International Journal of Membrane Science and Technology, 2023, Vol. 10, No. 3, pp 950-959

Decarbonization Technology in Road Infrastructure Projects

C. M. Chavarry-Vallejos[1*], J. S. Támara-Rodríguez[2], L. J. Chavarría-Reyes[3], O. F. Alva-Villacorta[4], R. M. Reyes-Roque[5], E. A. Milla-Vergara[6], A. E. Gómez-Ramírez[7]

[1,3] *Universidad Ricardo Palma, Peru; E-mail: carlos.chavarry@urp.edu.pe*

[2, 4,5,6,7] *Universidad Nacional Santiago Antúnez de Mayolo, Peru*

Abstracts: This study aims to determine the appropriate decarbonization technologies to reduce carbon dioxide (CO2) emissions in road infrastructure projects. Decarbonization is a process that seeks to reduce or eliminate CO2 emissions that contribute to climate change and that comes from the energy sources consumed by the transport sector. With statistical information from different studies, the most appropriate technologies were identified to control the triangle of effectiveness, productivity, and profitability derived from the costs, time, and quality of the projects associated with decarbonization technologies. The study is documentary and bibliographic, with the deductive method, quantitative approach, applied orientation, and descriptive, correlational, and explanatory types. The design is non-experimental, cross-sectional, and retrospective. The energy conversion efficiency of all technologies is identified in three domains: with fossil fuels from compressed natural gas, with natural gas, and with electricity by hydrogen electrolysis. GHG (Greenhouse Gas) emissions savings using BIM (Building Information Modeling) can reach up to 14% and 30% of emissions and 47% and 65% when the scope of maintenance and rehabilitation is restricted, and pavement construction is excluded.

Keywords: Decarbonization Technologies, CO2 Emissions, Energy Efficiency, Renewable Energy, Electrification, Biomass Modeling, Industrialization, Road Infrastructure.

1. INTRODUCTION

Latin America and the Caribbean (LAC) face the challenge of covering the road infrastructure gap and reducing GHG emissions by 50% by 2030. Hossain et al. (2023) indicate that deep decarbonization is required in all sectors to achieve carbon neutrality by 2070, where introducing Electric Vehicles (EVs) can be a clean and alternative option to meet this target. By 2070, model evaluations illustrate that net-zero technology could reduce total CO2 emissions from transport by more than 80%. Lu et al. [1] state that decarbonization is a critical issue for CO2 emissions from the iron and steel industries. The options for decarbonizing the steel sector were discussed based on a systematic, low-carbon three-dimensional analysis related to resource use, energy use, and energy cleanliness, which are assessed using a general emission factor of the process. Helgeson & Peter [2] offer a decarbonization option to power electric vehicles and run energy systems that produce synthetic fuels. By 2050, the shares of fuel for electricity and fuels in the European road transport sector will reach 37% and 27%, respectively, creating an additional electricity demand of 1200 TWh in that region. To assess the added value of the integrated modeling approach, further analysis is performed in which all endogenous linkages between sectors are eliminated. The life cycle of a road infrastructure shows that most of the emissions are due to the production of materials during the construction phase (70%) and lighting during operation (13%).

Tsakalidis et al. [3] developed a Transport Research and Innovation Monitoring and Information System (TRIMIS). It is an integrated transport policy support tool with a modular design. It is a knowledge management system offering open access information and an inventory of transport technologies and innovations. Finally, TRIMIS provides insight into current technological trends in road transport, focusing on intelligent innovation and identifying emerging trends with a potential future impact.

The concept of sustainability must be incorporated from road design, through maintenance to recycling, involving new materials associated with lower carbon dioxide emissions in the construction and operation phases and improving the management of traffic and road assets.

The development of decarbonization strategies under sustainability criteria must start with sectoral development plans, evaluating and awarding projects, and managing assets by the public and private sectors. Climate change requires resilient and net-zero emissions road infrastructures in the medium term, as indicated in their study by researchers Yu & van Son [4], where they mention that climate change is becoming an essential issue in the future - all fields of road infrastructure development. Electricity plays a central role in the path of the decarbonized energy system toward a regional pattern of zero emissions. Improved home networks, substations, and harmonized network codes and frequency, voltage, and communication technology standards are prerequisites for developing household appliances, equipment, and vehicles more efficiently. The above is consubstantial in the construction, transport, and decarbonized industry sectors.

2. MATERIEL AND METHODS

Due to the increase in CO2 emissions, which substantially impact Planet Earth due to the greenhouse effect, the project manager has to analyze the appropriate decarbonization technologies. Carpio & Carrasco [5] consider five models with different geometries depending on their exposed surface and volume relationship. In addition, the authors chose three constructive solutions so that their thermal transmission gradually complied with the values required by the regulations according to the climatic zone and established other parameters for all the necessary simulations.

