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MORALITY BEFORE KNOWLEDGE

Alpha methanol city: IoT-integrated energy independent city concept as a realization of Sustainable Development Goals 2030

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ABSTRACT
Background: Climate change, driven by rising greenhouse gas (GHG) emissions, necessitates innovative approaches to achieve sustainability. Indonesia's energy and industrial sectors are significant contributors to these emissions. Traditional CO_2 mitigation strategies, like reforestation, face limitations due to land and time requirements. Thus, technological solutions are critical to address the urgent climate crisis. **Methods**: This study introduces the Alpha Methanol City (AMC) concept, integrating direct air capture-carbon recycle society (DAC-CRS) systems with renewable energy sources, specifically solar and wind power, alongside IoT and big data technologies. Data were collected through an extensive literature review, analyzing advancements in DAC technology, renewable energy and IoT systems. Theoretical and practical insights were synthesized to propose an energy-independent city model. **Findings:** The AMC concept processes atmospheric CO_2 into methanol, leveraging renewable energy to reduce operational costs and emissions. IoT and smart grid technologies enable real-time monitoring, optimizing energy use and system performance. SWOT analysis highlighted strengths such as environmental impact and energy independence, alongside challenges like high initial costs and technical complexities. The integration of circular economy principles further enhances AMC's sustainability. **Conclusion**: AMC presents a transformative model for urban sustainability by addressing CO_2 emissions and promoting renewable energy adoption. With an implementation timeline of approximately ten years, the concept provides a replicable framework for global sustainable urban development. **Novelty/Originality of this article:** This study uniquely integrates DAC technology with IoT and renewable energy to create a self-sustaining urban environment. By combining carbon recycling, smart energy management, and circular economy principles, AMC offers a holistic solution to climate and energy challenges, positioning it as a groundbreaking model for sustainable cities.

KEYWORDS: direct air capture; renewable energy; internet of things; methanol conversion; alpha methanol city.

1. Introduction

Erratic weather is a result of climate change, which is still a global environmental issue today. This is one of the impacts of global warming that occurs due to the trapping of sunlight in the Earth's atmosphere due to high levels of greenhouse gases (Natural Resources Defense Council, 2016). Greenhouse gases are classified into six types, namely carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), sulfurhexafluoride (SF_x),

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perfluorocarbons (PFC), and hydrofluorocarbons (HFC) (Sejati, 2011). One of the greenhouse gas components that is the largest pollutant is CO_2 with a percentage of 90%, while in Indonesia the largest percentage of greenhouse gases are carbon dioxide, methane, and nitrous oxide. Globally, greenhouse gas emissions come from the contribution of various sectors of life, including the industrial sector, the use of motor vehicles and electronic devices (Rosegrant, 2008).

Based on data from the International Energy Agency (IEA) in 2015, the energy utilization sector is the largest contributor to greenhouse gas levels at 68%. In detail, it can be written that the energy sector contributed 63%, the forestry sector 18%, the agricultural sector 13%, and the household waste sector by 3%. The increase in CO_2 concentration in Indonesia and the world will still experience a significant increase until early 2021 (BMKG, 2021). The three things that most affect the high CO_2 emissions are electricity 42%, transportation 23%, and housing 6% (Subkhan et al., 2017). The continuous increase in CO_2 concentration will have a negative impact on the earth. Therefore, an innovation is needed to overcome this problem.

Various parties ranging from the Indonesian government to the world have thought of various efforts to suppress the increase in CO_2 emissions in the atmosphere. The Indonesian government itself has issued several policies related to this matter, such as Undang-Undang No. 17 of 2004 concerning the Ratification of the Kyoto Protocol to the United Nations Framework Convention on Climate Change and Peraturan Presiden No. 61 of 2011 concerning the National Action Plan for Reducing Greenhouse Gas Emissions.

However, these policies are considered unable to suppress the increase in CO_2 emissions. This is evidenced in the range of 2012-2017 there was still an 18% increase in CO_2 emissions in Indonesia (Enerdata, 2018). In addition, green land areas or commonly called green open spaces (RTH) have been created in several cities (Subkhan et al., 2017). This solution is also still considered not optimal because the land required is quite large and the time needed for plants to grow is also not short, so it is considered less solutive for urgent situations like today.

Based on these shortcomings, several countries began trying to create a technological innovation to reduce the concentration of CO_2 emissions in the atmosphere. One of them is in Squamish, British Columbia. In the area there is a company that designed a technology called Carbon Engineering. The working principle of this tool is to integrate giant fans and complex chemical processes to remove CO_2 from the air through a procedure known as direct air capture (Breyer et al., 2019). The carbon capture device has been able to capture one mega ton of CO_2 per year or comparable to the work of 40 million trees. However, the existence of this technology still has its drawbacks, namely dependence on fossil fuels. This dependence is due to the large amount of energy required to operate the tool.

The impact of using fossil fuels, which still produces carbon emissions. This encourages the use of new renewable energy (EBT) as the main energy source in providing national energy in the future. Geographically, Indonesia has a very diverse EBT potential. However, the potential of EBT in Indonesia has not been maximized. The utilization of EBT should be the main focus in an effort to reduce the use of fossil energy to realize clean energy and suppress carbon emission levels in the air. Based on its location, Indonesia has strategic EBT potential, namely the duration of sunlight that is evenly distributed throughout the year and a cluster of beaches and mountains that have great wind potential.

