is really needed to fulfil this gap within the country's sustainable development process.

To conclude and to address the EAMs limitations in Algeria, it is crucial to get more insightful primary data regarding the green/environmental architecture practice and its challenges in the country. This provides first-hand information that could help in informing the design of any assessment method. In addition, local and international knowledge and experience of EAMs should be investigated to understand the opportunities, shortcomes and challenges, as well as to identify key criteria that could contribute to the Algerian Environmental Assessment Method. It is important that the criteria emerging from this investigation should be tailored and aligned with the country's environmental challenges and resources and equally addressing the three pillars of sustainability development (Environmental, economic and social).

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The Role of Buildings Envelope Renovation to Improve the Visual Image for Existing Buildings Toward Ecological Balance

Amal Ismail and Haby Hosney

Abstract

Recently, there has been a growing interest in ecological issues worldwide. On the contrary, scientists have demonstrated that humans face two significant problems; first, many natural resources that we consider their presence for granted are now near to depletion. Second, the environment suffers from the ever-increasing pollution levels due to the enormous production processes and associated waste that we produce, affecting the planet's well-being and its inhabitants. Therefore, ecological conservation is a significant issue in various fields, particularly architecture. The aim of this research is to focus on the critical role of buildings envelope in improving the visual image of buildings and how we can use it to promote the ecological balance. Furthermore, the research focused on existing buildings because they account for a significant percentage of the building stock. In order to achieve this, the research hypothesized that there are treatments that could be used in existing buildings envelope to preserve the environment, energy and reduce emissions.

Keywords

Ecological balance • Buildings envelope • Buildings renovation • Building materials • Envelopes renovation • Eco-friendly architecture

1 Introduction

The building sector plays a fundamental role in mitigating the impact of climate change and conserving energy consumption. Furthermore, the majority of existing buildings are not compatible with ecological balance. On the contrary, there are successful experiences of many new buildings that have benefited from modern materials and construction strategies technology. Consequently, renovating existing buildings to achieve ecological balance has become a significant challenge.

2 The Applied Research Work

The building envelope is a middle interface between a building's internal and external environments. In addition, numerous materials have been developed to optimize the envelope role toward the environment, making it more energy efficient and eco-friendly. For these reasons, the research aims to investigate the worldwide experiments of changing building envelopes, especially in existing buildings, to find solutions to improve the efficiency of the building envelope. It also highlights the importance of changing the properties of building materials for existing buildings as a solution to simultaneously improve the visual image in the components of the existing cities. There are still many gaps in the research field of building materials compatible with the environment and could be used on existing building envelopes. Consequently, there is a need to study some projects that applied renovation to achieve ecological balance.

3 Ecological Balance

Ecological balance is a component of the accurate balance of the universe's system, such as the equilibrium between different living organisms and their environment. Human activities can contribute positively to the creation and maintenance of ecological balance. In contrast, these activities can influence the potential of natural ecosystems and lead to environmental disruption. Therefore, this balance is

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crucial because it ensures the existence, survival, and stability of the environment as well as human beings (Ghoneem, 2011).

4 Building Envelope Renovation Strategies and Techniques Compatible with the Environment and Their Properties

4.1 Vacuum Insulation Panels (VIPs)

Vacuum insulation panels (VIP) are highly efficient thermal insulators. Since the vacuum is one of the most effective thermal insulators, low thermal conductivity is accomplished not by containing air pockets but by completely emptying them (i.e., the existence of a vacuum is the principle idea), in which heat is only transmitted by radiation, not by convection, as it would occur in an air environment. The panels consist of a core and outer skin envelope made from plastic foil. It creates a vacuum around the fill material and is frequently coated with aluminum or stainless steel; the fill material may be foam, powder, or glass fibers and must always be permeable and porous, resistant to pressure, and can be evacuated (Fig. 1). The hermetically sealed ends protrude on either side and are typically folded back and adhered to the panel. Compared to others already massively marketed in the market, the great advantage of this system is its great capacity as an insulator with the smallest thickness, ranging from 2 to 40 mm.

VIP panels are suitable for buildings under construction and existing buildings renovation. They are mainly used in the rehabilitation of buildings and be incorporated as an insulating element to replace the more traditional actions that did not provide insulating capacity in the envelope of the repaired buildings.

The disadvantage of these panels is their elevated costs and complicated production processes. The vacuum-enclosing skin must not be penetrated to ensure the proper operation of the panels. Similarly, the panels must be handled carefully on-site and during transportation to avoid damaging the panel's delicate skin (GarciaRama; Hesham et al., 2019).

4.2 Double-Skin Facades System

It is a two-layer facade system with a space between them of about 20 cm, and air could flow through the intermediate space naturally or mechanically to act as insulation against the external environment (Fig. 2). Additionally, double-skin facades have become more adaptable to their surroundings. By the movement of inlet and outlet fins or activating air circulators, the facade's behavior can be altered in response to changing climate conditions and building requirements. As a result, designing a double-skin facade system is a complex process that begins with collecting critical data concerning sun orientation, temperature conditions, local radiation, context, and building occupancy (Souza, 2019).

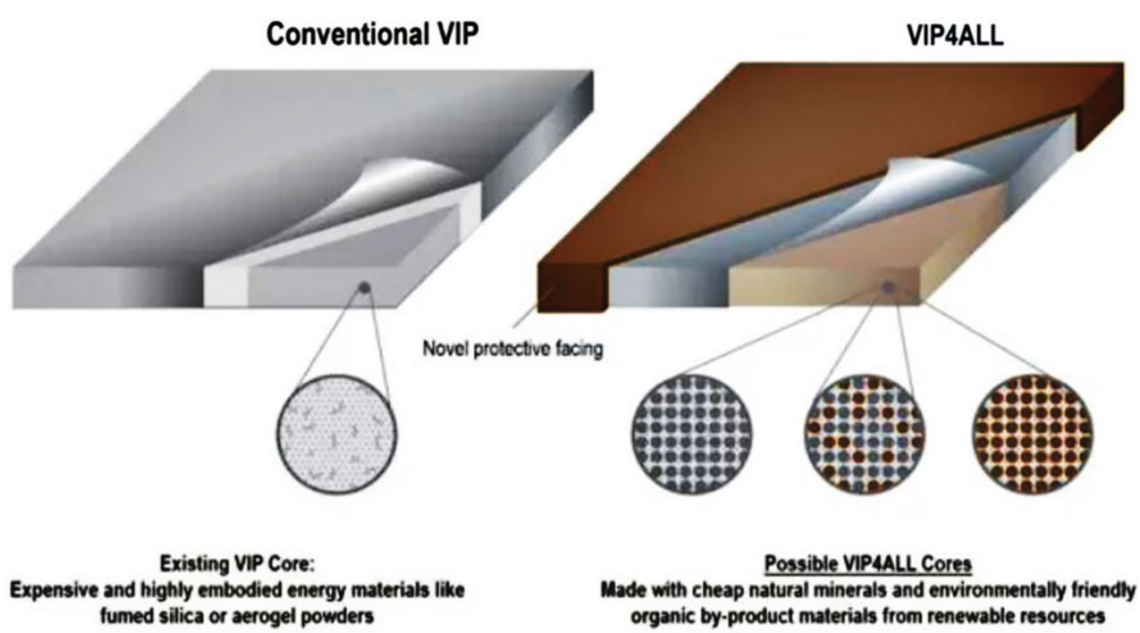


Fig. 1 VIP consists of a core and outer skin envelope (Rinnovabili.it, 2016)

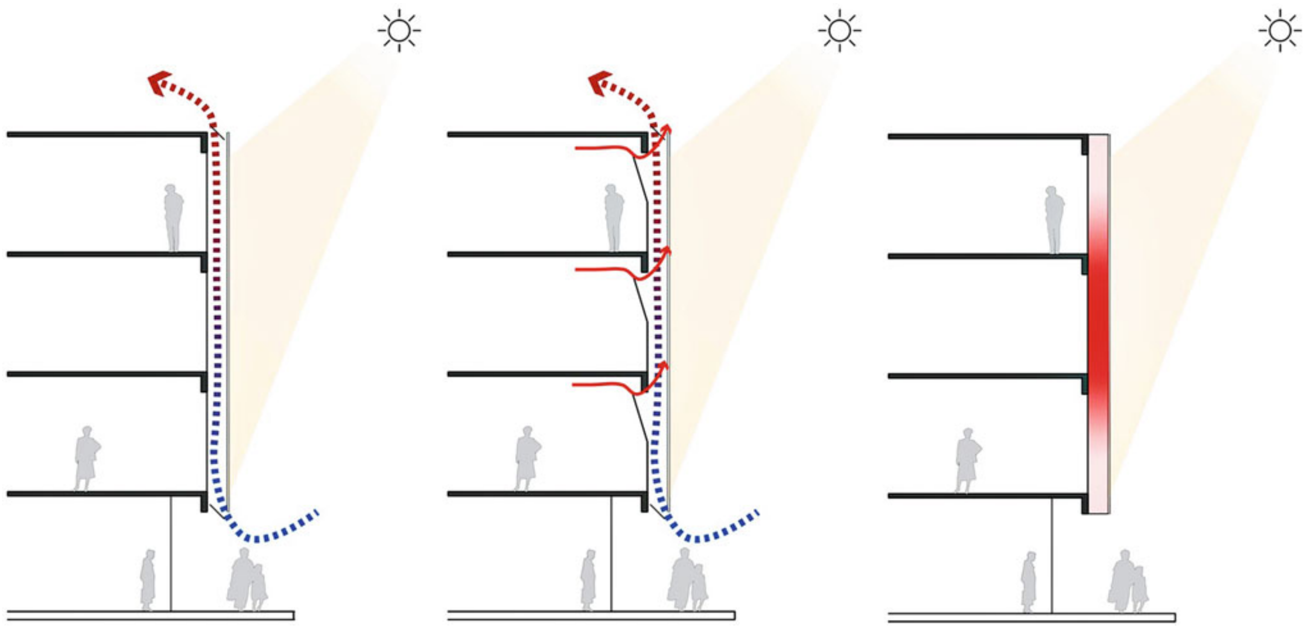


Fig. 2 Double-skin facade role in protecting the building and improving thermal comfort (Souza, 2019)

4.3 Aerogel

Aerogel is a translucent gel composed primarily of air and composed of a dry silica particulate. Aerogel has a unique structure with special properties, including the least density, thermal conductivity, refractive index, and dielectric constant of any solid material. It is among the lightest and most effective insulating materials in the world. Due to these reasons, it is high performance in reducing glare, sound transmission, and thermal transfer (Fig. 3). Aerogels have a variety of applications in construction, including optical transparency control in window panels and solar collector coverings, in addition to low thermal insulation and noise reduction (Riffat & Qiu, 2012).