Khahro et al. [6] conducted a study on environmentally sustainable decision-making with Building Information Modeling (BIM) to reduce energy waste in construction projects. To do this, they initially identified the beneficial factors of BIM in the literature and classified them using questionnaires answered by experts. They used the average index to analyze the data and validated their findings by performing energy analyses on a 3D model through BIM.

On the other hand, Brooks et al. [7] focused on analyzing the carbon life cycle, considering implementing clean technologies to reduce embodied and operational carbon. Their research was based on a deductive approach, looking at the causes of emissions generation, electrification, materials, and equipment used in the facilities. They also presented percentages of reduction of CO2 emissions at national and international levels, using retrospective data obtained from publications on the subject.

The type of research conducted by both groups is classified as application-oriented, as it seeks to establish criteria for design and construction using decarbonization technologies. It also quantifies results and relies on retrospective data sources that align with the study's objectives.

This research is descriptive since it identifies and describes the leading causes of success or failure in designs and construction procedures to identify and establish appropriate decarbonization technologies. It is also considered bibliographic documentary research with a correlational and explanatory approach since it recognizes the relationship between decarbonization technologies and CO2 emissions, providing the necessary knowledge to improve procedures and identify factors that foster a culture of decarbonization in the organization [8].

The level of research is classified as descriptive since it seeks to define and establish the causes that originate CO2 emissions. It is a quantitative study since it determines frequencies, averages, and confidence intervals to guide the improvement plan guidelines for reducing CO2 emissions. In contrast technique, this is a non-experimental approach, as researchers do not deliberately manipulate variables or create situations but observe existing conditions. Regarding directionality, the research is cross-sectional and retrospective since the data were collected simultaneously and over a single period. The study design adopted is cohort since the phenomenon studied has a cause in the present and an effect in the future.

The population considered for this study consists of the articles consulted, from which reliable information was obtained on the subject investigated. A literature review was conducted to determine the relationship between energy efficiency, electrification, renewable energy, modeling and industrialization, and CO2 emissions. Based on these factors, a sustainability concept was applied using decarbonization technologies to define energy consumption and reduce the high rate of CO2 emissions.

3. RESULTADOS

3.1. Energy Efficiency

Prussi et al. [9] indicate that using electricity is an essential option for decarbonizing transport, making comparisons and modeling based on the well-to-wheels method of using electricity. The results show that the direct use of electricity can provide high greenhouse gas savings and, in the case of e-fuels, when using low electricity carbon intensity for its production. Such technological and non-technological barriers have been assessed to compare alternative pathways for the heavy-duty sector. Among the options available, the flexibility to use energy-dense liquid fuels represents a clear and substantial immediate advantage for decarbonization. In addition, the approach makes it possible to quantify the potential benefits of using e-fuels as chemical storage capable of accumulating electricity from renewable energy production.

The heavy dependence on coal in countries responsible for large and rapidly growing carbon dioxide emissions, according to Sweet & Bretz [10], requires maximum ingenuity to reduce that dependence and its potentially adverse effects. Countries like the United States can mitigate the risks of climate change, helping China and India realistically do the same over the next three decades to reduce reliance on coal and move toward decarbonization, either by burning coal more cleanly and efficiently or by adopting alternative energy technologies.

For Küng et al. [11], alternative technologies are essential to meet the decarbonization targets for motorized road passenger transport. The energy conversion efficiency of all powertrain technologies using empirical data from a chassis dynamometer measurement campaign in actual and current vehicles. Three domains are identified: (1) above 600g CO2/kWh, the optimal passenger car fleet only runs on fossil fuels from compressed natural gas but could avoid about 35% of CO2 emissions, (2) between 600 and 235g CO2/ kWh of electricity is used as an energy carrier, but the long daily distances still use natural gas, (3) below 235g CO2/kWh, the entire fleet runs on electricity, directly or by hydrogen electrolysis. Plug-in vehicles have the largest fleet share of around 80%. They function primarily as small-capacity battery electric vehicles, as most daily trips are short. Significant decarbonization requires a large amount of additional electricity, in the optimal case, 34% of the current chemical energy of the fuel.

3.2. Renewable Energies

Lindstad et al. [12] mention that the transport sector accounts for about 25% of global energy use, considering fuel production and consumption. Therefore, rapid decarbonization of transport is often seen as necessary to mitigate climate change, as the International Energy Agency advocates in its Net Zero Scenario 2050. In contrast, Shell's Sky scenario envisages Net Zero by 2070 by picking up within all sectors and, thus, much slower decarbonization of the transport sector. The results emphasize that the priority until 2050 must be: First, to use new renewables to replace coal-based electricity production to almost decarbonize the electricity grid; Second, gradually electrifying road transport; Third, the continued use of fossil fuels in shipping and aviation.