Solar and wind energy sources can be used as a source of power generation such as solar power plants (PLTS) and wind power plants (PLTB). The combination of these two sources of power generation can be a solution to complement the shortcomings of each power plant (Sandzali et al., 2019). The concept of the combination is able to support the carbon recycle society system or better known as the carbon cycle.

The carbon cycle is a system for repeated utilization of the remaining carbon emissions of an activity as an effort to reduce CO_2 levels in the air and realize green energy. One type of green energy that is widely used today is green methanol as a fuel source to replace fossil fuels. This type of methanol is green energy because its combustion results in minimal carbon emissions, making it environmentally friendly. In addition, the production of methanol comes from CO_2 which is processed by utilizing wind and solar energy, so that the production process and results are green energy products. From these potentials, the author provides an idea, namely the Alpha Methanol City (AMC) concept to realize a smart green city that is energy independent in Indonesia by creating a technology to capture CO_2 in the atmosphere with a direct air capture system to support the carbon recycle society system and process it into methanol with integrated Internet of Things (IoT). The operation of this tool is by integrating with PLTS and PLTB so that the concept of an energy independent city is realized.

2. Methods

Data collection techniques are carried out by conducting library research and extracting digital information that has a target goal for literature studies. Literature sources are obtained by reading, analyzing, and connecting information from various reading sources with the topics discussed. This literature study includes books and research journals that are considered relevant to the topic. The research method of the journal, as it primarily utilizes a literature review, involves gathering, analyzing, and synthesizing secondary data from a range of credible sources. This method allows the author to explore the theoretical and practical foundations of the Alpha Methanol City (AMC) concept by examining existing studies, reports, and technological advancements.

The type of data used in writing this journal is secondary data which is part of the research data obtained by researchers indirectly or through intermediary media. This literature study is generally carried out by collecting data from various references, then processing it for different analysis or presentation. These references play an important role as a foundation in developing new ideas and deepening existing knowledge.

The journal draws extensively on literature from academic journals, scientific studies, and technical reports to construct the argument for integrating IoT and renewable energy technologies in developing a sustainable smart city. For example, it references studies on direct air capture (DAC) technology, its operational costs, and its environmental benefits. Additionally, sources on renewable energy systems, including six-junction III-V solar cells and wind turbines, provide critical insights into their efficiency and potential applications. The literature on IoT systems enriches the discussion about real-time monitoring and system optimization for urban management.

Data processing techniques explain the steps in processing and analyzing data based on the approach used. Because this study uses a qualitative method, data processing is carried out by arranging data in structured, sequential, logical, non-overlapping, and clear sentences, so as to facilitate understanding and interpretation. This process includes the following stages: data checking (editing), classifying, verifying, analysing, and concluding. The analysis process is carried out through the data that has been obtained, then described in the discussion. Synthesis is carried out using a cross-study approach (crosslink) between the collected data with relevant theories and concepts. From the results of this analysis, the main points can be identified which are processed into several conclusions. These conclusions are supported by relevant suggestions and recommendations.

This method enables a comprehensive understanding of the AMC concept by exploring various technologies and their applications. By reviewing advancements in DAC technology and its role in reducing CO_2 emissions, the author connects scientific innovation with practical urban planning. Furthermore, references to environmental data and climate statistics frame the research in the context of global challenges, such as rising CO_2 levels and their impacts on climate change.

The literature review approach allows the journal to build on existing knowledge, identify gaps, and propose innovative integrations of technology to address sustainability goals. It also facilitates a critical evaluation of potential challenges, including the high costs and technical complexity of implementing the AMC concept. The reliance on diverse sources ensures the credibility and depth of the research, making it a robust foundation for proposing the Alpha Methanol City as a solution to climate and urban development issues.

3. Results and Discussion

3.1 Idea triggers

As the industrial sector in Indonesia grows and the excessive use of fossil fuels makes the climate in various regions uncertain. This climate change is triggered by the rising concentration of CO_2 in the atmosphere. The increase in CO_2 concentration is caused by the inability of plants and the sea to absorb the remaining combustion of fuel oil (BBM), coal, and other organic fuels. The average CO_2 concentration varies from 0.03% (300 ppm) to 0.06% (600 ppm) depending on the location (Nebath et al., 2014). However, CO_2 concentrations will continue to increase as industrial products such as motor vehicles, cement, etc. are added.

According to Lehne & Preston (2018), the cement industry accounts for about 8% of CO_2 emissions in the world. CO_2 emissions are also generated by airports from aviation activities during aircraft landing and take-off (LTO). Carbon dioxide is the largest source of emissions due to the combustion of carbon-rich fossil fuels in aircraft engines (CAA, 2017). By 2025, CO_2 levels in the Earth's atmosphere are expected to break a 3.3 million-year record (Vega et al., 2020). This has led to warmer temperatures on Earth.

The increase in temperature every year is evidence of a critical climate period. The World Meteorological Organization (WMO) in 2020 declared 2020 as the second warmest year on record after 2016. The 2015-2019 period was the hottest five-year period in Earth's history with an average temperature increase of about 1.1°C. 2020 itself ranks as the second hottest year with an anomalous value of 0.7°C, with 2019 ranking third with an anomalous value of 0.6°C. Overcoming this temperature rise problem can be done by reducing CO_2 emissions.

Currently, there are two methods to reduce CO_2 emissions, namely the classical and advanced methods. The classical method is done by planting trees. Planting trees to reduce CO_2 emissions requires a large area of land and a long growing time. The weaknesses of this method can be overcome with the latest methods, one of which is through direct air capture (DAC) technology.

