Mining Software Repositories to Identify Electric Vehicle Trends: The Case of GitHub

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***Abstract*—Climate change is a pressing global issue, posing severe threats to societies worldwide, primarily attributed to the accumulation of CO_2 in the atmosphere from the burning of fossil fuels. This accumulation triggers the greenhouse effect, subsequently elevating average global temperatures. As the transportation sector is a substantial contributor to CO2 emissions, a shift from internal combustion engine vehicles to those utilizing clean energy sources is imperative, underscoring the role of Electric Vehicles (EVs) in climate change mitigation. Electric vehicles, powered by an electric motor and equipped with batteries for energy storage, have been the focal point of intensive research and development efforts by academia and industry over the last decade to address associated production and deployment challenges. In this study, we concentrate on the software developed for EVs, using GitHub to gauge the developer community's interest in EVs in a global and in a country level, explore prevalent programming languages and licenses, and assess the continuity of projects as reflected in the available repositories.**

***Index Terms*—electric vehicles, EVs, software repositories, GitHub, data analytics, trends, green economy**

I. Introduction

In recent years, human societies across the world have started realizing the effects of global warming and the consequent climate change. Extreme weather phenomena such as storms, heat, floods and forest fires are happening with an increasing frequency even in areas where they rarely occurred in the past. In this context, it becomes imperative to find ways to reduce the production of CO_2 and other pollutants that are responsible for this change [1]. Given that the transportation sector is accountable for a significant portion of total CO_2 emissions, in the last decade or so, governments and car manufacturers are pushing towards the adoption of Electric Vehicles (EVs). Such vehicles are not powered by an internal combustion engine that uses petrol, rather with a large battery and one, or more electric motors and they are charged with electricity that, preferably, is produced from renewable sources [2]. Despite being a relatively new technology, EVs are gaining ground as car manufacturers insert to the market more and more EV models. Additionally, it is a fact that the European Commission is planning to enforce that only zero-emission vehicles will be soled in the EU by 2035 and targets to have 30 million EVs in Europe by 2030.[1] Similar decisions have been taken by governments around the world.

Apart from public authorities and the industry, the research community has been actively researching areas related to EVs [3]. Some of the main problems to solve are related to the placement of the charging stations [4] which is highly important to ensure the largest possible coverage with stations in a certain area; the scheduling of the charging of EVs across a set of charging stations [5] and the prediction of future charging demand [6], both tasks being very important to ensure that the available charging infrastructure is optimally utilized and the waiting time and delays are minimized; the scheduling and management of the use of EVs as temporal storage devices, the so-called Vehicle-to-Grid (V2G) operation, [7] which can increase the utilization of intermittent renewable energy sources; and the scheduling and coordination of EVs with Mobility on Demand schemes [8] which have the potential to increase vehicle utilization and reduce vehicle ownership.

Given the wealth of research on Electric Vehicles (EVs), a key inquiry is whether the burgeoning academic and industrial interest is reflected in software repositories like GitHub.[2] GitHub is pivotal for sharing code and fostering innovation, enabling researchers and developers to build upon existing software solutions and accelerate advancements in the EV sector. The availability of such software is critical for enhancing research and optimizing existing technologies, and it also acts as a barometer of the community's vibrancy and the field's progress. It offers insights into ongoing initiatives, collaborative endeavors, and the collective expertise in the domain of EVs. Examining EV-related repositories reveals the

[1] https://ec.europa.eu/commission/presscorner/detail/en/IP_22_6462
[2] https://github.com/

scope of communal interest and the diversity of intellectual contributions, illuminating the trajectory of innovations and advancements in electric vehicles. The analysis of software availability and community activity in repositories is instrumental for spurring further research, collaboration, and innovation in the field, serving as both a measure and a catalyst for development in the EV sector.

Existing literature, such as the work by Kochanthara et al. [9], has analyzed automotive software by mining GitHub repositories to discern general trends in the sector. Additionally, research like [10] has used terms related to Electric Vehicles (EVs) to explore the labor market. However, these studies predominantly concentrate on broader sector or industry-level insights and do not delve deeply into individual software repositories related to EVs to extract detailed trends and insights. A more focused exploration of these repositories is essential for understanding the intricate developments, challenges, and innovations occurring specifically in the realm of EV software, providing a nuanced perspective on the technological advancements in this field.

In order to address this gap and gain some initial insights, we have formulated the following research questions (RQs):

RQ1: How mining GitHub repositories could help EVs researchers and practitioners gain first insights for the EVs' land-space?

Electric Vehicles are a rapidly expanding component within various industries and research communities. Amidst this dynamic growth, identifying and extracting trends related to EVs from web sources and vibrant communities become crucial. This effort aims to benefit researchers and practitioners by leveraging emerging ideas and trends.

GitHub is one such continually evolving community that can offer valuable insights into trends shaping the EV landscape. Within this platform, numerous developers and organizations regularly create and update software repositories focusing on different aspects of EVs, such as charging stations, scheduling, or mechanical components. Essentially, GitHub repositories are rich sources for understanding trends in EVs, covering areas from low-level components like battery construction and charging station implementations to advanced topics, including efficient scheduling and charging algorithms [10].