B. Li et al. [13] indicate that deploying renewable energy sources, gas-fired power systems (P2G), and zero-emission vehicles provides a synergistic opportunity to accelerate the decarbonization of both the energy system and transport. It proposes a new coordinated long-term planning model of the Integrated Public Transport System (IPTS) on a regional scale to simulate the balance of the electricity system and travel demand simultaneously while subjecting to several constraints, such as CO2 emissions restrictions. The results show unique decarbonization trajectories of the proposed coordinated planning model, in which the IPTS prefers to decarbonize the electricity sector first. With the P2G system, IPTS could achieve 100% reductions in CO2 emissions by adding a combination of approximately 143.5 GW of wind power, 50 GW of solar PV, and 40 GW of P2G systems with a 2.5% reduction of renewables. The integration of the P2G system can produce hydrogen by using surplus RES generation to meet the hydrogen demand of Fuel Cell Electric Vehicles (FCEVs) and to meet multi-day electricity supply imbalances.

Allwright et al. [14] mention that the electrification of vehicles from the automotive and public transport industries can reduce harmful emissions if implemented correctly. Still, there needs to be more evidence of whether the Heavy Fleet Transport Vehicles (HFTVs), such as multi-articulated vehicles, used in the freight transport industry could see the same benefits. The positive reduction in tailpipe emissions, but the total greenhouse emission was worse for operation if the batteries were charged off-grid. Moving towards more renewable energy and changing its emission factor to generate electricity up to 0.49 kg CO2-e/kWh can be moved, substantial decarbonization could be possible for the road transport industry and help meet the emission reduction targets set out in the 2015 Paris Agreement.

Yuan et al. [15] consider that the electrification of transport is one of the key strategies in the sustainable energy transition. The main focus is on coupling the deployment of electric vehicles (EVs) and the decarbonization of the energy system. Without increasing renewable energy capacity, 100% EV penetration can generate energy savings and reduce carbon dioxide emissions by a minimum of 11% by 2050. In addition, considering the foreseeable technological progress in the battery, a 25% reduction in the initial EV investment is feasible in all future scenarios investigated.

3.3. Electrification of Transport

As mentioned in their study by Leone & Longo [16], the electrification of road transport is essential to meet the objectives of decarbonization and climate change. An ultra-fast charging (UFC) system to facilitate the mass penetration of Electric Vehicles (EVs) into the market, particularly concerning medium and long-distance travel. An ultra-fast charging infrastructure represents the most critical point regarding hardware technology, network-related issues, and financial sustainability. For Gan et al [17] , the electrification of vehicles is considered a pathway for the decarbonization of road transport. Unlike conventional gasoline vehicles, whose emissions come mainly from vehicle tailpipes, emissions from battery electric vehicles (BEVs) come from previous electricity generation and vehicle manufacturing processes. The study compares the life-cycle greenhouse gas emissions of gasoline and electric cars and analyzes the reduction of greenhouse gas emissions from vehicle electrification. The consumption of low-carbon fuels such as high-level bioethanol blend gasoline and electricity decarbonization, national average C2G emissions from hybrid electric vehicles (HEVs), and BEV300s can be reduced to 55g and 73g CO 2 eq/km, respectively. A further decrease in GHG emissions C2G is based on reducing vehicle cycle emissions from material processing and manufacturing of vehicle components.

Qiu et al. [18] evaluate the applications of Capacitive Power Transfer (CPT) and Wireless Power Transfer (WPT) technologies in motion. They calculate and analyze various costs, such as driving heavy electric trucks using CPT technology. Costs vary from \$0.242 to \$0.666 per km, and the cost of driving a heavy electric truck in motion using WPT technology varies from \$0.279 to \$ 1.031 per km, depending on the daily traffic volume. If fuel and vehicle prices evolve as predicted between now and 2050, e-highways could become an economically viable form of road transport, especially for the heavy-duty truck segment, resulting in energy savings and, thus, significant reductions in CO2 emissions.

3.4. Biomass Modeling

Researchers Sobrino et al. [19] developed an improved modeling framework with the HERA (Highway EneRgy Assessment) methodology, which allows evaluating the energy and carbon footprint of different highways and traffic flow scenarios and their comparison. HERA incorporates an adjusted average speed consumption model with a correction factor that considers the slope of the road. It provides a more comprehensive method for estimating the footprint of particular road segments under specific traffic conditions. It includes the application of the methodology to the Spanish road network to validate it.