DAC technology has high CO_2 emission absorption effectiveness, but still requires expensive operational costs of 200 dollars per ton of CO_2 when compared to the tree planting method which only costs 10 dollars per ton of CO_2 (Hook, 2020). In addition, the operation of DAC technology still uses fossil fuels. In this case, fossil fuels can be replaced with renewable energy derived from solar power plants and wind farms which will reduce operational costs.

3.2 Alpha Methanol City (AMC) as a solution

Alpha Methanol City (AMC) is an energy independent city concept that focuses on processing CO_2 gas in the atmosphere into crude methanol as a solution to the problem of climate change due to greenhouse gases in order to realize a smart and green city. The AMC concept will combine four technologies, including the direct air capture-carbon recycle society (DAC-CRS) system, wind turbine, solar cell, and internet of things (IoT). The application of the AMC concept will be carried out in an area that has coastal and/or hilly areas with considerable wind and solar heat potential. The illustration of the AMC smart city design can be seen in Figure 1.

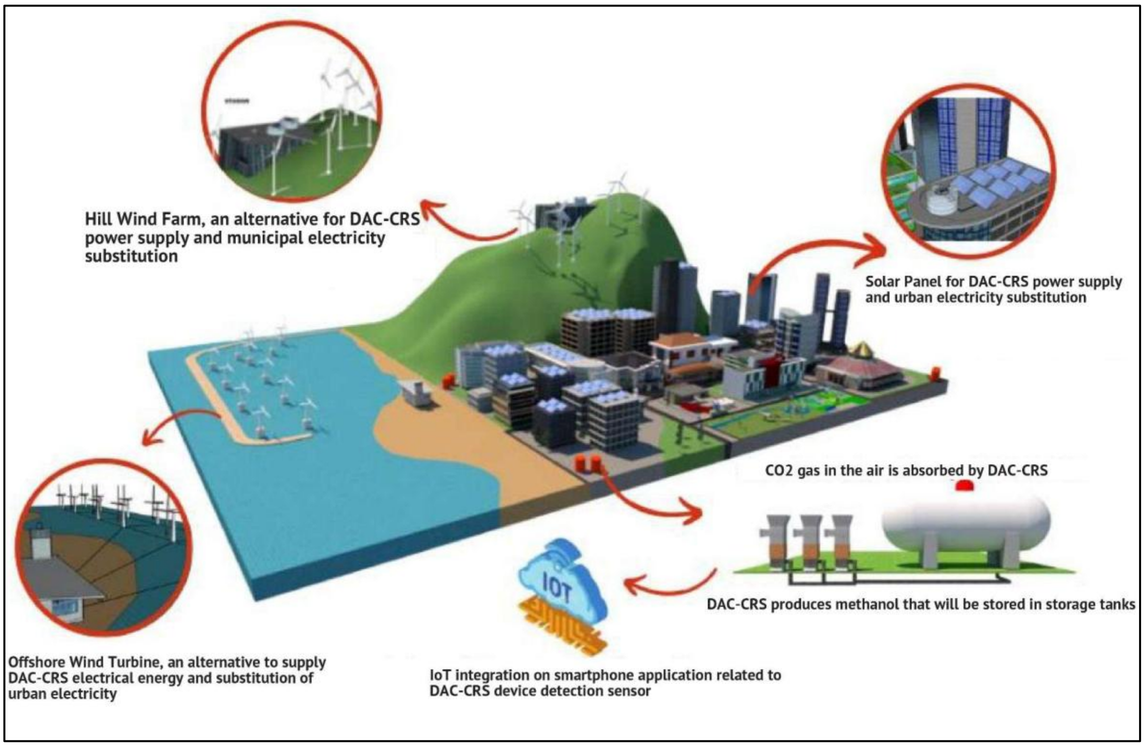

Fig. 1. AMC smart city design

The DAC-CRS system (Figure 2) is a device designed to capture CO_2 gas in the atmosphere and then process the gas into methanol. The DAC-CRS design consists of an inlet air filter, vacuum pump, outlet air chimney, CO_2 capture membrane, propeller, methanol synthesis reactor or electrochemical conversion system, and crude methanol collector.

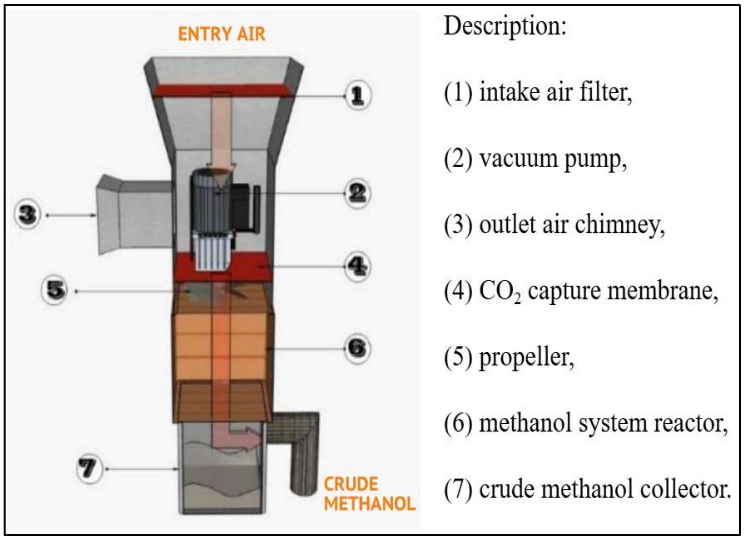

Fig. 2. DAC-CRS tool design

Air entering the DAC system is filtered using a membrane to capture CO_2, while other gases are released back into the environment. The system uses a vacuum pump to increase the volume of incoming air and a filter to remove fine dust or dirt. The captured CO_2 is then processed through a chemical reaction to produce methanol, which can be used as fuel or industrial feedstock. The methanol is transported to storage tanks through underground pipes to reduce the risk of fire before being distributed to industries that require it.