4.4 Smart Glass

This material is based on the operation mode, and there are different types of smart glass; it depends on the user's needs.

4.4.1 Passive Dynamic Glass

The passive dynamic glass system is not based on electricity but responds to natural catalysts such as light or heat.

A. *Photochromic glass*

The photochromic glass changes its transparent characteristics in response to the intensity of incident light. When directly exposed to solar radiation, the difference in spectrum

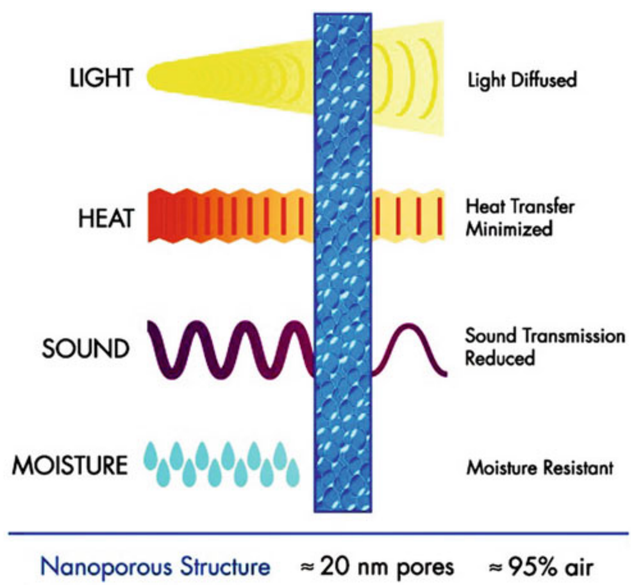


Fig. 3 Aerogel has a high performance in insulating (Solarwall)

absorption between the energy layers of glass and the added chemicals causes a reversible coloring process.

B. *Thermochromic glass*

Thermochromic glass alters its optical characteristics in response to the temperature of the exterior surface. When the ambient temperature is lower than the transition temperature, the material remains transparent and becomes opaque for higher temperatures (Fig. 4).

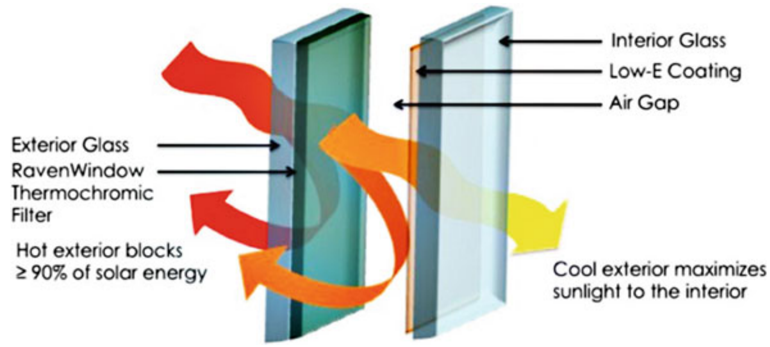


Fig. 4 Thermochromic operation process (Smartwindows)

4.4.2 Active Dynamic Systems

In order to respond to changes in the external environment, internal climatic conditions, or user needs, active dynamic systems can be operated directly or through a computerized building management system.

A. *Electrochromic glass*

Electrochromic glazing benefits from the potentials of certain materials to alter the parameters of solar radiation reflection, absorption, and transmission, in response to an externally adjusted electrical stimulus.

B. *Suspended particles glass*

Suspended particles glass is made of a double sheet of glass (Fig. 5), with a thin laminated layer of suspended particles similar to rods immersed in fluid sandwiched between two transparent thin plastic film conductors. The suspended rod particles align when power is applied, allowing light to pass and clearing the smart glass display. When the electricity is turned off, the suspended rod particles become randomly orientated, obstructing the light and making the glass appear opaque (Casini, 2014; Dashdoor).

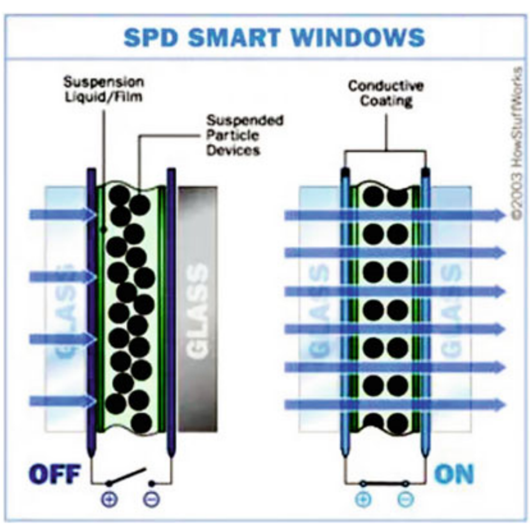


Fig. 5 Suspended particles smart glass and how it works (Bonsor)

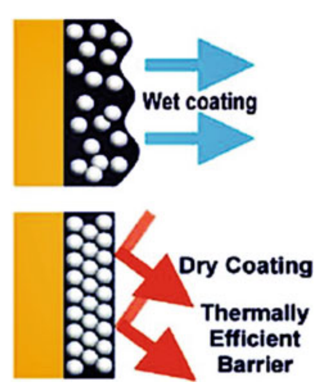
4.5 Insuladd Insulating Paint

Insuladd paint was created by Mr. David Page, the founder of Tech Traders, participating in the 1995 NASA Technology Exchange Program. These paint products are proven ability to decrease unwanted heat gain and heat loss from homes (Fig. 6), other buildings to which they have been applied, and its environmentally friendly. It incorporates a special ceramic microsphere-based insulating ingredient designed to be mixed into conventional paints to create a radiant barrier paint. Insuladd is a paint additive that has been used for a long time to make buildings, warehouses, and ships more energy efficient. Using Insuladd paint additive in painting projects is an excellent method to reduce energy consumption and save money on electricity bills. It has been demonstrated to save households up to 40% on their typical heating and cooling bills (Flowers, 2017; Insuladd).

4.6 StoLotusan Paint

Lotusan is a paint inspired by the lotus leaf, which is always clean and dry even after rain. The paint facilitated the transfer of the lotus leaf concept from biology to technology by

Fig. 6 Insuladd insulating paint with a unique ceramic microsphere creating a radiant barrier paint (Flowers, 2017)



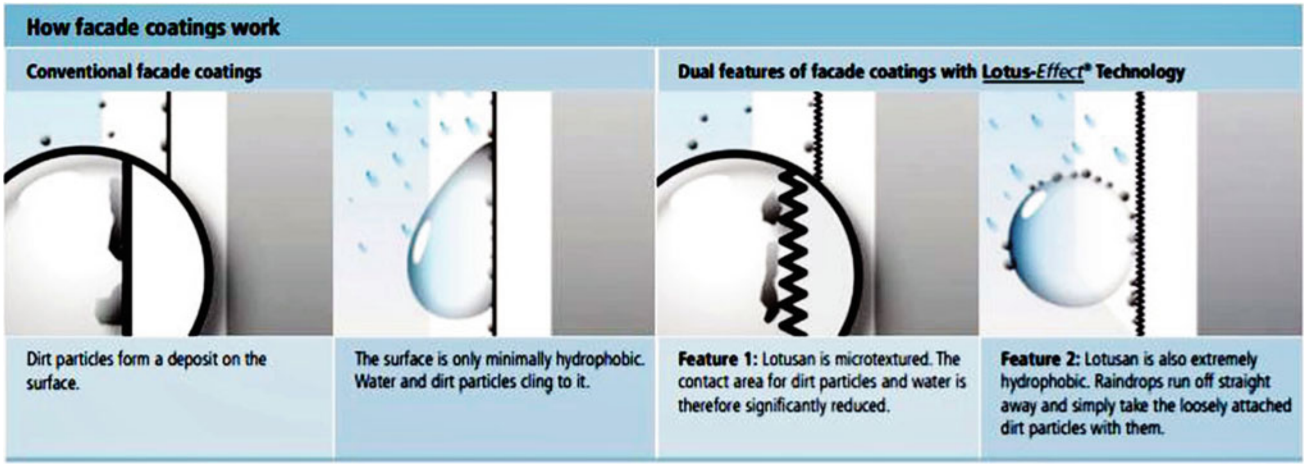


Fig. 7 Before and after using StoLotusan paint on façade (Sto)

utilizing specifically selected raw ingredients and binder combinations with a microstructure made of extremely fine mineral rock flour and metal oxides. Due to the paint's strong water repellency, dirt is washed away by rain (Fig. 7), a deft blend of a water-repellent surface, and a unique microstructure resembling a lotus leaf. As a result, most dirt particles fail to cling to the facade surface correctly and are rinsed away by rains during the next rain shower (Nessim, 2016).