Bortoli et al. [20] propose an environmental quantification of the impact of Building Information Modeling (BIM) in the construction sector. Specifically, the direct and indirect greenhouse gas (GHG) emissions generated by a monofunctional BIM for road maintenance planning, a Pavement Management System (PMS), are assessed using field data. Three pavement design-construction-maintenance alternatives are compared: Scenario (1) relates to massive design and surface maintenance, scenario (2) to progressive design and pre-planned structural maintenance, and scenario (3) with progressive design and custom structural maintenance supported by the PMS. First, the results show negligible direct emissions due to PMS: 0.02% of scenario three pavement lifecycle emissions. Second, the base case and two complementary sensitivity analyses show that using a PMS is climate-positive during the cycle. Of life when the load capacity of the subgrade of the pavement. GHG emissions savings using BIM can reach up to 14% and 30% of lifecycle emissions, respectively, compared to scenarios 2 and 1, and 47% and 65% when it restricts the scope of maintenance and rehabilitation and excludes the original construction of the pavement. Thirdly, the neutral effect of BIM in case of deterioration of the bearing capacity of the subgrade can be explained by design practices and safety margins, which could be improved using BIM. Fourth, the decarbonization potential of a multifunctional BIM is discussed, and research perspectives are presented.

Parolin et al. [21] developed a mixed integer linear programming model to optimize the design and operation of a hydrogen infrastructure comprising the entire supply chain from production to demand. A crucial novelty element is the combination of technical alternatives and modeling features. The proposed multimodality formulation optimizes the conveyor technology at each stage, selecting between pipelines, compressed hydrogen trucks, and liquid hydrogen trucks. The model application analyzes the use of hydrogen for clean mobility in a long-term scenario in the Italian region of Sicily, assuming demand for 1.1 million equivalent passenger cars (30% of current stock). The resulting cost-effective infrastructure has an average cost of hydrogen supplied of €3.81/kg, in line with mobility objectives.

P. Li et al. [22] extend the existing modeling framework of activity, modal share, energy intensity, and fuel/carbon intensity of The Australian Securities Income Fund (ASIF) by breaking down travel activity into critical structural components and factors specific to the city. They built testable econometric modeling systems to link split, mode-specific travel distances to local economic and urban shape characteristics across four different population sizes and two urban forms. In 2010 urban road passenger transport generated 396 Mt of CO2 emissions, and per capita, energy use from urban passenger transport increased as the size of the city increased. By 2030, under business-as-usual scenarios, energy use in the urban passenger transport sector comprised 23.2 Mt of gasoline, 1.72 Mt of diesel, 3.36 billion m3 of natural gas, and 0.62 billion kWh of electricity.

3.5. Industrialization

Liu et al. [23] mention that the unique life cycle assessment of advanced vehicle technologies and clean construction supply chains offers the potential to reduce carbon dioxide emissions from vehicle operation and road infrastructure separately. However, the impact of combining these two aspects on mitigating road life-cycle CO2 emissions has yet to be well known. However, it is critical for the long-term decarbonization of road transport and policy-making for the transport sector, especially under the latest global target of net-zero carbon emissions. Timely implementation of combined decarbonization measures of advanced vehicle technologies and construction supply chains by 2035 could reduce 16.3% of a road's total lifecycle CO2 emissions. In detail, total CO2 emissions are reduced by 32% and 16.2% for maintenance activities and the use phase. Construction equipment remains the main contributor of emissions for maintenance activities. Hybrid Electric Vehicles (HEVs), not battery electric vehicles (EVs), replace conventional internal combustion engine vehicles (ICEVs) and become the largest source of passenger-related CO2 emissions from the use phase for 2035.

Payri et al. [24] generate in terms of transition of methods and forms of use of different energy sources, with short and medium-term developments on decarbonization. One of the most accepted measures in this way is the reduction of CO2 emissions from internal combustion engines, so they are studying different concepts to optimize combustion. Experimental results showed that the new engine definition achieved higher indicated efficiency levels than the reference engine (around a 3% increase under high load conditions/ speed). A complete dynamic 1D model of a current passenger car was developed for transient driving cycle simulations, showing a 15% reduction in fuel consumption and a 25% reduction in CO2 emissions for the new engine definition compared to the reference engine.

Peng et al. [25] mention that energy consumption and greenhouse gas (GHG) emissions from the road transport sector have increased rapidly in recent years. The detailed technical characteristics of future vehicle fleets are analyzed in several updated scenarios. Total direct oil demand and associated GHG emissions will peak at 508 million tons of oil equivalent (Mtoe) and 1500 million tons of CO2 equivalent (Mt CO2e) around 2030 in the reference scenario. The vehicular diffusion of natural gas has a significant impact on reducing oil demand in the short term, with decreases of 41-46 Mtoe in 2050. Compared to the reference case, battery and fuel cell electric vehicles will reduce oil demand by 94-157 and 28-54 Mtoe in 2050. When combined with decarbonizing future energy supply, battery electric vehicles can play an essential role in reducing Well's GHG emissions. To-Wheels in 2050 with reductions of 295-449 MtCO2e. Spatial distributions of future vehicle stock, energy demand, and GHG emissions.

3.6. Global State 2020 for Buildings and Construction (IEA 2020d and IEA 2020b, 2020)

The State of Buildings and Construction Global State of Buildings and Construction Report, a reference document from the Global Alliance for Buildings and Construction, presents a new index to track progress on decarbonization in the sector (Figure 1).