The DAC-CRS technology is designed to use renewable energy from solar power plants and wind farms to reduce operational costs. Solar PV energy is generated from six-junction III-V solar cells with an efficiency of 47.1% (Geisz et al., 2020), which are installed on the roofs of houses or buildings. Wind farms are placed on hills or coasts, complete with cathodic protection in coastal areas to prevent corrosion. These locations are chosen to obtain an optimal wind source and minimize noise interference. In addition to the DAC-CRS, electricity from the solar and wind farms is also delivered for city needs such as street lights and public facilities, stored in advance in power banks to ensure a stable supply when the DAC-CRS is not operating.

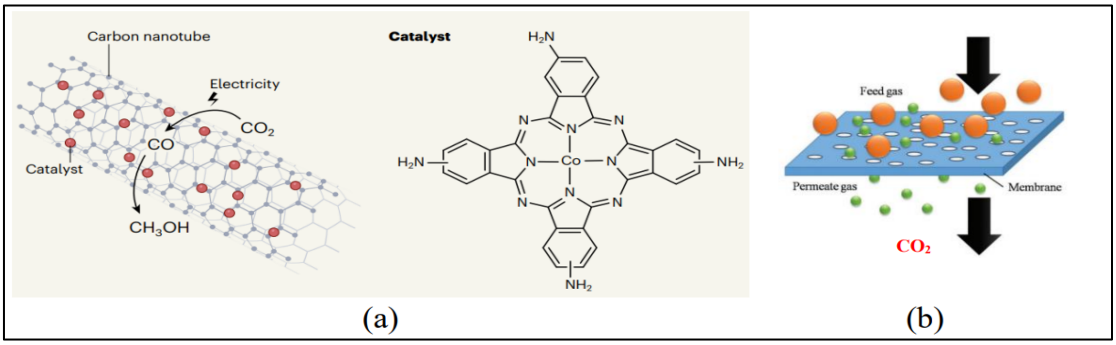

Fig. 3. (a) CO_2 to methanol conversion reaction and cobalt phthalocyanine catalyst structure; (b) illustration of how the membrane works
(Wu et al., 2019b)

The ACM smart city concept integrates IoT technology for remote monitoring and control through an Android app, featuring CO_2 level monitoring, leak detection in tanks and pipes, early fire detection on methanol lines, and notifications for full methanol tanks. The CO_2 monitor operates via a microcontroller and Wi-Fi, enabling device-based control. An automatic proximity sensor alerts users when methanol tanks are full, prompting flow to the main tank. A gas sensor detects leaks, and a smoke detector with a buzzer warns nearby residents of fires, activating an automatic hydrant and sending app notifications for fire mitigation. Environmental sensors installed throughout urban areas can monitor air quality, temperature, humidity, as well as pollution levels, including CO_2 concentrations. This information can be used to optimize the performance of the DAC-CRS and adjust energy production according to environmental requirements. Real-time Data from these sensors also support the city management system in decision-making that is responsive to environmental conditions (Kumar & Tripathi, 2022).

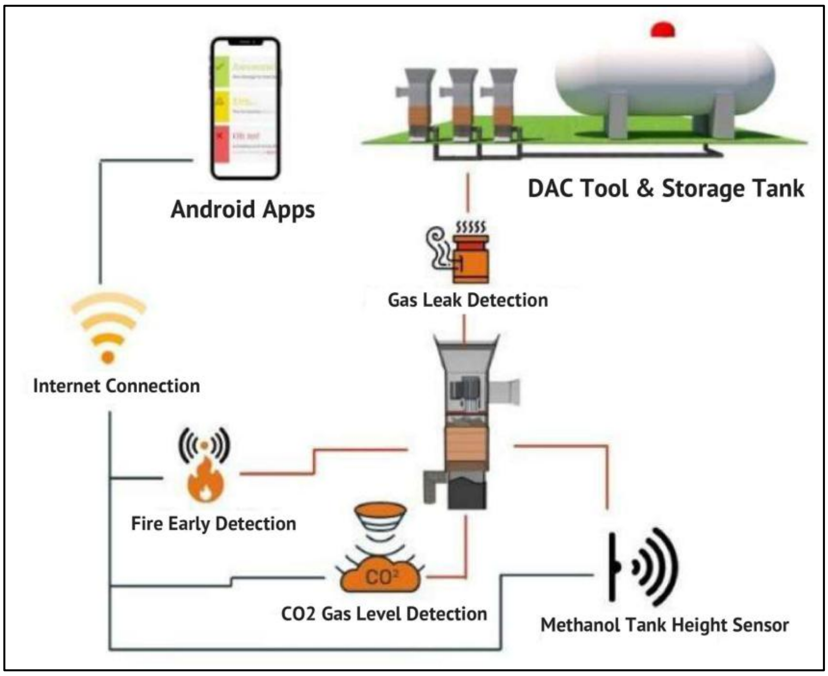

Fig. 4. IoT system concept network

The processing of CO_2 into methanol is also further optimized by the application of big data technology. The big data system will collect, process, and analyze real-time data from various sources such as IoT sensors, meteorological data, CO_2 sensors, energy output from wind turbines and solar panels, and energy consumption patterns in the Greater Jakarta area. Using big data technology, these data will be integrated and processed through algorithms that are able to predict and manage methanol production and energy consumption efficiently.

