Machine learning modeling for reducing greenhouse gas emissions in urban areas

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Abstract

The transport sector is one of the main contributors to global warming and carbon dioxide emissions and it is crucial to find sustainable solutions that balance economic, social, and environmental factors for long-term development. Machine learning and neural networks have the potential to significantly reduce greenhouse gas emissions in urban areas by optimizing transportation systems and reducing energy consumption. The main purpose of this paper is to identify the applications of machine learning and neural networks in reducing greenhouse gas emissions. The current topics of applying machine learning and neural networks in reducing greenhouse gas emissions have been synthesized. These technologies are useful for traffic prediction, prediction of the concentration of greenhouse gases, detection of environmental law violators, and route optimization, etc. Finally, recommendations for future research are at the end of the paper.

***Keywords**: Machine Learning, Neural Networks, greenhouse gases, reduction, urban areas, city*

1 Introduction

Emission of harmful gases in urban environments is an important research topic because urbanization and the increasing population in cities have a significant impact on the environment and human health. Urban environments are often exposed to increased levels of air pollution due to traffic, industrial facilities, and heating.

The main substances emitted into the air are carbon dioxide (CO2), nitrogen oxide (NO2), sulfur dioxide (SO2), and ozone (O3), and they have different effects on the environment. Therefore, managing the emission of harmful gases plays an important role in sustainable development and environmental protection. As the world moves towards cleaner energy and lower emissions of harmful gases, understanding and implementing new technologies and policies becomes increasingly important.

In addition to the use of renewable energy sources, electric vehicles and bicycles, drones in delivery, robots and automation [1], sustainability in urban areas is achieved through the use of modern technologies and innovative transportation approaches. Recently, machine learning has received great attention in the green supply chain as it has the potential to dramatically improve the sustainability and efficiency of supply chains [2].

The application of machine learning in order to reduce greenhouse gas emissions in urban areas is an active research area. Research on this topic has shown that there is sufficient literature on the possibilities that machine learning offers in this field. However, these possibilities have been individually processed, so this paper provides an overview of the literature and a systematic analysis of the potential of machine learning in this area.

This is the main goal of the paper. The areas of application for ML methods have been identified.

Conceptually, the paper consists of five thematic sections. In the introduction, the subject and research objective is defined, followed by thde second chapter which deals with the issue of greenhouse gas emissions in cities. The third chapter provides insight into the conceptual meaning of machine learning and neural networks as artificial intelligence technologies. The fourth

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chapter presents the areas of application of machine learning and neural networks to reduce harmful emissions, followed by the concluding remarks in the fifth chapter.

2 Greenhouse gas emission in urban areas

Urban areas are the main sources of greenhouse gas emissions [3] and represent a complex problem that has enormous consequences for the environment and climate. The increased number of inhabitants in cities and the growing demand for delivery and transportation of various types of goods leads to traffic congestion and the emission of harmful gases. By using fossil fuels, vehicles cause the emission of carbon dioxide, nitrogen oxide and other harmful particles that impair the quality of life in urban areas [4].

Freight transport in cities accounts for 16-50% of air pollutant emissions [5]. The impact of freight transportation in cities is also discussed by the authors in the paper [6], where the impact of emissions is divided into three groups:

- the global impact such as climate change and acidity,
- local influence such as air pollution, noise, vibrations and
- consumption of materials, energy and space.

For these reasons, the sustainability of urban areas is of great importance for environmental protection and refers to the management of traffic flows in urban areas in a way that minimizes the negative impact on the environment. In addition to the application of alternative fuels, it also includes artificial intelligence technologies that have a huge impact on the sustainable management chain and the integration of ecological processes [7].

Machine learning and neural networks as technologies for overcoming air pollution challenges are discussed in more detail in Sections 3 and 4.

3 Machine learning and artificial neural networks

Machine learning (ML) is a branch of artificial intelligence that deals with the development of algorithms and techniques that can teach computers how to solve problems without explicit programming. The idea is to equip computers with algorithms capable of spotting patterns in data and based on them making decisions, recognizing forms, and predict future events. Artificial intelligence is a broad term that encompasses the application of machine learning techniques, neural networks and deep learning [8].