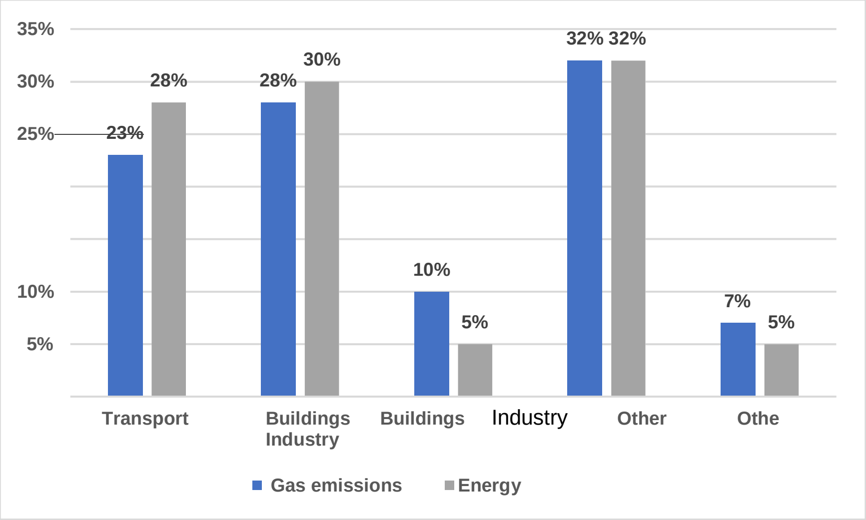

Figure 1. Global State 2020 for Buildings and Construction – Gas and Energy Emissions (Globally)

Sources: [1].

To put the construction sector on track to achieve net-zero carbon emissions by 2050, all value chain actors must multiply the decarbonization actions and their impact by five. To move towards a net-zero carbon inventory by 2050, the International Energy Agency (IEA) estimates that direct CO2 emissions must be reduced by 50.00% by 2030 and indirect emissions from the construction sector by 60.00%. This equates to a fall in emissions from the construction sector of around 6.00% annually until 2030, close to the 7.00% decrease in CO2 emissions from the global energy sector in 2020 due to the pandemic IEA 2020d and IEA 2020b, [1].

3.7. CO2 emissions in Peru

Muntean [27] mentions that CO2 emissions in Peru have grown 8,557 megatons, 18.37% compared to 2020. CO2 emissions in 2021 have been 55,144 megatons of 13,798,151 internationally, making Peru the 129th country in the ranking of countries by CO2 emissions, formed by 184 countries, in which the countries are ordered from least to most polluting. In addition to its total CO2 emissions into the atmosphere, which logically depends among other variables on the country's population, it is convenient to analyze the behavior of its emissions per inhabitant. GDP, which measures, for the same country, the "environmental efficiency" with which it is produced over time. In the last period, Peru has emitted 0.13 kilos per $ 1,000 of GDP, the same as in 2020. However, in the last five years, total emissions have decreased in Peru, as have per capita emissions, so the situation is improving -a percentage of resistance at national and international levels of reduction of CO2 emissions and energy reduction.

4. DISCUSSION

Prussi [28] indicates that the use of electricity is an essential option for the decarbonization of transport, made comparisons and modeling based on the well-to-wheels method of the options to use electricity to supply heavy vehicles, evaluated technological and non-technological barriers to compare alternative pathways for the heavy-duty sector allowing quantifying the potential benefits of using e-fuels capable of accumulating electricity from variable renewable energy production peaks, which would otherwise be wasted due to grid limitations. Sweet & Bretz (1999) indicate that dependence and its effects on mitigating the risks of climate change are reflected in reducing dependence on coal and moving towards decarbonization, either by burning coal more cleanly and efficiently or adopting alternative energy technologies. Alternative technologies meet decarbonization targets for motorized road passenger transport. The energy conversion efficiency of all powertrain technologies using empirical data from a chassis dynamometer measurement campaign in actual vehicles currently only runs on fossil fuels from compressed natural gas but could avoid CO2 emissions.

B. Li et al. indicate that deploying renewable energy sources, gas-fired power systems (P2G), and zero-emission vehicles provides a synergistic opportunity to accelerate the decarbonization of both the energy system and transport. It proposes a new coordinated long-term planning model of the integrated energy and transport system (IPTS) on a regional scale to simulate the balance of the electricity system and travel demand simultaneously while subjecting to several constraints, such as CO2 emissions restrictions. Lindstad et al, the transport sector accounts for around 25% of global energy use, considering fuel production and consumption. Therefore, rapid decarbonization of transport is often seen as necessary to mitigate climate change, as the International Energy Agency advocates in its Net Zero Scenario 2050.