4.7 Titanium Dioxide (TiO_2)

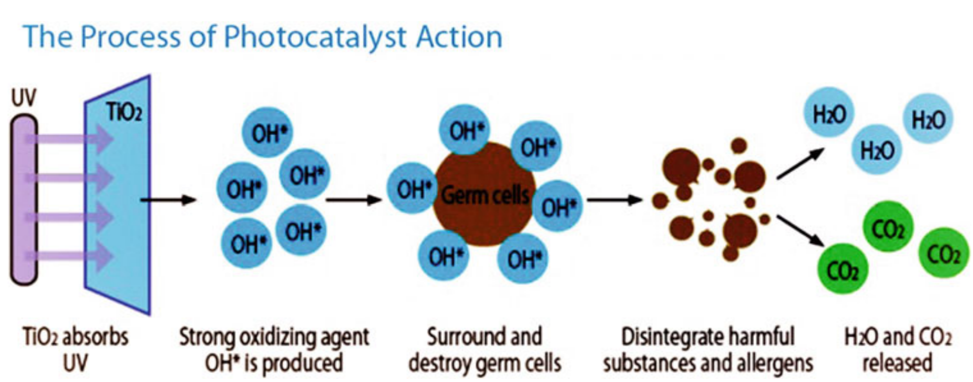
Photocatalytic materials are a recent breakthrough that contributes significantly to reducing pollution. These materials are self-cleaning, absorb many pollutants in the air, and operate as an antibacterial agent by converting the surfaces to that they are applied into multifunctional constituents due to solar radiation. It is a particular titanium dioxide mineral form (TiO_2) (Fig. 8). By integrating anti-pollution and antibacterial properties, a photocatalyst speeds the oxidation process by assisting pollutants to degrade into water-soluble inorganic salts. Nitric oxide (NO_x), particulate debris, and volatile organic compounds (VOC) are converted into harmless substances for humans and the environment, like sodium nitrate ($NaNO_3$) and carbonate. Additionally, photocatalytic paints applied on the exterior of buildings may help reduce (CO_2) and other chemical pollutants. In addition, the envelope serves as a protective barrier between the interior and the exterior (Di salvo, 2018).

4.8 Photovoltaic Panels (PV)

Solar energy is a renewable source that is both free and clean. By photovoltaic cells, we can transfer light energy into electricity. Hence, this energy can provide us with most of our electricity needs. There are different types of photovoltaic cells; the first type or old one contains crystalline silicon. After that, the new generation contains amorphous silicon, and other types contain thin technology layers; however, more than 90% of solar cells still consist of wafer-based silicon cells.

Light carries energy flowing into the cells, where it is converted into electricity (Fig. 9). Light dislodges electrons from highly energetic silicon atoms; the internal electric field forces electrons to the front of the cell and conducts electricity to adjacent cells. The fundamental building block of a

Fig. 8 Photocatalyst process (J, 2013)



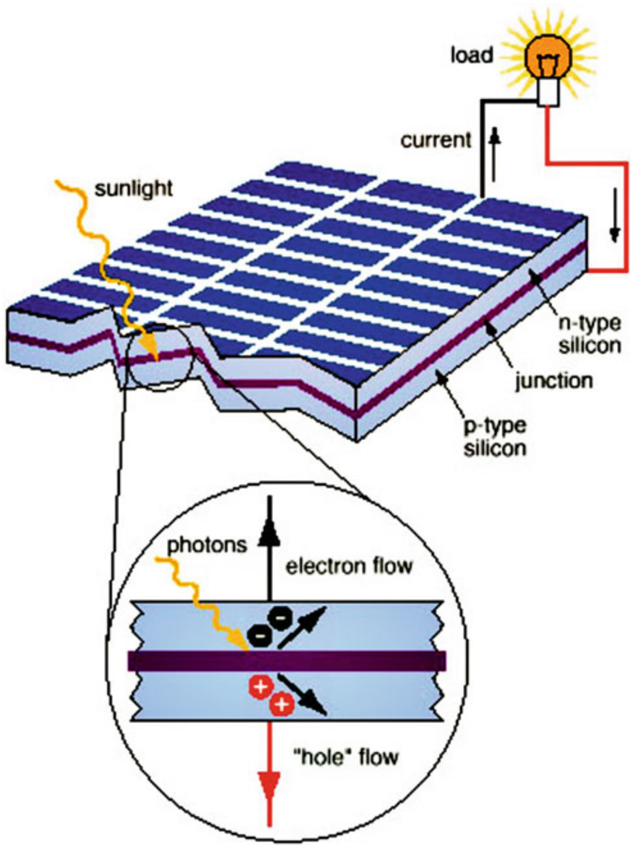


Fig. 9 Process of converting sunlight energy into electricity (Alec, 2011)

photovoltaic system is modules that contain cells. On the other hand, the (PV) panel is a group of modules, and also (PV) array contains a group of (PV) panels (Bagher et al., 2015; Grant, 2016).

5 Research Methodology

The research was conducted using a descriptive and analytical method based on resourcing data from the researches relating to modern building materials, as well as a comparative method between five world experiments that applied renovation for existing buildings envelopes to find solutions to enhance the visual image in the components of the existing cities toward ecological balance.

Overall, these five case studies have been chosen and analyzed in order to highlight the importance of changing the properties of building materials for existing building envelopes to be more efficient in terms of energy consumption, construction economics, and air quality.

6 Examples of Buildings that Applied Envelope Renovation Toward Ecological Balance

6.1 Manuel Gea González Hospital Renovation as an Example of (TiO_2) Material

Criteria of selection: This case study demonstrates the use and performance of (TiO_2) material in building envelopes to clean the air that goes into the building and surrounds it to enhance the indoor environmental quality.

Location: Mexico City
Principal architect: Manuel Villagrán and Elegant Embellishment (Allison Dring and Daniel Schwaag, Berlin)
Date of completion: 2012
Building type: Hospital
Strategies used in the project envelope: (TiO_2), Prosolve 370e.

The original Manuel Gea González Hospital was constructed in 1942 and was designed by architect Manuel Villagrán (Fig. 10). On the contrary, a new medical specialties tower was built in 2013 (Fig. 11). A 2500m2 facade is built out of 100 m-long, composed of a lightweight plastic material that satisfies environmental requirements entitled Prosolve 370e. The facade panels are coated with a fragile titanium dioxide coating (TiO_2).

Pollutants and other toxins are neutralized when the new façade is exposed to direct sunlight. Excessive UV radiation levels are not required to activate the coating electrons, converting nitrogen oxides and other chemicals to water and calcium nitrate that will be rinsed away by rain.

6.1.1 Observation and Results

The hospital facade panels purify the air that enters and surrounds the site. Additionally, the tiles screen filters sunlight, reducing the need for air conditioning and avoiding damaging emissions.

The new façade of the Manuel Gea González Hospital is expected to neutralize 1000 automobiles' daily nitrogen oxide emissions.

The new, non-orthogonal grid generates an apparently random tiled pattern, leading to visual randomization, a desirable aesthetic generally accomplished through bespoke design and price.

Consequently, the sculptural surfaces exhibit a natural harmony between design form and molecular technology (Tokuç et al., 2018; Prosolve370).

Fig. 10 Manuel Gea González Hospital original facade (Bitencourt & Monza, 2017)

Fig. 11 Manuel Gea González Hospital renovation façade (Embellishments, 2014)

6.2 American Geophysical Union (AGU) Headquarters Renovation as an Example of Dynamic Glass Windows

Criteria of selection: This case study demonstrates how to use triple-pane, air-filled, 1–3/4-inch thick dynamic glass windows to regulate the solar heat gain coefficient, reducing heat, and cold transmission.

Location: Washington DC, USA
Principal architect: Hickok Cole
Date of completion: 2018
Building type: American geophysical union
Strategies used in the project envelope: Smart glass and photovoltaic panels.

The American Geophysical Union is a nonprofit organization dedicated to improving research and ensuring a sustainable future. AGU restored its existing 62,000-square-foot headquarters facility to become the district's first net-zero energy renovation. Net-zero energy will be attained using a combination of architectural, engineering, and innovative technology solutions that conserve, reclaim, absorb, or generate energy or water (Fig. 12).

To minimize energy efficiency losses, AGU will utilize a microgrid for energy distribution, which will be powered by the photovoltaic array's DC power. AGU's solar photovoltaic array comprises 720 sunpower solar panels, totaling 250 kilowatts. The system is strategically placed to maximize efficiency, with 24 panels on the vertical, south-facing surface and 696 panels lifted and set out horizontally above the penthouse roof.

Fig. 12 (AGU) Before and after renovation design (Koski, 2016)

AGU's current windows have been replaced with triple-pane, air-filled, 1–3/4-inch thick dynamic glass windows. The addition of a third pane results in a lower U-value and solar heat uptake coefficient, which reduces heat and cold transmission. Additionally, this glazing features an electrochromic layer that colors on-demand, reduces glare and heat transfer, and allows natural light and views.

The outdoor air system provides a reliable method of building ventilation. This system simultaneously conditions entering air and recovers heat from the outgoing exhaust to warm incoming air for space heating purposes. Rainwater collected from the roof and photovoltaic array will be stored in an 11,300-gallon cistern positioned in the garage of the building. Greywater will be filtered and treated before being reused for flushing fixtures and irrigation of the green roof (Fig. 13).

6.2.1 Observation and Results

AGU seeks to receive a perfect score of 100 in the LEED credit categories for water efficiency, energy and atmosphere, innovation in design, and regional priority.

Water consumption is reduced by 77% due to effective water fixtures and rainwater collection. Approximately 90% of construction waste was recycled. AGU will rank in the top 5% of the world's 110,000 + LEED projects with 96 points.

Beyond net-zero energy use, the project incorporates additional sustainability features such as reusing distinctive architectural elements, repurposing existing building materials, and offsite recycling of construction and demolition waste (AGU, 2019; Jacobsen, 2016).

6.3 Leaves Performative Walls (LPW) as an Example of Solar Collectors-Pollution Control Devices and the Branches as Energy Conductors

Criteria of selection: This case study demonstrates the usage of Leaves Performative Walls (LPW), which are made up of a succession of leaf-shaped panels, some of which are photovoltaic and the rest of which are smog-eaters that are coated with chemical treatment of titanium dioxide for air cleaning.