As Fig. 1 shows, there are six components that make up a generic machine learning model:

- The input data set is a component that aims to acquire and prepare data to be used for model training. This phase includes data from various sources, such as databases, text documents, images or videos. After that, the data is prepared in a form suitable for further analysis and only the relevant characteristics for the algorithm are defined.

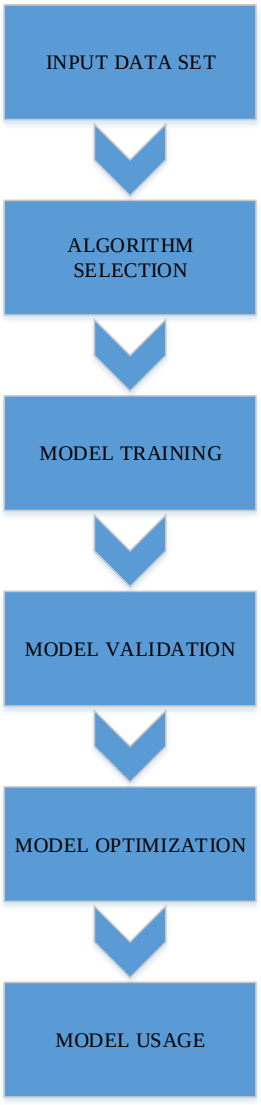

Fig. 1. Generic machine learning model

- The choice of algorithm depends on the problem to be solved and the data set. When choosing an algorithm, the type of task, amount of available data, and their variety.
- After selecting the appropriate algorithm and appropriate parameter values, the model trains on the input data and learns how to recognize patterns and characteristics, and based on that, predicts the output values.
- Model validation includes an assessment how well the model generally performs on new, unseen data and helps identify whether the model is over- or under-fitted. It is evaluated based on the parameters of accuracy, precision and recall.
- Model optimization involves optimizing the hyperparameters of the model in order to achieve better performance.
- Model usage - applying the trained model to predict new values or make decisions based on new data.

There are three main techniques that machine learning uses: supervised, unsupervised, and reinforcement learning. In supervised learning, the algorithm works with labeled data, where it maps the input variable to the output and predicts the result. In unsupervised learning, algorithms recognize patterns in data and derive rules based on them. Reinforcement learning algorithms involve interaction between the system and the environment. The agent or AI-powered system has an initial and final state andencounters different paths to achieve the ultimate goal.

Artificial Neural Networks (ANN), also known as Neural Networks (NN), are a part of artificial intelligence and are designed based on the human brain. The structure of a neural network consists of a series of individual units, artificial neurons or processing elements connected by weight values. Each individual unit has weighted inputs, transfer functions, and outputs.

The weights are parameters that can be adjusted, and in this sense, the neural network is a parameterized system [9]. Input data pass through the network, and each neuron processes the input values it receives by combining them with its weight values and applying an activation function to generate an output.

The output from one neuron becomes the input to the next neuron in the network, allowing the neural network to learn complex patterns in data (see Fig. 2).

They are used for pattern recognition, classification, prediction, and generating new data.

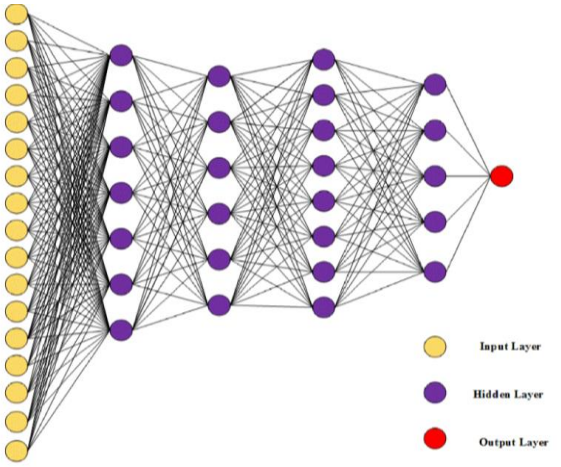

Fig. 2. Flow diagram of ANN algorithm for predicting greenhouse gas emissions [10]

The technology of machine learning, which is capable of imitating human intelligence, relies on various disciplines such as artificial intelligence, probability and statistics, computer science, information theory, psychology, and has a wide range of applications in different fields such as pattern recognition, computer vision, engineering, finance, entertainment [11], marketing, telecommunications, analytics [12].

The following section discusses the application of machine learning for environmental protection and reducing greenhouse gas emissions.