Allwright et al. indicate that electrification of vehicles from the automotive and public transport industries can reduce harmful emissions if implemented correctly. Still, there needs to be more evidence on whether the electrification of heavy cargo transport vehicles, such as multi-articulated vehicles, used in the freight transport industry could see the same benefits. Yuan et al., the electrification of transport is currently considered one of the key strategies in the sustainable energy transition. This paper aims to identify the role of transport electrification from a medium and long-term perspective. The main focus is on coupling the deployment of electric vehicles and the decarbonization of the energy system. As mentioned in their study by Leone & Longo, the electrification of road transport is essential to meet the objectives of decarbonization and climate change. An ultra-fast charging system to facilitate the mass penetration of electric vehicles in the market, particularly concerning medium and long-distance travel. For (Gan et al., 2023), the electrification of vehicles is considered a pathway for the decarbonization of road transport, unlike conventional gasoline vehicles, whose emissions come mainly from vehicle tailpipes. Qiu et al. evaluate the applications of CPT and WPT technologies in motion. A case study is conducted, and various costs are calculated and analyzed. The results show that the driving cost for a heavy electric truck using CPT technology ranges from $0.242 to 0.666 per km. The driving cost of a heavy electric truck using WPT technology in motion ranges from $0.279 to 1.031 per km, depending on the daily traffic volume.

Sobrino et al. developed an improved modeling framework, the HERA methodology (Highway EneRgy Assessment), which allows to evaluate the energy and carbon footprint of Different highways and traffic flow scenarios and their comparison. HERA incorporates an adjusted average speed consumption model with a correction factor that considers the slope of the road. It provides a more comprehensive method for estimating the footprint of particular road segments under specific traffic conditions. Bortoli et al. propose an environmental quantification of the impact of Building Information Modeling (BIM) in the construction sector. Specifically, the direct and indirect greenhouse gas emissions a monofunctional BIM generates to plan road maintenance. Parolin et al. developed a mixed integer linear programming model to optimize the design and operation of a hydrogen infrastructure comprising the entire supply chain from production to demand. A crucial novelty element is the combination of technical alternatives and modeling features. Li et al. (2018) extend the existing modeling framework of activity, modal share, energy intensity, and fuel/carbon intensity by breaking down travel activity into critical structural components and city-specific factors.

Liu et al. mention that the unique life cycle assessment of advanced vehicle technologies and clean construction supply chains offers the potential to reduce carbon dioxide emissions from vehicle operation and road infrastructure separately. The impact of combining these two aspects on mitigating road life-cycle CO2 emissions has yet to be well known. However, it is critical for the long-term decarbonization of road transport and formulating Policies for the transport sector. Payri et al. (2023) generate in terms of transition of methods and forms of use of different energy sources, with short- and medium-term developments on decarbonization. One of the most accepted measures in this way is the reduction of CO2 emissions from internal combustion engines, so different concepts are being studied to optimize combustion. Peng et al. (2018) mention that energy consumption and greenhouse gas (GHG) emissions from the road transport sector have increased rapidly in recent years. The detailed technical characteristics of future vehicle fleets are analyzed in several updated scenarios.

CONCLUSIONS

The energy conversion efficiency of all powertrain technologies using empirical data from a chassis dynamometer measurement campaign in actual and current vehicles, three domains are identified: (1) above 600g CO2/kWh, the optimal passenger car fleet runs only on fossil fuels from compressed natural gas, avoiding approximately 35% of CO2 emissions, (2) between 600g and 235g of CO2/kWh of electricity is used as an energy carrier, but the long daily distances still use natural gas, (3) below 235g CO2/kWh, the entire fleet runs on electricity, directly or by hydrogen electrolysis.

Gas power systems (P2G) and zero vehicles can achieve 100% reductions in CO2 emissions by adding a combination of approximately 143.5 GW of wind power, 50 GW of solar PV, and 40 GW of P2G systems with a reduction of 2.5% renewable energy. Without increasing renewable energy capacity, a 100% penetration of electric vehicles (EVs) can generate energy savings and reduce greenhouse gas emissions. Carbon at a minimum of 11% by 2050. In addition, considering the foreseeable technological progress in the battery, a 25% reduction in the initial EV investment is feasible in all future scenarios investigated.

For battery electric vehicles, 100 miles and 300 miles of all-electric range are 231 and 279g CO2eq/km, respectively, 22% and 5% lower than gasoline internal combustion engine vehicles. The driving cost for a heavy electric truck using technology ranges from $0.242 to 0.666 per km. The cost of driving a heavy electric truck using moving technology ranges from $0.279 to 1.031 per km, depending on the daily traffic volume.

GHG emissions savings using BIM can reach up to 14% and 30% of emissions and 47% and 65% when the scope of maintenance and rehabilitation is restricted, and the original pavement construction is excluded. The cost-effective infrastructure has an average cost of hydrogen supplied of €3.8 l/kg, in line with mobility targets.