Location: Barcelona, Spain
Principal architect: Javier F.Ponce and PGI Engineering

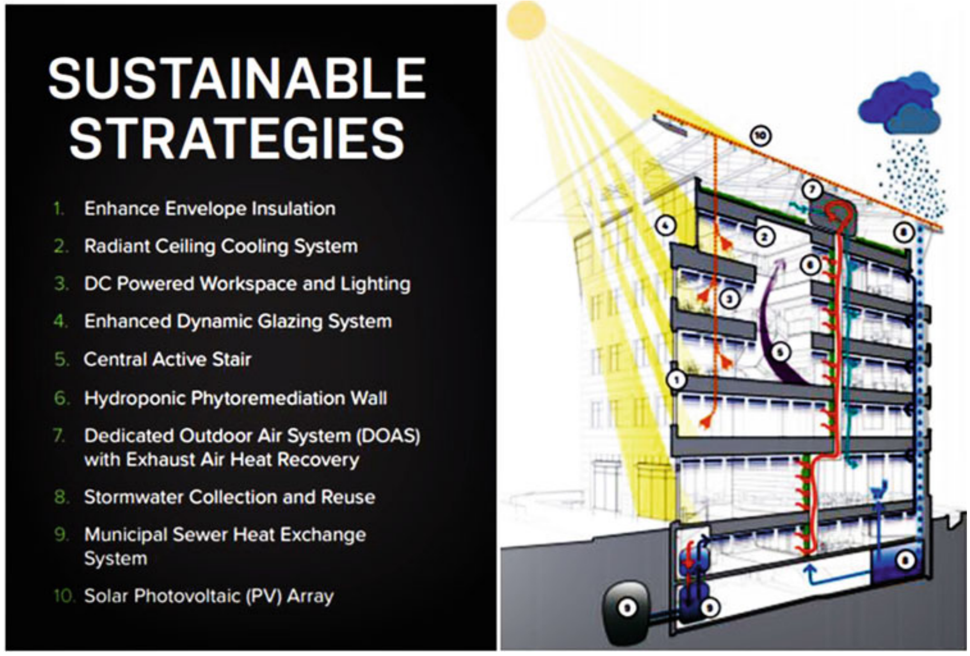


Fig. 13 Section through the (AGU) building showing renovation strategies (Hickok Cole Architects, 2019)

Date of completion: Data not available
Building type: Various.
Strategies used in the project envelope: Leaves Performative Walls (LPW).

Barcelona can try novel ways for party wall recovery and implement smart city solutions, thereby advancing into the present and future. LPW is an experimental concept inspired by the morphology of Barcelona's trees (Fig. 14). The project is a manufactured alternative that consists of a succession of leaf-shaped panels, some of which are photovoltaic and others of which are smog-eaters via the chemical treatment of titanium dioxide for air cleaning, emulating the primary internal functions of trees, solar collectors-pollution control devices on the leaves and energy conductors on the branches (Fig. 15).

6.3.1 Observation and Results

Simulation results on the energy performance of example party walls in Barcelona have an impact on ecological issues for example:

- Energy facade savings about 37 kWh
- Photovoltaic generated energy about 380 kWh
- CO_2 emissions reduction about 110 Tn CO_2
- Smog-eater production about two trees (PGI ENGINEERING, 2012; Ponce, 2014).

On the contrary, this solution helps to improve the visual image of old buildings while remaining environmentally friendly.

Fig. 14 Series of leaves shape panels applied on an old building in Barcelona (Samper & Juncadella, 2014)

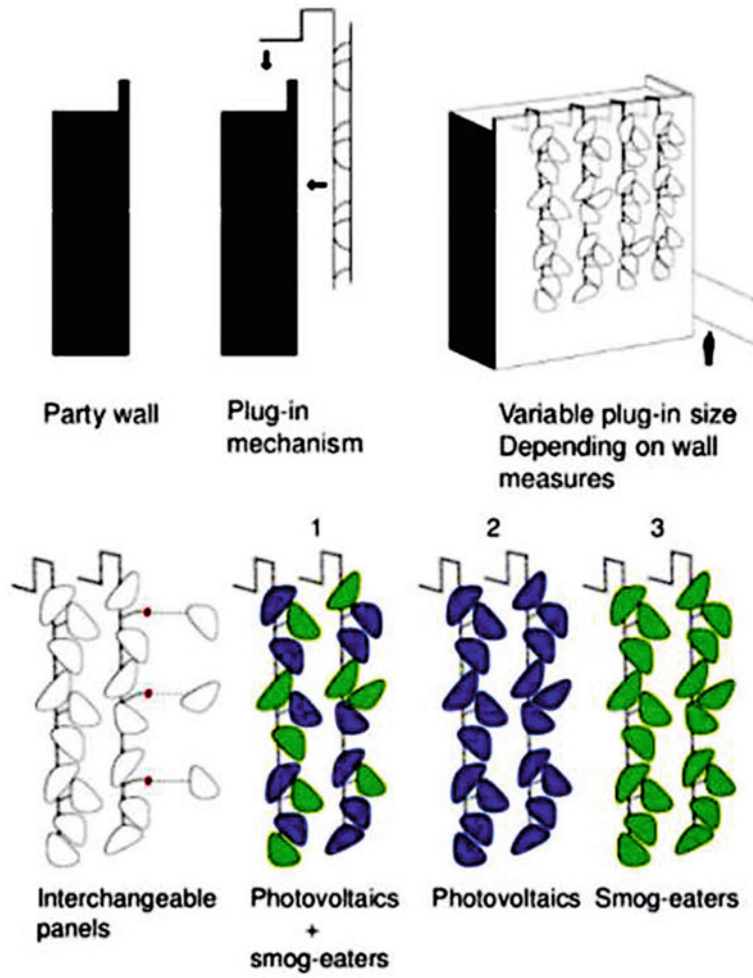


Fig. 15 Fixing system on the old building facade and the flexibility of changing leaves between photoelectric and pollution-eating leaves according to building needs (PGI ENGINEERING, 2012)

6.4 RB12 Office Block as an Example of Smart Glass Windows and Photovoltaic Panels

Criteria of selection: This case study demonstrates the usage of smart glass windows equipped with an automatic night-time opening system, which allows for the intake of fresh air and its retention throughout the day. Additionally, photovoltaic panels were installed on the building's north-facing sidewall as feasible, generating solar energy for the building.

Location: Rio de Janeiro, Brazil
Principal architect: Triptyque, a Franco-Brazilian architecture agency
Date of completion: 2016
Building type: Commercial building
Strategies used in the project envelope: Bioclimatic facade and photovoltaic panels.

The RB12 was constructed in the 1970s. Natekko, a property developer, commissioned Triptyque to investigate ways to reduce the building's energy consumption. RB12 epitomized avant-garde new principles of sustainable development centered on energy production. The technological equipment, which was installed for the first time, enables effective management of water usage, optimizes natural light, and provides a higher level of well-being to real estate buildings.

RB12 has a bioclimatic facade made up of a series of windows that reflect light like a diamond (Fig. 16). It is the first commercial building in Brazil to be powered entirely by photovoltaic panels. The suspended gardens on the terraces enable the interior sections to be more efficiently cooled and heated.

The RB12 is situated on an avenue flanked with tightly packed buildings, the architectural team explains. "Because of the height of the buildings, heat tends to accumulate between them, and the sun shines straight on the windows."

The glass facade is deliberately veiled to minimize heat intake from direct solar radiation while being transparent enough to permit abundant natural light to walk through the building indirectly (Fig. 17).

Fig. 16 RB12 bioclimatic diamond façade after building renovation at daylight and night (Finotti, 2016)

Fig. 17 RB12 bioclimatic winding facade from inside (Finotti, 2016)

At night, the windows of the building are opened to allow for air and to chill the inside. An automatic window opening system makes it feasible to bring in the fresh air and retain it throughout the day, owing to the building's insulation.

Triptyque asserts that this is the first commercial building in Brazil to generate electricity in this method. Any energy generated that is not consumed will be sold back to the grid.

6.4.1 Observation and Results

Photovoltaic panels and a small vertical installation will provide approximately 18% of the building's energy requirements. Additionally, RB12 will utilize fuel cell advancements to turn additional methane gas from city streets into electricity. The suspended gardens on the terraces reduce the electricity demand in internal areas because of the thermal control. The façade system reduces artificial lighting along the walls results in a reduction in power usage and internal temperatures.

After assessing all of the green measures implemented in RB12, it was determined that the building would consume around 60% less energy than a regular office building. Furthermore, because the facility will generate electricity 24 h a day but consume it for approximately eight, any excess energy generated will be sold back to the electrical system.

By rehabilitating the structure, it is possible to reduce material waste from demolition and carbon emissions associated with new construction (ArchDaily, 2016; Singhal, 2016).

6.5 The CDER Building as an Example of the Double-Skin Facade and Photovoltaic Panels

Criteria of selection: This case study demonstrates how a double-skin system can be used to control sunlight transmission through the facade. Also, photovoltaic panels were added to the building roof to provide clean energy for the building needs.

Location: Épernay, France
Principal architect: OuyOut
Date of completion: Renovation under construction
Building type: Office building
Strategies used in the project envelope: Double-skin system and photovoltaic panels.

The site where CDER hoped to extend was constructed in 1963 instead of demolishing the building. While developing an environmental rehabilitation, the architect chose to maintain a portion of the original structure. With double-flowered facades of vines and green roofs (Fig. 18), this building has the ambition to become a significant marker of the city center, emblematic of a city combining anchoring in the Champagne terroir and a vision of the future.

By removing the addition of three floors on rue M. Cerveaux and the one-story garage on rue de Huguenots, this solution gives views from the street toward the interior of the plot on green reception areas.

The green roof connects to the garden level of the terraced plot, 4 m higher, and creates a heart of plant block. The team created a design that insulates the building from the outside, shielding it from the sun while also capturing the thermal inertia of the concrete structure on the inside.

The double facade is a thin metal structure composed of vertical mesh strips 80 cm wide to support the vine. This structure is set back one meter from the facade and has enormous flowerpots that will enable the vine to flourish on each level of the construction.

6.5.1 Observation and Results

The final design not only shields the building from the outside, but also uses the thermal inertia of the concrete structure on the inside. Autodesk determines this insight.