The way big data technology works in the AMC system will involve several stages. First, real-time data from sensors placed throughout the city will be collected and sent to the computing center. This data will include CO_2 emissions, wind speed, sunlight intensity, and energy consumption levels in various sectors, including residential, industrial, and transportation. Then, machine learning algorithms will analyze these data patterns to make more accurate predictions regarding fluctuations in emissions and energy demand, as well as optimal conditions for methanol production from CO_2.

AMC also integrates the application of a smart grid system to optimize the management of various energy sources simultaneously, distribute electricity to various city needs, and optimize the use of energy generated from solar and wind farms. One of the reasons for choosing a smart grid is its ability to overcome the challenges posed by the fluctuating nature of renewable energy sources. Energy generated from solar and wind is highly dependent on natural conditions, so these systems need to have high flexibility in managing energy distribution and storage (Zhou et al., 2018a).

Smart grids work by feeding energy from solar and wind farms into the main grid. The system will convert energy from renewable sources into energy that can be used by various needs, such as the operation of DAC-CRS technology for CO_2 treatment, city lighting, and household electricity needs. Unused energy will be stored in a power bank that acts as an energy reserve to be used at the right time. In addition, the smart grid is also equipped with IoT sensors that enable real-time monitoring of energy consumption. This technology can be used by the public to see how much energy they are consuming, as well as provide clear information on how they can be more efficient in their use of electricity. With this implementation, people can play an active role in reducing excessive energy use and reducing carbon emissions (Li et al., 2020).

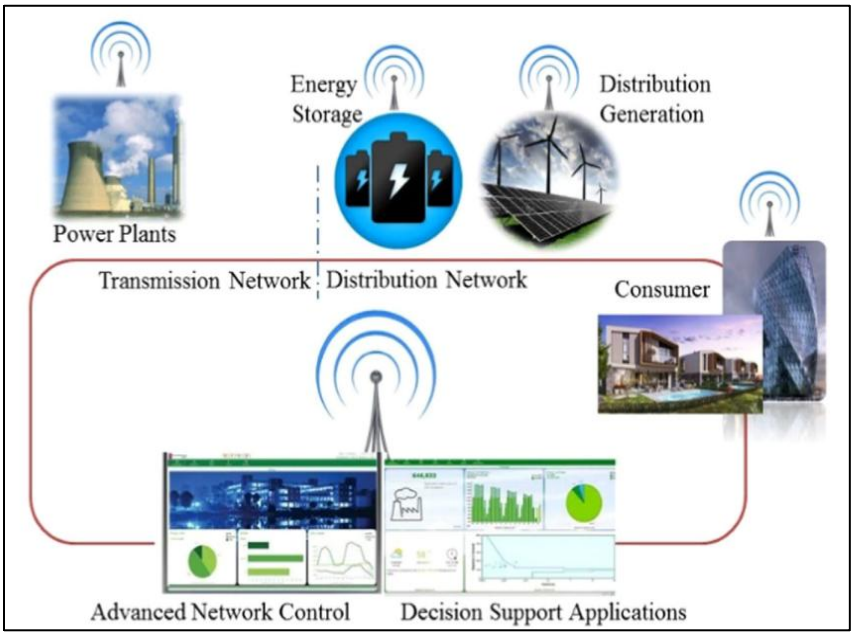

Fig. 5. Smart-grid concept

Alpha Methanol City integrates the concept of circular economy in waste management to create a closed cycle that minimizes waste and optimizes resource use. This approach aims to reduce environmental impact through the application of the “reduce, reuse, recycle”

(3R) principle with the help of modern technology based on the Internet of Things (IoT). With this step, AMC is modeling a city that implements sustainability holistically. The management process begins with waste collection and sorting using smart bins installed in every house and building. These bins are equipped with IoT-based sensors that are able to detect the type of waste material, such as plastic, metal, glass and paper, and monitor the volume of waste in real-time. The data collected from the smart bins is sent to a control center to assist with logistical planning of waste transportation, thereby reducing operational costs and carbon emissions from transport vehicles (Amin et al., 2021).

The collected organic waste is treated in a biogas facility using anaerobic digestion technology. In this process, organic matter is decomposed by microorganisms to produce two main products, namely biogas and liquid compost. Biogas is used as a renewable energy source for electricity and heating needs, while liquid compost is used as an organic fertilizer that supports urban agriculture in AMC (Hassan et al., 2022). Inorganic waste such as plastics, metals, glass and paper are processed at recycling facilities equipped with AI-based sorting technology. Plastics and metals are reprocessed into raw materials for new products, glass is remelted to produce other glass products, and paper is recycled for local needs. This process ensures that the quality of recycled materials remains high, allowing them to be reused in various industrial sectors (Zhang et al., 2023).