Timely implementation of combined decarbonization measures of advanced vehicle technologies and construction supply chains by 2035 could reduce 16.3% of a road's total lifecycle CO2 emissions. For maintenance activities and the use phase, total CO2 emissions are reduced by 32% and 16.2% separately. The development of a dynamic 1D model shows a 15% reduction in fuel consumption and a 25% reduction in CO2 emissions.

RECOMMENDATIONS

Develop alternative fuels and vehicle technologies with a focus on natural gas vehicle market expansion and electric vehicle market penetration. Use new renewables to replace electricity production in road transport gradually. Mitigate the risks of climate change realistically over the next three decades to reduce dependence on coal and move towards decarbonization, either burning coal more cleanly and efficiently or adopting alternative energy technologies. Produce hydrogen to meet the demand for fuel-cell electric vehicles. Consume low-carbon fuels such as high-level bioethanol blend gasoline and electric vehicles in such a way as to reduce emissions in the vehicle life cycle, material processing, and vehicle component manufacturing. Develop electronic highways to become an economically viable form of transportation, especially for the heavy-duty truck segment, resulting in energy savings and reduced CO2 emissions. Estimate the footprint of particular road segments under specific traffic conditions and integrate the carbon footprint reduction target into the design, operation, and comparison of road scenarios. Combined with the decarbonization of energy supply in the future, battery electric vehicles can reduce GHG emissions.

REFERENCES

[1] IEA 2020d and IEA 2020b. (2020). "IEA Global Energy Statistics and Balances" and "Energy Technology Outlook." OBJECTIVES The Global Alliance for Buildings and Construction (Global ABC).

[2] J. Allwright, A. Rahman, M. Coleman & A. Kulkarni. (2022). Heavy Multi-Articulated Vehicles with Electric and Hybrid Power Trains for Road Freight Activity: An Australian Context. Energies, 15(17), 6237. https://doi.org/10.3390/en15176237

[3] A. Bortoli, Y. Baouch, & M. Masdan. (2023). BIM can help decarbonize the construction sector: Primary life cycle evidence from pavement management systems. Journal of Cleaner Production, 391, 136056. https://doi.org/10.1016/j.jclepro.2023.136056

[4] M. Brooks, M. Abdellatif & R. Alkhaddar. (2021). Application of life cycle carbon assessment for a sustainable building design: a case study in the UK. International Journal of GreenEnergy,18(4), 351–362. https://doi.org/10.1080/15435075.2020.1865360.

[5] M. Carpio & D. Carrasco. (2021). Impact of Shape Factor on Energy Demand, CO2 Emissions and Energy Cost of Residential Buildings in Cold Oceanic Climates: Case Study of South Chile. Sustainability, 13(17), 9491.https://doi.org/10.3390/su13179491

[6] Y. Gan, Z. Lu, X. He, M. Wang & A. Amer. (2023). Cradle-to-Grave Lifecycle Analysis of Greenhouse Gas Emissions of Light-Duty Passenger Vehicles in China: Towards a Carbon-Neutral Future. Sustainability, 15(3), 2627.https://doi.org/10.3390/su15032627

[7] B. Helgeson & J. Peter. (2020). The role of electricity in decarbonizing European road transport – Development and assessment of an integrated multi-sectoral model. Applied Energy, 262, 114365. https://doi.org/10.1016/j.apenergy.2019.114365.

[8] F. Hernandez (2014). Methodology of the research (Sixth).

[9] M. Hossain, Y. Fang, T. Ma, C. Huang & H. Dai (2023). The role of electric vehicles in decarbonizing India's road passenger toward carbon neutrality and clean air: A state-level analysis. Energy, p. 273, 127218. https://doi.org/10.1016/j.energy.2023.127218.

[10] S. Khahro, D. Kumar, F. Siddiqui, T. Ali, M. Raza & A. Khoso (2021). Optimizing Energy Use, Cost and Carbon Emission through Building Information Modelling and a Sustainability Approach: A Case-Study of a Hospital Building. Sustainability, 13(7), 3675. https://doi.org/10.3390/su13073675.

[11] L. Küng, T. Bütler, G. Georges & K. Boulouchos. (2018). Decarbonizing passenger cars using different powertrain technologies: Optimal fleet composition under evolving electricity supply. Transportation Research Part C: Emerging Technologies, 95, 785–801. https://doi.org/10.1016/j.trc.2018.09.003

[12] C. Leone & M. Longo (2021). Modular Approach to Ultra-fast Charging Stations. Journal of Electrical Engineering & Technology, 16(4), 1971–1984. https://doi.org/10.1007/s42835-021-00757-x.