Fig. 18 CDER building before and after renovation design (OuyOut, 2019)

Table 1 Envelope renovation case studies analysis

Project	Manuel Gea González Hospital	(AGU) American Geophysical Union Headquarters	Leaves Performative Walls (LPW)	RB12 Office Block	The CDER Building
Project location	Mexico City	Washington DC, USA	Barcelona, Spain	Rio de Janeiro, Brazil	Épernay, France
Climate	Sub-tropical	Sub-tropical	Mediterranean	Tropical	Semi-oceanic climate
Envelope renovation type	• Double-skin pieces made of a lightweight plastic called Prosolve 370e	• Enhanced building envelope insulation • Solar rooftop photovoltaic (PV)	• Leaves Performative Walls (LPW)	• Bioclimatic glass facade • Suspended gardens on the terraces • Solar photovoltaic (PV)	• Double flowered facades thin metal structure • Green roofs • Photovoltaic roof panels
Envelope renovation strategies for ecological balance	• Promote outdoor air quality by using Prosolve 370e panels covered with titanium dioxide (TiO_2) powder • The covered panels have photocatalytic and anti-microbial properties	• Energy efficiency loss and transmission of heat and cold by dynamic glass windows and the dedicated outdoor air system • Reducing glare while allowing natural light to enter and exit by new glazing • Generated clean energy from the sun by solar rooftop photovoltaic (PV)	• CO_2 emissions and generate clean energy through Leaves Performative Walls (LPW) • The leaves are composed of a succession of leaf-shaped panels, some of which are photovoltaic and the remainder of which are smog-eaters due to titanium dioxide's chemical treatment	• Generating solar electricity for the building by solar photovoltaic (PV) • Reduce energy consumption by bioclimatic glass façade and suspended gardens terraces • Provide the internal areas with fresh air and keep it all day by automatically opening the windows system	• Control sunlight radiation through the building by double-skin flowered facades • Photovoltaic panels on the roof provide the building with electrical demands
Maintenance	Easy	Special	Easy	Special	Special
Air pollution reduction	Yes	No	Yes	No	No
Benefits	Public	Private	Public	Public	Private
Reduced energy use	No	Yes	No	Yes	Yes
Temp. control	No	Yes	No	Yes	Yes
Improved indoor air quality	Yes	No	No	Yes	No
Increased market value	Yes	Yes	Yes	Yes	Yes
Renovation cost	Depends on the facade design and area	High cost	Medium	Depends on the facade design and area	High cost
Visual image	Modern	Better than before	Better than before	Modern	Nice
Envelope renovation disadvantages	• Prosolve 370e panels required special labors • Prevent visible natural solar light	• Not suitable for all kinds of existing buildings • Requires high technology for the application	• Requires solid façade for leaves supporting	• Not suitable for all kinds of existing buildings	• Not suitable for all kinds of existing buildings and layout surround

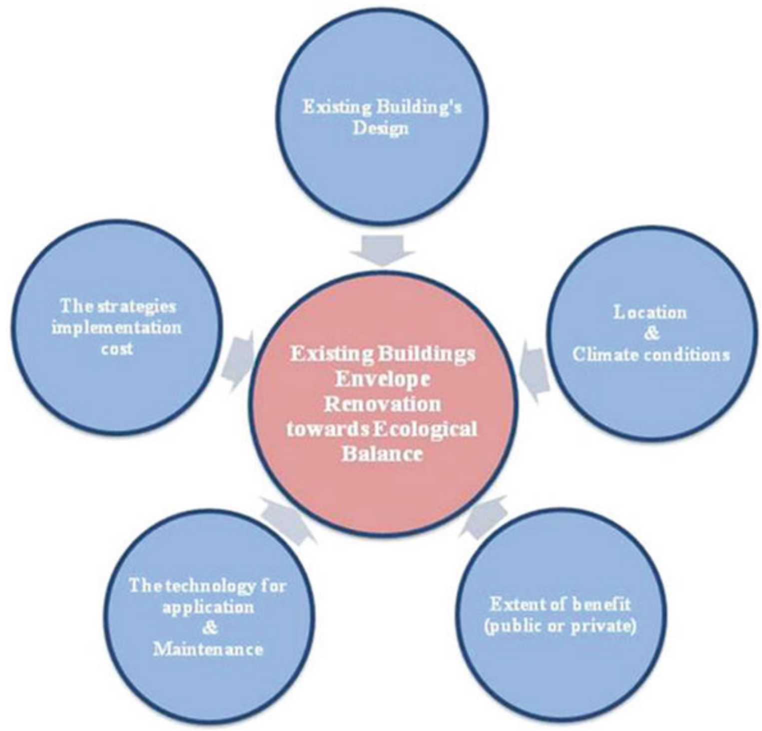


Fig. 19 Factors which impact on buildings envelope renovation toward ecological balance (author)

The smart envelope, designed for the new renovation, contains exterior insulation, a self-supporting green roof, sun protection mesh, vegetation support mesh, and photovoltaic panels to protect buildings from direct sun radiation and provide electricity demand.

The double-skin facade allows the natural light to pass through the windows without glare, reduces artificial light, and saves energy.

Envelope renovation instead of building demolition could help save the raw material and reduce carbon emissions (Autodesk, 2019; Goldberg, 2019).

7 Concluding Remarks and Further Work

In this research, we focused on existing buildings envelope renovation applications with various strategies and techniques in different types of projects. For the current research scope, three primary purposes were selected: improving the visual image, efficiency, and ecological balance compatibility. Designing the building envelope is critical because it is a building's first layer that defends against climate conditions and environmental pollution. Regarding the effect of the envelope renovation on cooling and heating demand, the results confirmed that the double-skin system in renovation could save the building from direct sun radiation to reduce energy consumption. Additionally, glazing refurbishment with smart glass reduces the use of artificial lighting, reducing energy consumption without sacrificing comfortability or outer visibility. Moreover, the building envelope renovation could improve air quality in the surrounding environment and buildings (Table 1). For these reasons, many strategies can be applied to the building envelope toward achieving ecological balance. However, they differ from one building to another due to several factors, such as the building's design, its location, climate conditions, the strategies implementation cost, the ability to provide the technology for its application and maintenance, and finally, the extent of benefit from these strategies (Fig. 19). In addition, the renovation does not mean only a beautiful visual image but should consider nature and ecological issues.

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Instant Cities and Their Impact on the Environment: Al Zaatari Case Study

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Abstract

Conflicts in the Arab world have produced multiple waves of refugees in the past decades. Jordan amongst has received a massive number of refugees located in different camps and considered to be the heaven of refugees. The new state of the camp became negatively impacting the host country and the environment in different layers. This research identified these various layers of impact; water, waste, electricity, soil, medical waste and social, which may not meet the sustainability requirements, disregarding their use as temporary panacea. This study aims at tracing the various environmental layers of impact in Al Zaatari camp. The paper then moves to focus on suggesting sustainable development tactics for each of these identified layers of impact. The methodology that has been used, to identify the various layers of impact and recommending their sustainable solutions or approaches, through tracing the literature and looking at other case studies related to our case. Finally, the paper concludes through generating some reflections about the identified layers and their solutions, recommending what is needed to be done to enhance the current camp status quo as well as future instant cities.

Keywords

Zaatari • Environmental impact • Sustainable development

1 Introduction

Forced migration is the mechanical response of refugees generated by natural disaster or external force, usually for the purpose of seeking better life conditions as the current situation is unbearable (Cohen, 1991; El-Hinnawi, 1985; McGregor, 1996; Renaud et al., 2011; Wilkinson et al., 2016). The 2011 political conflict in Syria has forced many citizens to immigrate in different countries across the world (Ledwith, 2014). On 28 July 2012, in the capital city of Mafraq Governorate in Jordan located 80 km to the north from the capital Amman, opened the second world's largest Syrian refugees camp (Al-Rai, 2012; Dalal, 2020; Ledwith, 2014). The initial plan was capped at 15,000 persons, but soon this number has multiplied more than 10 times and reached 200,000 in May 2013 (Dalal, 2014; 2020). Yet, the camp has already 8000 tents, 17,000 caravans, 120 mosques, 3 hospitals, 680 large shops and spread on 530 hectares (Abu Al-Sha'r, 2017; Al-Makhadhi, 2013; Betts et al., 2013; Khandaji & Makawi, 2013; Ledwith, 2014).

This has resulted in a chaotic situation and the birth of instant city. Both the United Nations High Commissioner for Refugees (UNHCR) and the Jordan Hashemite Charity Organisation (JHCO) who created this camp have no plan to face the developed situation (Ledwith, 2014; Scheel & Ratfisch, 2014). However, UNHCR took full responsibility and responded to the challenges faced on the ground by imposing many humanitarians' disciplinary plans (Dalal, 2014). First, there was a decomposition of the camp into 12 small districts using asphalt streets to clearly determine the boundaries. These districts are composed of blocks that contain caravans in a homogeneous order (Dalal, 2020). After that, the

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implementation of basic home facility's needs, such as the communal latrines, kitchens, and multi-use spaces (Ledwith, 2014; Scheel & Ratfisch, 2014). Finally, for a better camp's management, there were two distinctive areas planned to control the flow of the incoming refugees. One of these areas was like a waiting room for the new arriving refugees, and the second was where the final allocation for settlement. However, soon this plan collapsed due to the socio-cultural relationship amongst families. Syrian refugees moved their shelters around the camp resulting in change of the surface area on a daily basis (Dalal, 2020).

Due to the reason behind the necessity to survive in a dignified manner (Bayat, 1997), the camp became out of control, houses made out of metal sheets, canvas bags, Styrofoam, wooden pieces, metal nets, and water tanks (Dalal, 2020). This is mainly due to the fact that UNHCR provides these refugees with only one-space shelter unit for several members of family, which has broken the respect, and results in a discomfort expression amongst members of the family that is eminent. Young daughter had to change her clothes in front of her brothers, a situation that never happened back home country (Dalal, 2020). In addition to the poor design of the camp and the lack of skills amongst refugees, the severity of local climate and water shortage in the country has intensified the disorder of the camp. The new state of the camp became very harmful to the surrounding areas and negatively impacted the host country and the environment in different layers (Alshoubaki, 2017). Therefore, this research aims at tracing the various environmental layers of impact in Al Zaatari camp, suggesting sustainable solutions.