4 Machine learning for reducing greenhouse gas emissions in cities

Sustainable urban logistics is achieved through changes in consumer habits, the use of innovative transportation approaches, and modern technologies.

Machine learning and neural networks can provide a significant contribution to improving sustainability in the transportation sector and reducing real-time CO_2 emissions (Fig. 3).

Fig. 3. The potential of machine learning and neural networks in reducing greenhouse gas emissions

In paper [13], the authors propose a model for detecting environmental law violators in the context of harmful gas emissions.

The prediction model uses machine learning techniques on two sets of data:

- A dataset of daily environmental pollutant emission activities, such as average and mean gas concentrations, deviations, reported by production plants.
- A dataset of a list of companies previously identified as environmental violators.

Machine learning methods were used to identify factories that emit high levels of harmful gases and deviate from typical emission patterns.

Paper [14] describes a model for predicting CO_2 emissions in multiple stages, including predicting missing values in data sets, clustering, and machine learning techniques. The main objective of this study is to reduce the complexity of the model and improve the accuracy of CO_2 emissions prediction.

The application of machine learning methods for calculating data on carbon dioxide emissions for cities is also discussed in paper [15].

In this process, collaboration and support at all decision-making levels, from individuals to governments, are particularly important to achieve significant reductions in air pollution in urban areas and preserve the quality of life and health of people.

By employing decision trees and random forest algorithms, this study identified the key determinants of carbon dioxide emissions, such as socioeconomic factors, humidity, average temperature, and precipitation. The analysis revealed significant variation in emissions levels among different cities.

The application of machine learning in the field of testing air pollution with greenhouse gases is discussed and recommended in papers [16] and [10].

In [17], the authors proposed an artificial intelligence and Internet of Things-based model for controlling urban traffic with the aim of reducing greenhouse gas emissions in urban areas. Mathematical models of traffic flow and intersections were primarily proposed to reduce congestion and, consequently, negative environmental impacts, followed by a deep learning model for predicting urban traffic. The model relies on the application of a neural network to predict traffic flows based on traffic data, weather conditions, and other relevant factors. After obtaining predicted traffic flows, the authors used this information to optimize routes and delivery schedules in urban areas, with the goal of reducing overall greenhouse gas emissions.

Neural networks are also used for air quality forecasting [18]. The model predicts the concentration of particulate matter, nitrogen dioxide, and sulfur dioxide for five days in advance at thirty-two different locations in Delhi. The model was trained on meteorological parameters and hourly pollution concentration data for the year 2018.

To evaluate the concentration of nitrogen dioxide in the air, the authors conducted a study for the city of Tehran in paper [19]. To predict the daily concentration of NO_2 in the air, they used data on urban traffic, green areas, weather, and meteorological parameters as input variables. Prediction was performed using a neural network model and regression analysis method, where the neural network model showed more accurate predictions.

Neural networks can also be used for modeling ozone and simulating its behavior in relation to other atmospheric parameters of interest, as

shown by the authors in [20], who conducted a simulation on a model in Thessaloniki, Greece.

The potential applications of neural networks in transportation and the analytical possibilities it offers in this area are also mentioned by the authors in [21].

5 Conclusion

This paper thoroughly investigated and analyzed the role that machine learning and neural networks have in reducing the harmful effects of greenhouse gases on the environment. Based on the analysis of relevant literature, it can be concluded that ML and ANN models are very significant for operational use in managing air quality in cities and have great potential for future research activities in the field of environmental protection. The prediction and identification of the biggest environmental pollutants is what these tools offer, and the accuracy in the prediction forms the basis for the management and planning of greenhouse gas emissions. By comparing different sources of pollution and greenhouse gas emissions, it is possible to identify the main sources of pollution and potentially define measures to reduce emissions in the most effective way, as well as make decisions related to environmental protection and climate change.

ML and NN-based models can also help predict future pollution emissions, which can be useful in planning long-term emission reduction measures and selecting technologies to be used. They are also useful in the field of urban traffic control. Based on information obtained by predicting traffic flows, routes and schedules of vehicle movements in urban areas are optimized, which directly affects the reduction of overall greenhouse gas emissions.

Although it offers a number of advantages, the impact that this technology has on the environment should also be taken into account. Due to the great need for energy-efficient models and insufficiently covered topics in the literature, this area is recommended for future research.

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