The energy used in waste management at AMC comes entirely from solar and wind power plants. These plants are designed to meet the energy needs of the waste management facility while supplying additional energy for the city's needs. The use of renewable energy is in line with AMC's commitment to minimize its carbon footprint (Lee et al., 2020). In addition to technology, community participation is also key to the success of this system. AMC implements education and incentive programs to encourage citizens to sort waste properly. People who actively contribute earn reward points that can be exchanged for discounts on city services or renewable energy tokens. This not only increases environmental awareness but also creates a culture of sustainability in the community (Kim & Park, 2021).

This entire waste management system is monitored and optimized using IoT technology. Smart sensors monitor activities from waste collection to treatment, sending real-time data to the control center. This technology enables early detection of problems such as equipment malfunction or waste accumulation, thus ensuring operational sustainability and environmental cleanliness (Chen et al., 2021). Through the implementation of a circular economy-based waste management system, Alpha Methanol City not only solves waste problems but also creates added value for the environment, economy and society. The city is a model for the future that is harmonious with nature while supporting the development of technology and a sustainable society.

3.3 Analysis

Alpha Methanol City was analyzed to determine the feasibility of implementation in Indonesia to address the problem of high atmospheric CO_2 emissions and climate change challenges using SWOT (Strengths, Weaknesses, Opportunities and Threats) indicators.

Strengths	Weaknesses
1) Environmental impact: AMC's focus on transforming CO_2 into crude methanol directly addresses greenhouse gas emissions, offering a tangible solution to climate change. 2) Energy Independence: By utilizing wind turbines and solar cells, AMC can generate its own renewable energy, reducing dependency on fossil fuels. 3) Innovative integration: The combination of DAC-CRS, renewable energy sources, and	1) High initial costs: Setting up DAC-CRS technology, renewable energy infrastructure, and IoT systems requires significant financial investment, which may deter initial adoption. 2) Complex implementation: Integrating various advanced technologies (DAC-CRS, renewable energy, and IoT) involves technical complexity, requiring skilled labor and extensive maintenance.

IoT creates a cutting-edge approach to sustainability, positioning AMC as a leader in smart city development. 4) Adaptability: Targeting coastal and hilly areas with high wind and solar potential maximizes the effectiveness of renewable energy sources, allowing AMC to be implemented in diverse locations. 5) Smart city appeal: The integration of IoT for energy monitoring, emissions tracking, and efficiency optimization enhances the city's intelligence and operational sustainability.	3) Dependency on natural conditions: The concept relies heavily on wind and solar energy, which may lead to inconsistencies in energy production in areas with variable weather patterns. 4) Technology maturity: DAC-CRS technology is still developing, and its long-term efficiency, scalability and cost-effectiveness in city-wide applications remain uncertain.
Opportunities 1) Global demand for climate solutions: With the increasing focus on climate change mitigation, AMC aligns with international sustainability goals, attracting potential support and investment. 2) Potential for scaling: Successful implementation in one region could lead to broader adoption, creating a replicable model for other cities facing similar environmental challenges. 3) Economic benefits: Methanol production offers economic opportunities through fuel export or local usage, potentially creating a circular economy and new job sectors within AMC. 4) Collaboration potential: AMC could collaborate with environmental organizations, governments and research institutions to further develop and optimize green city technologies. 5) Technology advancement: As DAC-CRS and renewable technologies evolve, AMC's efficiency and cost-effectiveness could improve, making it a more attractive option for other cities.	Threats 1) Economic viability: Market fluctuations in crude methanol prices could affect AMC's economic sustainability if methanol sales are a primary revenue stream. 2) Regulatory challenges: Environmental regulations, land use policies, and local government support may vary by region, affecting the speed and feasibility of implementation. 3) Competition from other technologies: Other clean energy and smart city models may compete with AMC, potentially diverting funding and resources. 4) Environmental risks: Changes in coastal or hilly environments (e.g., sea-level rise, extreme weather) could impact AMC's infrastructure and operations, posing risks to long-term viability. 5) Public acceptance: Introducing new technologies and infrastructure in cities often faces public scrutiny, requiring community engagement to build trust and support.

AMC is also analyzed using ESG (Environmental, Social and Governance) indicators to measure the impact and become a parameter in sustainable development as follows.

Environmental	Social	Governance
1) CO_2 reduction and climate change mitigation: AMC focuses on capturing atmospheric CO_2 and converting it into methanol, effectively reducing greenhouse gases. The DAC-CRS system uses cobalt phthalocyanine as a catalyst for efficient carbon recycling (Wu et al., 2019a). 2) Utilization of renewable energy: AMC utilizes 47.1% efficient six-junction III-V solar cells, a significant technological advancement in solar energy (Geisz et al.,	1) Improved public health and safety: Enhanced air quality reduces health risks, while IoT systems detect leaks, fires, and tank overflows to prevent accidents. Early warnings from IoT-enabled sensors ensure timely mitigation. 2) Community empowerment and awareness: IoT apps enable residents to monitor and optimize energy consumption, encouraging sustainable behavior.	1) Integration of advanced technologies: Big data analytics process real-time inputs to predict and manage energy production and methanol synthesis effectively. Machine learning algorithms enhance decision-making efficiency. 2) Safety and compliance framework: Underground pipes for methanol transport reduce fire risks, meeting global safety standards. IoT sensors ensure compliance with

2020). Wind turbines strategically placed in coastal and hilly areas maximize renewable energy potential. 3) Optimized energy management: Smart grids ensure efficient energy distribution and storage to address the fluctuating output of renewable energy sources (Zhou et al., 2018b). Unused energy is stored in power banks to maintain consistent availability. 4) Environmental monitoring with IoT: Real-time IoT sensors track air quality, CO_2 levels, and pollution, optimizing the performance of DAC-CRS systems and energy resources (Kumar & Tripathi, 2022).	3) Economic opportunities and energy savings: Efficient energy systems lower electricity costs, while methanol production supports local industries, creating economic growth opportunities. 4) Enhanced urban living standards: Reliable renewable energy ensures consistent power for public utilities and improves quality of life.	environmental and operational regulations. 3) Transparent and inclusive stakeholder collaboration: Partnerships between governments, industries, and communities accelerate technology adoption and funding. 4) Alignment with Sustainable Development Goals (SDGs): AMC aligns with UN Sustainable Development Goals, particularly Goal 7 (Affordable and Clean Energy) and Goal 13 (Climate Action).