2 The Layers of Impacts

2.1 Water

Regardless, there is no formal building code that clearly states the refugees' camps in Jordan can or cannot be temporarily implemented in the country. It is rather indicated that the average lifespan of refugees' camps is estimated at 17 years (Abu Al-Sha'r, 2017; Van der Helm et al., 2017). Yet, still up to date, the water is supplied using trucks to the camp. An average between 300 and 360 trucks transport water to the camp reaching 15.1 million litres daily (Abu Al-Sha'r, 2017; Al-Makhadhi, 2013; Ledwith, 2014; Farishta, 2014) to guarantee only as little as 35 L/p/d (Aburamadan et al., 2020; Ledwith, 2014) compared to 900 L per capital averages in the US (Ledwith, 2014). It is worth to state that since the opening of the Zaatari camp, it was only the Agency for Technical Cooperation and Development (ACTED) and the United Nations Children's Fund (UNICEF) who joined forces to mainly supply water to the Zaatari camp (Al-Makhadhi, 2013; Ledwith, 2014; Namrouqa 2014). Furthermore, Alshoubaki (2017) indicates that there is a huge increase in the water shortages following the Syrian's migration to the country (Fig. 1). Rural and urban areas are now witnessing two times water cut in a single month and by 33–44% less water of usual supply. Jordan is the country most affected by the Syrian refugees; more than 70% of the total Syrian refugees are hosted by Jordan and are increasing the demand of water supply by 62% of the total water vulnerability index (Alshoubaki, 2017). In turn, the increased water demand in the country resulted in the decline of the level of aquifers specially after the acute drop of renewable water in the country since 1967 at 1857 m^3/capital/year to 145 m^3/capital/year in 2013 (Al-Harahsheh et al., 2020; Schoeffler et al., 2012).

However, due to the fact that Al Zaatari refugee camp was built on the Amman-Zarqa Basin where the majority of the Jordanian's groundwater aquifer system and wells are located (Al-Harahsheh et al., 2020). The tension and fairs have started escalating about the condition and the quality of groundwater, especially in a country like Jordan which is recognised as the fourth poorest country in the world in terms of water resources (Abu Al-Sha'r, 2017; Alshoubaki, 2017). This is mainly caused by the communal WASH blocks comprising toilets blocks, showers and laundries, and multipurpose water points and sinks at an estimation use of 50 persons per communal toilet (Aburamadan et al., 2020; Alshirah et al., 2020; Van der Helm et al., 2017). In addition to the lack of drainage in a camp as huge as the Zaatari which results in areas swamped with run-off surface or prevent the harvesting of gray water (Millican et al., 2019). There is also an average of another 200 vacuum trucks that collect daily the wastewater in cesspits or block of latrines due to the lack of no existing waste infrastructure or sewage system in the camp (Abu Al-Sha'r, 2017; Melloni et al., 2016). Moreover, this massive transportation has initially caused the damage and degradation of the surrounding areas' road where complaints from the neighbourhood were registered to the local authorities (Abu Al-Sha'r, 2017).

However, there are some research that denies the abuse of water consumption from as many as 6000,000 Syrian refugees in the Zaatari camp. For instance, Farishta (2014) claims that the water consumed in the country is less than the existing supply amount. The country is using its resources sustainably. Farishta (2014) indicates that only 2.3% of the total water consumption in Jordan is being used by all the Syrian refugees in the country. Even in the worst-case scenario where the number of refugees reaches 1.2 million as projected, still that number affects the total water consumption only by an additional 2.2% (Farishta, 2014). Regarding the water shortage crisis in the country, Farishta (2014) explains that this issue has been long before the arrival of the Syrian refugees in the country. The Amman-Zarqa Basin was already experiencing overdraft

Fig. 1 Truck delivering water at Zaatari camp. From the ministry of water and irrigation, Jordan through Fanak-Water (2018)

extraction of 8.6 MCM since 2009 (Farishta, 2014). The unsustainable water management in the country resulted in the over pumping in the last few decades (Farishta, 2014).

Hence, Al-Harahsheh et al. (2015) have conducted research about the analysis of chemical and biological composition from different water samples collected from the Zaatari camp site and the surrounding areas. The results of chemical oxygen demand (COD) in the camp shows that there is pollution in the surface water. This is due to the chemical organic substance which is undegradable by the bacteria. Regarding the biochemical oxygen demand (BOD) in the camp, results show a high amount of BOD due to the swampy water that is mixed with sewage (Al-Harahsheh et al., 2015). Additionally, the results also show that the microorganisms in drinking water available in the camp are considered as very dangerous due to the pollution in the surface water. However, the deep aquifers and groundwater are faraway to be exposed to the pollution. But, because of the high permeability of the existing rocks in the area, there is a high risk that these resources can be affected (Al-Harahsheh et al., 2015). It is therefore obvious based on Al-Harahsheh et al. (2015) results that the Zaatari camp is considered as a source of pollution to the environment, groundwater, and its refugees themselves.

Furthermore, a recent study by Al-Harahsheh et al. (2020) also conducted to identify the quality and conditions of the groundwater in the Zaatari refugee's camp and surrounding areas. More than 30 wells were sampled from the area in order to determine and analyse the results against the water quality before the establishment of the camp. Results show the average value in pH of 7.2, where the majority of the water quality in the Zaatari camp comply with the standards drinkable water data in Jordan and indicate no threats of pollution (Al-Harahsheh et al., 2020). However, the refugee's camp will eventually impact the quality of groundwater and aquifers due to the evidence of deterioration on the quality of water compared to the 2012 data before the establishment of the camp (Al-Harahsheh et al., 2020).

2.2 Waste

Another impact of the Zaatari refugee's camp is its waste. The camp regenerates two different types of waste: wastewater and solid waste.

2.2.1 Wastewater

Given the fact that these refugees are dissatisfied with their shelter, inhabitants have chosen to handle their own business (Abu Al-Sha'r, 2017). It has been recently reported by Aburamadan et al. (2020) that 84.6% of the refugees' households has already installed their own bathrooms within their shelters as early as 2014. Even worse, Ledwith (2014) indicates that the refugees have a limited access to the materials and have taken the needed components from the public toilets to build their own facilities. However, the skills and performance required to such adjustments are inadequate amongst the refugees (Abu Al-Sha'r, 2017) which resulted in an increase of the black and gray water (Ledwith, 2014) as these toilets cannot be fitted with sewage, and the refugees are unfamiliar with the provided shelters models (Boen & Jigyasu, 2005). Figure 3 shows the sewage situation in the camp. Van der Helm et al. (2017) further indicates that 93% of the refugee's households' toilets are unregulated and not sustainably connected. Regardless, 2.7 million litres of wastewater have been evacuated from the camp daily (Ledwith, 2014). Figure 2a demonstrates the disposition of the private toilets in the Zaatari camp as well as the outcome of the lack of sewage of those toilets Fig. 2b.

2.2.2 Solid waste

Another aspect of pollution is solid state where the Zaatari camp has an estimate of 680 large stores, and more than 120,000 refugees with 200 monthly children born (Ledwith, 2014). Thousands of tonnes of solid waste are generated from these population from different categories (Saidan et al., 2017) such as:

- Plastic mainly coming from packaging goods and carrying bags from the local shop in the camp,
- Organic, half million of pitas bread are distributed to the refugees in the Zaatari camp (Al-Makhadhi, 2013) on top from the household's waste,
- Paper cardboards are also generated from the existing local shops in the camp and from households' waste, newspapers, newsprint,
- Glass, all sort of glass from bottles, windows,
- Leather, wood, metal and textile are mainly from the construction of the refugees during their construction of facilities,
- Aluminium, from electronic devices, vehicle's batteries, computers and wires.

There was an attempt to construct a recycling point with the aid of refugees and humanitarian agencies to reuse such resources such as plastic and cardboard, but soon this was cancelled due to the lack of funds (Saidan et al., 2017).

As a result, the camp has become disastrous; each glass, cardboard, and plastic were found everywhere in the camp. Most of these materials have an estimation of life span between 5 and 450 years. This long process of non-biodegradability of those materials will add to the pollution of the environment dramatically.

2.3 Electricity

Jordan has not the water-shortage crisis in the country only; it imports up to 97% of its energy requirement from neighbouring Middle Eastern countries, where 96% of its electricity comes from fossil fuel (Alshoubaki, 2017). In addition, the increase of demand on electricity has risen by 1634 gigawatts only in five years starting from 2009. That has resulted in more consumption of petroleum gas by 336,000 tonnes in the same period (Alshoubaki, 2017). This is caused by the huge population coming to the refugees in Jordan that raised the consumption of electricity. For instance, to ensure safety in the Zaatari refugee's camp during the night, streets have to be lit. However, inhabitants in the camp started to illegally connect to those sources to aliment their shelters with electricity (Alshoubaki, 2017). It has been reported by Ledwith (2014) that more than 300 km of illegal electrical wires were connected to the public grid, Fig. 3a, b, representing 70% of the total residents in the camp (Alshoubaki, 2017). This has caused a resinous hazardous danger to the residents and to the humanitarians' organisations active in the camp. This huge distance only of electrical wires spread over a 530 hectares area has a negative impact on the environment (Ledwith, 2014).