To begin extracting insights into EV trends from software repositories, we will study the changes in popularity and growth of EV-related repositories over time and assess how frequently these repositories are updated. Furthermore, to deepen our understanding of the landscape of EV-related repositories, we will analyze the predominant programming languages being used. We will also conduct a contributor analysis to identify individuals actively involved in developing within EV repositories.

RQ2: Which are the types and the geographical distribution of the users?

Repositories related to EVs hold substantial potential to foster community growth, particularly as more countries prioritize the development of charging stations and networks at both city and national levels to accommodate EV transportation. As a result, local organizations, researchers, practitioners, individual contributors, hackathon participants, and smart city development labs are actively engaged in this domain. Examining user activity on GitHub allows us to trace the movements of the most active users or organizations within the field of EVs and to discern potential collaborative patterns between different entities, be they individuals or organizations.

The rest of the document is structured as follows: Section II provides some background information and related works in the area of mining software repositories and EVs. Section II describes the data collection and analysis procedure. Section IV presents and discusses the analysis' results, and finally Section V concludes and provides ideas for future work.

II. Background and Related work

In this section we present background information and related works related to mining software repositories to identify industrial trends and relarted to EV-related needs.

A. Mining Software Repositories to identify industrial trends

Over the last few years, software engineering (SE) empirical researchers have been using data from developer communities to capture multiple aspects of industrial needs. One interesting aspect is the utilization of data from version control systems such as GitHub [11], [12], or developer Q&A communities such as Stack Overflow [13], [14] to analyze trends in skills. Skill analytics play a crucial role in the labor market, as different industries require expertise in specific areas. Additionally, mining SE repositories serves as a valuable means for identifying experts in specific sectors of various development phases [15], [16]. It's also noteworthy that GitHub repositories are reliable sources for recognizing industry/firm-level requirements, as evidenced in industries like video games [17], and for discerning trends in Industry 4.0 [18].

Consequently, it can be concluded that repositories serve as invaluable resources for discerning industrial needs at the skill, employee, and firm levels. The present empirical approach emphasizes evaluating how Software Engineering (SE) repositories can be leveraged as a substantial source for detecting trends in Electric Vehicles, given that software engineering is integral at various stages of EV development.

Compared to prior studies, it is notable that GitHub, along with LinkedIn and Stack Overflow, is employed as an alternative source to discern labor market trends for EVs within the framework of a green economy [10]. In another empirical approach, EVs are treated as a segment of the automotive industry [9]. In each of these distinct approaches, repositories related to EVs are explored within the broader industry context. Evidently, there exists a need to delve deeper and extract more insights from repositories related to EVs. Consequently, we concentrate on several GitHub repository features to acquire preliminary insights into trends related to the fast growing sector of Electric Vehicles.

B. Electric Vehicles needs

As mentioned before, the research community has been actively researching the problems related to EVs for at least a

decade. During this time the main research directions and the main challenges have been identified and solutions for these challenges have been proposed. For example, in the area of charging station placement, methods and algorithms that have a general application in areas that can be represented as graphs and having certain constraints related to driving range of EVs and convenience of the drivers exist [4], [19]. Moreover, in the area of EV charging scheduling, solutions that study the online [20] (i.e., charging requests arrive dynamically) and the offline [21] (i.e., charging requests are collected in advance) fashion of the problem have been proposed. In this context, energy from renewable sources can be used to increase the efficiency of the EV usage [22]. Additionally, in the area of V2G operation there are solutions that study the transition of energy between EVs [7], the transition of energy between EVs and buildings [23], and of course the storage of renewable energy [24]. Finally, other innovative applications that can involve EVs exist. For example mobility on demand, where vehicles are shared by multiple users, is such an application. In this domain works related to the scheduling of the assignment of the EVs to customers [8] and the pricing [25] of such services exist.

III. Data acquisition and analysis

The initial step in our data analysis framework involves establishing a set of keywords for data collection. For this study, we opted to use a single keyword for constructing the dataset: "electric vehicle*". Although this might appear to be a restrictive selection at first, our team, which includes two experts in EVs, deemed this approach advantageous, considering the study's objectives and the relevant literature.

Upon evaluating the literature, we came across two studies that used keywords related to EVs. The first study aimed to capture GitHub data for specific words related to EVs processes and components [10] as part of skills analytics for labour market purposes. The keyword set in the second study was more generic, focusing on autonomous vehicles in general, where EVs were one part of the scope [9]. Since none of the previous research approaches have clearly focused on EVs, we believe that using a clear and specific search term will help us gain better initial insights. Finally, using a generic keyword it could be possible to help us identify more repositories which could have in their title, topic or description the following text "electric vehicle management", "electric vehicle charging", "electric vehicle control system" amongst others. In total 1881 repositories were found.

The data acquisition and analysis steps are depicted in Fig. 1. In order to answer our research questions (RQs), firstly, we collected repositories related to the search term. After that, we collected the commits from each repository, along with information about the committers. Once the data collection was complete, we handled the gathered information as variables, each with a specific type, to address each RQ.