3.4 Parties considered for involvement

3.4.1 Governments

Governments that have direct involvement in the application AMC smart city concept, namely Central Government and Local Government Province. The government acts as a policy maker, source of funding program, Development, Control and evaluation of the AMC smart city concept. The role of governments, particularly the Central and Local Governments, is pivotal in implementing the AMC smart city concept. As policymakers, they establish regulations and frameworks that guide the development and operation of the program. Their responsibility extends to securing and allocating funds, ensuring adequate resources for research, development, and execution. Governments also oversee the project through consistent monitoring and evaluation, ensuring alignment with the intended goals. Furthermore, they act as facilitators, creating platforms for collaboration among stakeholders, including investors, academics and private entities. By leading these initiatives, governments ensure the project's long-term sustainability and success.

3.4.2 Investors

Investors are critical stakeholders in the AMC smart city initiative, as their financial contributions enable the program's execution. These third-party entities provide the necessary funding to support the research, development and deployment of innovative technologies and infrastructure. Without adequate investment, many aspects of the project, such as IT systems, renewable energy sources and methanol processing facilities, would be difficult to realize. Investors often collaborate with governments and private sector partners to ensure their contributions are utilized efficiently. Their involvement not only drives economic growth but also fosters public-private partnerships that enhance the overall success of the AMC smart city project.

3.4.3 Academics

Academics serve as essential partners in the implementation of the AMC smart city concept, leveraging their expertise to provide scientific and technical insights. They assist the government by identifying suitable locations for infrastructure, designing innovative tools and conducting comprehensive cost analyses. Their contributions also include carrying out advanced research to improve system efficiency and sustainability. Academics play a dual role: as educators, they train future professionals in smart city technologies, and as innovators, they develop solutions that address urban challenges. By bridging the gap between theoretical knowledge and practical application, academics ensure the project's foundation is scientifically robust and forward-thinking.

3.4.4 IT experts

IT experts act as designers as well as developers of IoT systems and monitor applications. IT experts play a central role in designing and developing the technological backbone of the AMC smart city concept. They are responsible for creating IoT systems that enable seamless communication between devices and infrastructure. These experts design applications to monitor and manage resources, ensuring efficiency and reliability. Their work includes addressing cybersecurity concerns, maintaining data integrity, and implementing scalable solutions to meet the city's growing demands. IT experts also collaborate with other stakeholders, such as academics and chemical companies, to integrate technological solutions across sectors. Their expertise ensures the city remains technologically advanced, resilient and adaptive to future innovations.

3.4.5 Chemical companies

Chemical companies in the process of implementing this idea act as parties who process methanol into industrial end products that are ready to be distributed to the community, later chemical companies will work with IT experts to integrate the system to be applied. Chemical companies are integral to the implementation of the AMC smart city concept, particularly in the processing of methanol. They convert raw methanol into industrial products that serve as essential resources for various applications. These companies collaborate closely with IT experts to integrate advanced systems that monitor and optimize production processes. By ensuring the availability of high-quality methanol-based products, they support the development of sustainable energy solutions, such as fuel substitutes. Their role also extends to research and innovation, exploring new ways to improve methanol processing efficiency. This partnership ensures the smart city's chemical infrastructure is both sustainable and effective.

3.4.6 PT Pertamina

PT Pertamina here acts as a party that processes methanol into fuel substitution. PT Pertamina coordinates directly with chemical companies as the main supplier of methanol, and after that PT Pertamina will process raw methanol again into vehicle fuel that is ready to be distributed. PT Pertamina is a key player in the AMC smart city initiative, focusing on the conversion of methanol into alternative fuels. As a national energy company, it coordinates with chemical companies to source methanol and refine it into vehicle-ready fuel. PT Pertamina ensures the production process meets stringent environmental and quality standards, supporting the transition to cleaner energy. The company also plays a role in distribution, ensuring the fuel reaches end-users efficiently. By integrating renewable energy sources into its operations, PT Pertamina aligns with the AMC smart city's sustainability goals. Its involvement exemplifies the synergy between industrial expertise and environmental stewardship.

3.4.7 PT PLN

PT PLN in this case plays a role in designing PLTB and PLTS installation systems, as well as a provider of electricity generated before being distributed for use in the operation of DAC-CRS equipment and community electricity needs. PT PLN contributes to the AMC smart city by designing and installing renewable energy systems, including wind power plants (PLTB) and solar power systems (PLTS). These systems provide the electricity needed to operate DAC-CRS equipment and meet community energy demands. PT PLN expertise in grid management ensures the seamless integration of renewable energy into the city's power infrastructure. The company also focuses on optimizing energy efficiency, reducing reliance on non-renewable sources, and lowering carbon emissions. By spearheading the development of sustainable energy solutions, PT PLN plays a vital role in achieving the AMC smart city's vision of a greener and more energy-efficient future.