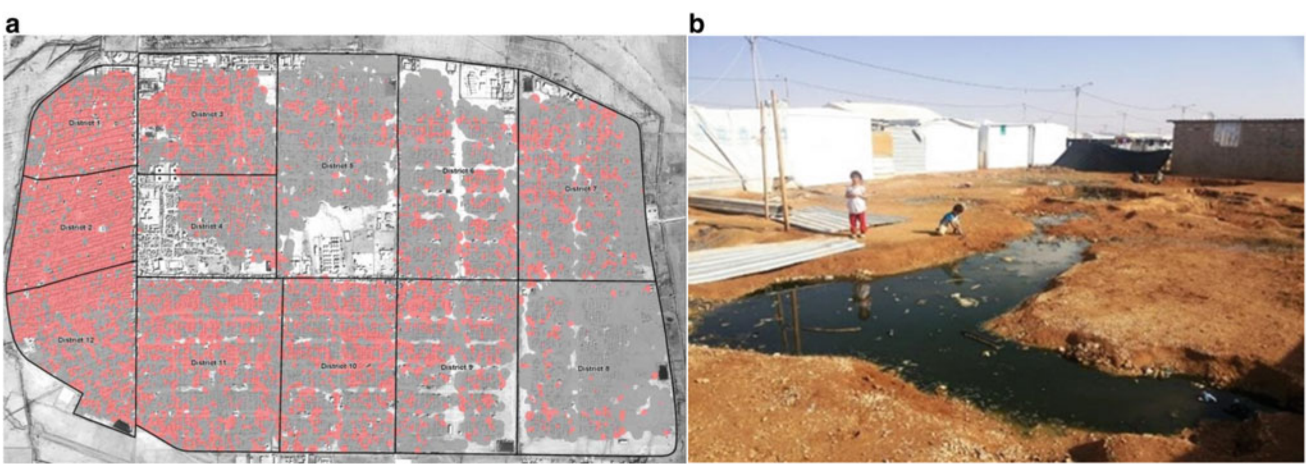

Fig. 2 **a** Unregulated toilets in the Zaatari camp. Der From Van der Helm et al. (2017, p. 523). **b** Children playing next to an open sewage pit in Zaatari. From Acted (2017)

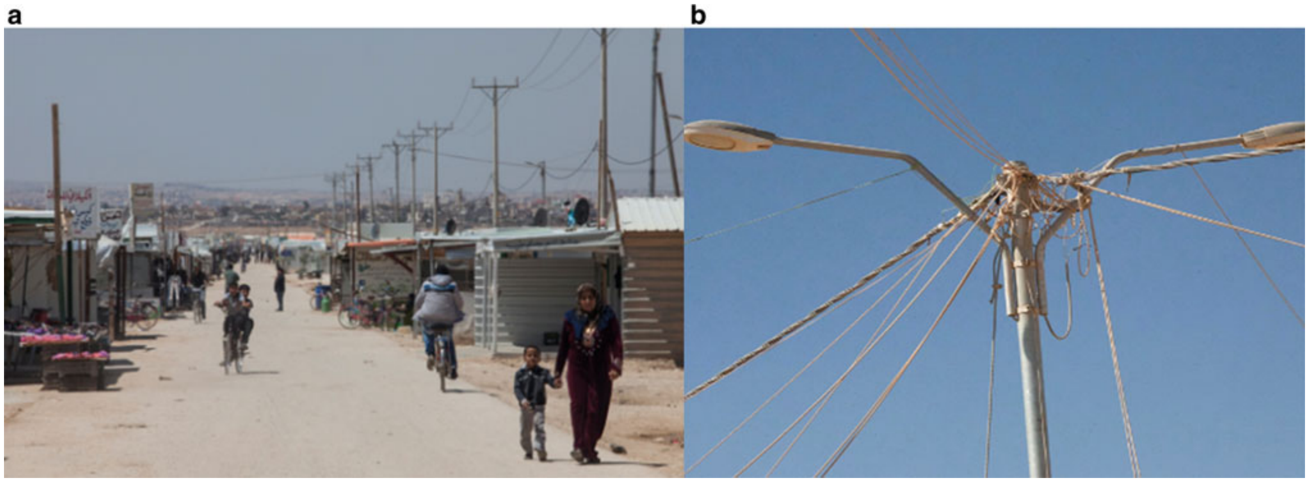

Fig. 3 **a** Electricity wires in Zaatari camp UNHCR (2017). **b** Illegal wireless connection. From Ledwith (2014, p. 33)

2.4 Air Pollution and Soil

It can be argued that the pressure on the road and transport system since the arrival of Syrian refugees has augmented. Thus, air pollution has certainly increased due to the different vehicle gas emissions (Alshoubaki, 2017). In addition, more than 500 water and vacuum tracks daily surrounding the area and the Zaatari refugees camp have also impacted the condition of the road due to the heavy weight of this last (Ledwith, 2004). However, research results of Al-Alshirah (2020) show that the amount of a slightly high concentration of heavy metals on the soil of the Zaatari camp. But, this does not consist of major pollution in the air or soil quality of the camp, instead it reflects the camp activities, and mobility of these low metals is inevitable. The only issue is that would increase the alkaline soil climate of the rock constitution in the Zaatari camp (Alshirah et al., 2020).

2.5 Medical Waste

The Syrian refugees often come in dramatic health conditions due to the civil war in their country. Since their presence in Jordan, pressure on the healthcare sector and emergency state occurred in the country. Similarly, Alshoubaki (2017) indicates that the medical waste is simultaneously augmented by 213,283 tonnes per year and 1127 m^3 equivalent of pharmaceutical waste per year. It is well known that Jordan has a lack and no adequate system that collects, treats and recycles or disposes of any sort of waste sector (AlDayyat et al., 2021). Thus, landfill capacity was exhausted, and disposal materials were found in the Zaatari refugees camp and surrounding areas which caused a deep environmental disaster (Alshoubaki, 2017). This will help the spread of the different diseases in the camp and will add to the pressure on the care sector of the country if even not the appearance of new viruses,

2.6 Social

Even though both the Syrian refugees and the Jordanian Indigenous share the same religion, language and ethnicity. This was not good enough to secure proper social cohesion between the two populations (Alshoubaki, 2017). Due to the fact that there are still many tribal identity variations amongst the two populations, tension has escalated, and conflict occurs especially in terms of use of public facilities and natural resources (Alshoubaki, 2017). Every part of the population wants to be recognised in its own way, if not become the leader. Whereas, it should be a mutual benefit between the two parties by taking into consideration the local conditions.

3 Sustainable Solutions and Development

The Zaatari Syrian refugee's camp has lasted nearly a decade since its establishment. Many researchers (Abu Al-Sha'r, 2017; Aburamadan et al., 2020; Dalal, 2020) indicate that the average lifespan of a refugee camp is 17 years. Therefore, the consideration of its design should meet the requirements during the period. However, in the case of Zaatari, there is evidence showing the negative impact of its poor design is the primary cause of the pollution (Abu Al-Sha'r, 2017; Aburamadan et al., 2020). Every component in the Zaatari's shelters is prefabricated and shipped to the camp (Abu Al-Sha'r, 2017) which justify the modifications of the inhabitants of their shelters that do not comply with what they were used to before the emergency (Aburamadan et al., 2020). The refugee's expression on the poor design of special and architecture of their camp was translated through the modification accrued in the camp. In addition, the design and mass production of such shelters has been made in a different country. These countries have no adequate knowledge on the context's culture nor the climate condition. The shelters were then imported without compromising with the existing conditions which make the recovery process of the refugees more difficult (Barakat, 2003). The Zaatari refugee's camp has been recognised as not a sustainable camp and causing pollution to the surrounding area as well as harming its inhabitants in terms of the quality of its water supply, wastewater treatment and solid waste management system (Alshirah et al., 2020).

Abu Al-Sha'r (2017) further indicates that such temporary shelters are not cost-effective solutions; disregarding their lack of adaptability in the context, they also require a long-distance shipment that will add to the cost of their implementation and waste funds that may be invested in the construction of permanent housing. Due to the lack of funding for a proper construction of sustainable and permanent refugees camp, this has resulted to acquire a cheap and prefabricated shelters. In turn, these camps made out of prefabricated shelters will be used for an extended period one of time from the designed and require half million USD daily to be run and maintain them (Abu Al-Sha'r, 2017; Ledwith, 2014). Thus, the transaction from the emergency use to the sustainable phase for a better urban development and preservation of natural resources will improve the potential health conditions, environmental and financial risks (Van der Helm et al., 2017) and additionally contribute to the local architectural context when implementing local construction materials and effectively adapt to the local climate condition too (Abu Al-Sha'r, 2017).

Indeed, humanitarian organisations and different NGOs have attempted to ameliorate the current situation of the camp through the FARE Studio Summarisation project (Abu Al-Sha'r, 2017). This project was an update of the refugee's shelters to the local climate conditions specially the Jordanian summer. The privacy and improvement of thermal comfort were the primary concerns of this project (Abu Al-Sha'r, 2017). The FARE project intended to meet the sustainability development requirement, which means preserving the resources for the present and future generations (Purvis et al., 2018). Jordan has an arid climate condition with more than 6 months of summer and high potential of solar radiation (Gijsbertsen et al., 2017). Therefore, the implementation of solar panels to the refugees' shelters was a cost-effective solution (Abu Al-Sha'r, 2017). The FARE project also updated the door of the refugees' shelters and provided them with the flexibility of choosing their placement for more privacy.

However, the FARE project occurred a couple of years after the settlement of the camp, whereas it should be implemented during the design, planning, construction and implementation of the project. In turn, building a camp using the local materials is not only a cost-effective solution by cutting down the fabrication, transportation and installation of the shelters. But, it would be rather an environmentally friendly and outstanding thermal comfort construction for the inhabitant too that has a significant low carbon footprint and at the same time perfectly integrated with the local environment and climate conditions.

3.1 Waste Recycling

Abu Al-Sha'r (2017) supports the idea that the Zaatari refugee's camp can be self-government if it effectively implements sustainable solutions and exquisite potential opportunities. One of these opportunities is the exploitation of the recycling of the huge quantity of the Zaatari's solid waste. A recent study conducted by AlDayyat et al. (2021) on the potential of pyrolyzing the Zaatari's solid waste to bio-oil that will be used as an alternative source of energy. The thermal conversion process of multiple solid waste (MSW) using Fourier transform infrared spectroscopy (FTIR) for energy recovery is the ultimate multi-layers beneficiary solution (AlDayyat et al., 2021). For that reason, AlDayyat et al. (2021) took a sample form the Zaatari's MSW, and the analysis results shows that the potential bio-oil produced will consist of 55% of carbon, 37% of O_2 and a 20.8 MJ/Kg of higher heat value (HHV).