[13] B. Li, M. Chen, Z. Ma, G. He, W. Dai, D. Liu, C. Zhang & H. Zhong. (2022). Modeling Integrated Power and Transportation Systems: Impacts of Power-to-Gas on the Deep Decarbonization. IEEE Transactions on Industry Applications, 58(2), 2677–2693. https://doi.org/10.1109/TIA.2021.3116916

[14] P. Li, P. Zhao & C. Brand. (2018). Future energy use and CO2 emissions of urban passenger transport in China: A travel behavior and urban form-based approach. Applied Energy, 211, 820–842. https://doi.org/10.1016/j.apenergy.2017.11.022

[15] E. Lindstad, T. Ask, P. Cariou, G. Eskeland & A. Rialland. (2023). Wise use of renewable energy in transport. Transportation Research Part D: Transport and Environment, 119, 103713. https://doi.org/10.1016/j.trd.2023.103713

[16] Y. Liu, Y. Wang, P. Lyu, S. Hu, L. Yang & G. Gao (2021). Rethinking the carbon dioxide emissions of road sector: Integrating advanced vehicle technologies and construction supply chains mitigation options under decarbonization plans. Journal of Cleaner Production, 321, 128769. https://doi.org/10.1016/j.jclepro.2021.128769

[17] X. Lu, W. Tian, H. Li, A. Li, K. Quan & H. Bai. (2023). Decarbonization options of the iron and steelmaking industry based on a three-dimensional analysis. International Journal of Minerals, Metallurgy and Materials, 30(2), 388–400. https://doi.org/10.1007/s12613-022-2475-7

[18] M. Muntean (2021). Fossil CO2 emissions of all world countries. Expansion.Com/ Datosmacro.Com.

[19] F. Parolin, P. Colbertaldo & S. Campanari. (2022). Development of a multi-modality hydrogen delivery infrastructure: An optimization model for design and operation. Energy Conversion and Management,266, 115650. https://doi.org/10.1016/j.enconman.2022.115650.

[20] R. Payri, R. Novella, I. Barbery & O. Bori-Fabra. (2023). Numerical and experimental evaluation of the passive pre-chamber concept for future CNG SI engines. Applied Thermal Engineering,230,120754. https://doi.org/10.1016/j.applthermaleng.2023.120754.

[21] T. Peng, X. Ou, Z, Yuan, X. Yan & X. Zhang (2018). Development and application of China provincial road transport energy demand and GHG emissions analysis model. Applied Energy, pp. 222, 313–328. https://doi.org/10.1016/j.apenergy.2018.03.139

[22] M. Prussi, L. Laveneziana, L. Testa & D. Chiaramonti. (2022). Comparing e-Fuels and Electrification for Decarbonization of Heavy-Duty Transports. Energies, 15(21), 8075. https://doi.org/10.3390/en15218075

[23] K. Qiu, H. Ribberink & E. Entchev. (2022). Economic feasibility of electrified highways for heavy-duty electric trucks. Applied Energy, p. 326, 119935. https://doi.org/10.1016/j.apenergy.2022.119935

[24] N. Sobrino, A. Monzon, & S. Hernandez. (2016). Reduced Carbon and Energy Footprint in Highway Operations: The Highway Energy Assessment (HERA) Methodology. Networks and Spatial Economics, 16(1), 395–414. https://doi.org/10.1007/s11067- 014-9225-y

[25] W. Sweet & E. Bretz. (1999). Toward carbon-free energy. IEEE Spectrum, 36(11), 28–33. https://doi.org/10.1109/6.803586

[26] A. Tsakalidis, K. Gkoumas, M. Grosso & F. Pekár. (2020). TRIMIS: Modular Development of an Integrated Policy-Support Tool for Forward-Oriented Transport Research and Innovation Analysis. Sustainability, 12(23), 10194. https://doi.org/10.3390/su122310194

[27] K. Yu & P. Van Son (2023). Review of trans-Mediterranean power grid interconnection: A regional roadmap towards energy sector decarbonization. Global Energy Interconnection, 6(1), 115–126. https://doi.org/10.1016/j.gloei.2023.02.010

[28] M. Yuan, J. Thellufsen, H. Lund & Y. Liang. (2021). The electrification of transportation in the energy transition. Energy,236,121564. https://doi.org/10.1016/j.energy.2021.121564

[29] Ziauddin, I., Khan, M., Jam, F., & Hijazi, S. (2010). The impacts of employees' job stress on organizational commitment. European Journal of Social Sciences, 13(4), 617-622.

[30] Jam, F. A., Sheikh, R. A., Iqbal, H., Zaidi, B. H., Anis, Y., & Muzaffar, M. (2011). Combined effects of perception of politics and political skill on employee job outcomes. African Journal of Business Management, 5(23), 9896-9904.

[31] Jam, F., Donia, M., Raja, U., & Ling, C. (2017). A time-lagged study on the moderating role of overall satisfaction in perceived politics: Job outcomes relationships. Journal of Management & Organization, 23(3), 321-336. doi:10.1017/jmo.2016.13

DOI: https://doi.org/10.15379/ijmst.v10i3.1634