3.4.8 Electrical contractors and consultants

The electrical system in the infrastructure connected to the AMC concept requires the services of Electrical Contractors and consultants as the implementation of the installation system designed by PT PLN. Electrical contractors and consultants are instrumental in implementing the AMC smart city's electrical systems. They provide specialized services, including the installation of infrastructure designed by PT PLN. These professionals ensure that all electrical components meet safety and efficiency standards, minimizing potential risks. Their work involves detailed planning, execution and maintenance of complex electrical networks, supporting the smooth operation of the city's infrastructure. By collaborating with other stakeholders, such as IT experts and energy providers, they ensure the systems are integrated seamlessly. Their contributions are essential for creating a reliable, scalable and future-proof electrical framework for the smart city.

3.4.9 Society

Society in this case has a vital role, namely maintaining and implementing the DAC-CRS tool so that it can be a pilot to be applied in other cities. The society also has a Supporting Role in order to realize the concept of this city. The community plays a foundational role in the success of the AMC smart city concept. As users of the city's infrastructure, residents are responsible for maintaining and operating tools such as the DAC-CRS system. Their active participation ensures the project remains functional and serves as a model for replication in other cities. By adopting sustainable practices and supporting innovation, society contributes to the realization of the smart city's vision. Educational initiatives and community engagement programs help residents understand their role and the benefits of the project. Their involvement fosters a sense of ownership, ensuring the city's long-term success and sustainability.

3.5 Strategy of implementation

The implementation of AMC technology is carried out in four main stages: preparation, pre-implementation, implementation, and monitoring and evaluation. In the initial stage, suitable locations need to be identified by considering the high CO_2 emission levels in urban areas and the potential for renewable energy in coastal and hilly areas. A SWOT analysis of the implementation of AMC is carried out to understand the potential and challenges in each location. In addition, cooperation with various parties, including government, industry, and communities, is the key to the success of this preparation stage. Preparation of human resources is also needed to ensure the sustainability of technology operations in the long term.

Before implementation, DAC-CRS technology testing was carried out to ensure its feasibility and efficiency. The spatial design and electrical system were also prepared in the form of a master plan by the government and PT PLN, with the involvement of electrical contractors and chemical companies to process the methanol produced. The implementation stage includes the construction of methanol production and distribution areas, installation of solar panels in urban areas, and construction of wind turbines in coastal and hilly areas. In addition, IoT infrastructure was developed to optimize the performance of the DAC-CRS system and support energy efficiency in the smart city concept.

After the AMC technology is operational, a monitoring and evaluation stage is carried out to identify emerging constraints and improve system efficiency. This evaluation includes DAC-CRS performance analysis, optimization of renewable energy use, and monitoring of methanol distribution. This stage aims to ensure that the implementation of AMC can run sustainably and provide maximum impact on reducing CO_2 emissions and more efficient energy management.

Stage	Description	Duration Estimation
Preparation for Technology Implementation	Identifying suitable locations in high-rise cities (for CO_2 capture and solar cells) and coastal/hilly areas (for windmill installation). Conducting SWOT analysis of AMC applications in selected cities. Establishing partnerships and preparing human resources. Socializing the concept to government and stakeholders for integration.	1 year
Pre-Implementation	Designing spatial plans and testing DAC-CRS technology to ensure functionality. Creating a government masterplan, electrical system design by PT PLN, and collaboration with chemical companies for methanol processing and distribution.	2 year
Implementation	Constructing crude methanol production areas, distribution networks, solar cell installations on urban buildings, and windmills in coastal/hilly areas. Developing IoT applications for DAC-CRS system management.	5 year
Monitoring & Evaluation	Assessing system performance, identifying deficiencies and operational issues in DAC-CRS, and optimizing for efficiency.	2 year

4. Conclusions

The Alpha Methanol City (AMC) concept is an energy independent city innovation concept with CO_2 processing innovation in the atmosphere using DAC-CRS technology integrated with IoT and big data. The operation of the DAC-CRS system is carried out by utilizing energy sourced from solar power plants and wind farms. The utilization of PLTS and PLTB aims to replace fossil fuels and create a smart green city. PLTS and PLTB will be built in urban areas which will then be used as an alternative energy source in the city as well as a substitute energy source in the operation of DAC-CRS to convert CO_2 into crude methanol. This innovation is very potential to be implemented in Indonesia, because of the potential for alternative wind and solar energy sources in Indonesia, as well as CO_2 emissions in big cities which are a problem causing climate change. The process of implementing this idea takes ± 10 years. Therefore, the AMC smart city concept offered can be a solution to overcome the problem of high CO_2 emissions in the atmosphere and the challenges of climate change on earth by optimizing EBT to realize a smart green city in Indonesia.

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Author Contribution

N.A.P.: Conceptualization, methodology, data collection, and writing the original draft. N.A.P. also contributed to the integration of IoT systems into the Alpha Methanol City (AMC) concept and conducted the literature review. A.F.F.: Review and editing, critical analysis of the renewable energy integration framework and evaluation of the ethical and social implications of the AMC project. A.F.F. also provided insights into the potential for community engagement and the cultural adaptation of the proposed smart city concept. With these contributions, the author provides a comprehensive understanding of the Alpha Methanol City concept, as well as provides information on the challenges that may be encountered and the benefits that can be gained from successful implementation.

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