It can be concluded from Table 1 that 52.7% of the Zaatari's MSW comes from organic category coming from 59 municipalities (Saidan et al., 2017). Al-Addous et al. (2019) report that there is a saturation of landfill capacity due to the huge amount of waste production mainly coming from the Zaatari's refugees camp on a daily basis. The plan (2016) quantifies the weight coming from the Zaatari's solid waste at 1689 tonnes per day where more than 55% of it consists of organic waste (Al-Addous et al., 2019). This has a great impact on the environmental, economic and social aspect of the country and the surrounding areas (Al-Addous et al., 2019; Saidan et al., 2017).

However, the pyrolysis process does not produce the bio-oil only; it rather produces biochar indeed. Biochar is recognised as a soil amendment worldwide. And the analysis results from the FTIR shows the content consists of 47% of carbon, 49% of O_2 and 11.5 MJ/Kg of HHV (AlDayyat et al., 2021). AlDayyat et al. (2021) calculate a potential amount of 38 Nm^3/day of methane out of 21–65 m^3 of MSW to produce as much as 4 MW. The 1689 tonnes of MSW daily that contains such amount of carbon, oxygen, and high-heat value as indicated above for an alternative

Table 1 Average percentage composition of MSW at Zaatari camp in 2015

Waste categories (%)	High populated districts	Low populated districts	Commercial area	Zaatari (Average)	Average MSW in municipalities
Organics	55.84	52.60	49.65	52.70	59
Paper and cardboard	5.60	3.74	17.67	9.00	14
Plastics	11.39	13.23	13.91	12.85	10
Leather, wood, textile and rubber	11.57	13.99	5.10	10.22	10
Metal	3.69	3.70	7.08	4.82	5
Aluminium	0.27	0.32	0.65	0.41	
Glass	0.90	0.81	2.04	1.25	4
Inert material	0.04	0.37	0.23	0.22	5
Special Waste (Hazardous, etc.)	0.17	0.45	0.20	0.28	6
Miscellaneous–Bread	0.35	0.41	3.9	1.28	
Miscellaneous–Nappies	10.18	10.38	0.38	6.97	
Total	100.00	100.00	100.00	100.00	

From Saidan et al. (2017, p. 62)

Table 2 Estimated budget required for the Zaatari camp 2014–2018 in USD

Environmental factor	2014	2015	2016	2017	2018
Ecosystem preservation	N/A	7,300,000	1,650,000	1,800,000	300,000
Waste and sanitation	158,793,612	87,390,000	238,800,000	263,520,000	246,560,000
Energy	N/A	134,006,100	107,400,000	111,075,000	87,000,000

source of energy that can be replaced the fuel used in the camp or in the surrounding areas, to improve the quality of life and mitigate the environmental impact of fossil fuels is an innovative idea (AlDayyat et al., 2021).

Moreover, such exploitation will also reduce the amount spent daily on the camp for running its different facilities. The solar electric panel equipped in the refugees' shelters during the FARE project has dramatically reduced the amount of energy budget by nearly one third, from 111 million USD to 87 million USD during 2017 and 2018, respectively, as indicated in Table 2. In addition, the massive quantity of the biochar will be used for the gardening and will be beneficiary to the refugees and surrounding areas as an alimentation source and agriculture exploitation (Gijsbertsen et al., 2017). As such, the impact of instant cities on both the local environment and the host country will be dramatically reduced if such a kind of bio-oil and biochar solution is explored.

3.2 Gardening

The forced migrants from the civil war in Syria have reallocated to seek better life opportunities and services such as food, shelter, health care, mental health and well-being (Aburamadan et al., 2020). Thus, Millican et al. (2019) stress the importance and benefits of outdoors interaction with greenspaces, as well as physical activities. If combined with the consumption of fruits and vegetables, the potential of mental health and well-being in terms of horticulture-based interventions in urban areas will improve (Leake et al., 2009; Millican et al., 2019). Millican et al. (2019) indicate that often refugee's camps' inhabitants suffer from highly traumatised populations as they have just lost their houses and left their country. However, they are reallocated in a place with a very high density of population too, as they all share the same situation, which causes health, environmental and social risks. The benefit of the study results of AlDayyat et al. (2021) can be implemented to generate biochar and used as soil amelioration gardening in the Zaatari camp in order to ameliorate the environmental conditions of the camp, rather than desertic bleak place. The recovery of resources and reuse of it to contribute to psycho-social well-being on the refugees, and/or source of alimentation/income, has a massive positive impact on the whole system (Millican et al., 2019). In addition to the severe climate conditions of the country, greenspaces have a great potential of reducing the urban temperature dramatical and provide share and fresh air (Millican et al., 2019). It is also worthwhile to state that communal activities and gathering will create a relationship amongst the inhabitants and result in a personal peace and well-being (Fig. 4). Gardening

Fig. 4 Family planting outside their trailer at the Zaatari refugee camp in Jordan. From Rudoren (2015)

will also provide a sense of possession and belonging of the camp, which in turn creates a place that would be called home and shared community (Millican et al., 2019).

3.3 Water Management

Gijsbertsen et al. (2017) support the idea of implementing green spaces and agriculture in the Zaatari refugee camp and anticipate that it will bring a positive impact to the inhabitants of the Zaatari refugees and help the recovery process speed up. However, Gijsbertsen et al. (2017) indicate additional potentials of upgrading the Zaatari camp to sustainable and green by exploiting the rainfall that usually left overflowed during the 6 months of rain in the country. Also, this causes a risk of flooding due to the lack of sewage and drainage in the camp that may be a danger to the inhabitants' lives. The exploitation of rainfall in a country that suffers from water scarcity is an inevitable opportunity to seize, whether to supply the refugees with drinkable water or use for agriculture and gardening, it is highly beneficial in both ways (Gijsbertsen et al., 2017). Hence, Gijsbertsen et al. (2017) provide sustainable harvesting techniques to collect the waste rainwater unattended for use and also mitigating the rainwater flow on the surface in order to protect the soil erosion too. In regard to the wastewater and gray water, Gijsbertsen et al. (2017) suggest the implementation of a helophyte filter where the process is treated by bacteria living in the roots. Take for instance the case of Uganda that has hosted refugees back to 1958 from Democratic Republic of Congo. The integration of the refugees to the society, environment and contribution to the local economy in the case of Uganda is one of the most durable models ever seen (Fall, 2009). The refugees at Uganda have stayed more than six decades, and the local authorities have provided them with lands, seeds and necessary tools to work in the resource poor of the host country specially agriculture (Millican et al., 2019). By creating low-density refugee camps in Uganda, the local environment and population have received less pollution and impact. Instead, both parties have a common shared beneficiary (Millican et al., 2019). Uganda has created sustainable self-governance refugees implemented within sustainable solutions, rather than just responding to one–off crises (Millican et al., 2019). Sadly, and after all these years, the Zaatari refugee's camp could not learn from the extraordinary experience of Uganda in dealing with their sustainable green camp implementation. Regardless of the availability of the natural resources such as the sun and local construction building materials that would make the camp more efficient, not to mention the novel and modern techniques for building a well-established and sustainable green camp such as solar panels and waste recycling centres.

4 Conclusion and Recommendation

This study concludes that Zaatari refugee's camp is intentionally a cause for pollution for the region and its surrounding. As well as it still needs basic requirements such as wastewater drainage and sewages, electrical grid, roads and sidewalks, freshwater system, and many more. Therefore, it is extremely important when it comes to building such instant cities is to take into consideration the local building materials to adapt to the local climate and cut the cost of fabrication and transportation of the shelters. Not with standing the importance and relevance of the implementation of sustainable, durable, and natural resources technology in such instant cities.

It is clear both visibly and through this study that the camp had already impacted the surrounding environment on so many levels. Part of it is due to the natural urbanisation process and the negative impacts that occur with it such as gray water, solid waste, and so on. On the other hand, the treatment and operational philosophy of the camp is causing more harm due to the "temporary notion" which prevents them from dealing with the environmental consequences. Although the authorities are initiating some management tactics for sustainable approaches like solar cells and some water treatment methods, a clear and focussed approach must be set, in order to ensure that the camp will not reduce the environmental balance in the area, on both short and long terms. The self-government of the Zaatari refugee's camp and existing potential for sustainable development seems to extend to an extent where the term "temporary" has changed, and therefore, local authorities and stakeholders' management of the camp has to change too (Abu Al-Sha's, 2017).

This research would like to highlight again the importance of dealing with the issue with the urgency and long-term impact that it has. Hence, this research recommends the initial establishment strategies for short and long-term plans to deal with the crisis for the purpose of enhancing and maintaining the environmental character of the area. The local authorities in the camp need to have a condition assessment to ensure dealing with pressing issues environmentally. Secondly, conducting environmental awareness programmes for the refugees to encourage them to enhance the environment quality of the camp. Finally, researchers must obtain their role in documenting the past, current and forecasted situation in order to highlight the situation and need for action. Chances of implementing and integrating sustainable solutions to better improve the quality of life and comfort of the residents never been too late. However, these solutions would be more efficient if they were implemented as early as the planning stage (Millican et al., 2019). The Zaatari refugee's camp still needs basic requirements such as wastewater drainage and sewages, electrical grid, roads and sidewalks, freshwater system, and many more. Yet, the most important strategy that the Zaatari refugees camp lacks is the awareness of the inhabitants to wisely use resources and facilities, especially in a country such as Jordan that lacks many natural resources and are in a serious decline (Al-Harahsheh, 2015). Also, the low-density refugee camp is more effective and less harmful to the environment than large-scale refugees that need to be taken into consideration in the planning stage for the next implementation of such a crisis.

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