For RQ1, we utilized the creation date and last update of each repository. Additionally, we recorded the main programming language used in each repository, the repository's

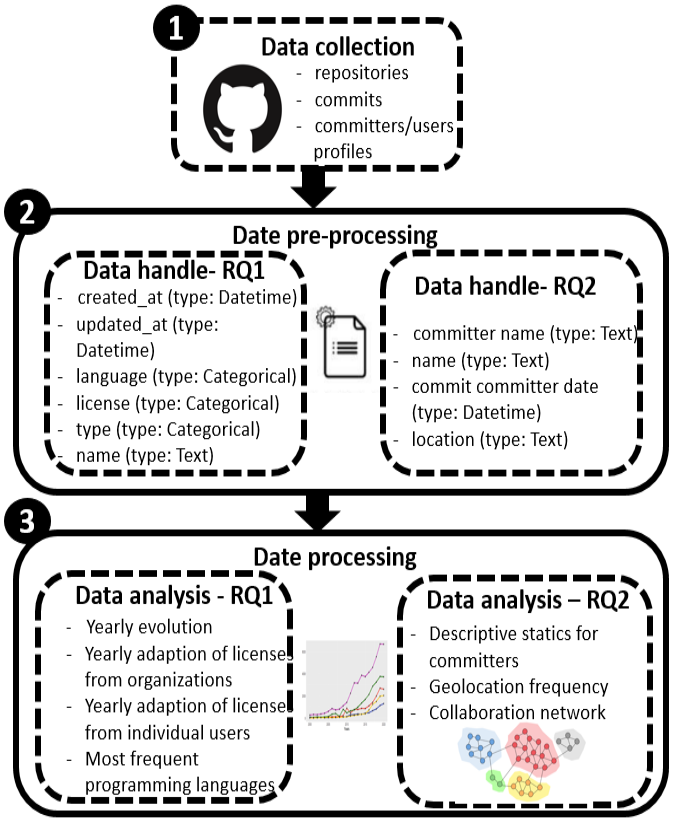

Fig. 1. Data acquisition and analysis steps

license (which is not a mandatory setting), user type (either an organization or an individual user), and the name of the repository. Using these variables, we calculated descriptive statistics based on yearly evolution and overall frequency.

Furthermore, after gaining initial insights into the repositories related to the research questions, for RQ2 we attempted to detect possible collaborations between users within the repositories. To identify collaborative patterns, we collected the commits that exist in each repository and obtained user information for each committer. It is important to note that the user type here refers to the committer user, which is distinct from the user type addressed in RQ1, which pertains to the owner of the repository.

IV. Empirical results

In this section we show the results of the analysis for the two RQs.

A. RQ1: How mining GitHub repositories could help EVs researchers and practitioners gain first insights for EVs landspace?

A first interesting insight is related to the amount of available repositories. Fig. 2 depicts the number of repositories that are created per year. We can observe that from 2008 until 2012 the number of new repositories is very low. However, from 2012 on-wards we see a steady increase which becomes

even higher from 2018. For example, although in 2012 only 4 new repositories were created, in 2022 392 repositories were created, and in 2023 despite being halfway of the year 353 repositories have been created. This clearly shows that the interest of the community in developing software related to EVs is increasing fast. Interestingly, despite using the generic keyword "electric vehicle*" and when compared with [10] where a more complex keyword was used, the number of repositories is still higher.

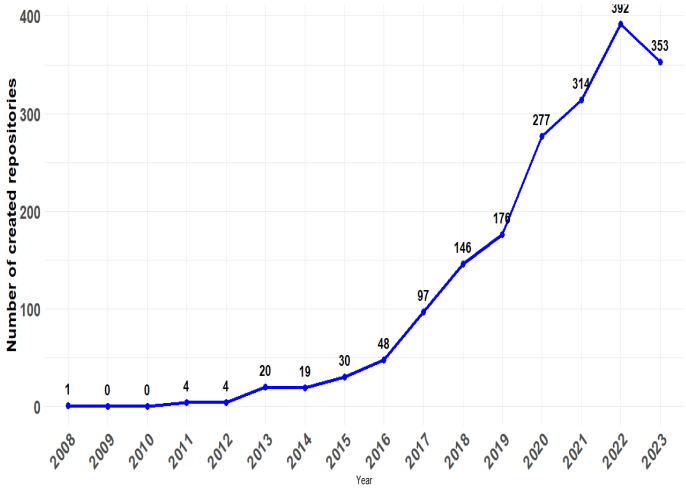

Fig. 2. Yearly creation of EVs related-repositories

The provided dataframe contains yearly frequency data for GitHub repositories based on the type of user, which can be either a "User" or an "Organization". Let's explore the yearly trends in the adoption of licenses for both user types:

For *users*, the data shows (see Fig. 3) that over the years, "MIT License" has been used more frequently by users, and its popularity has consistently increased. It is possible that the MIT License's simplicity and permissive nature make it a popular choice among individual contributors or smaller development teams. In contrast, other licenses are used to a lesser extent, suggesting that users might prefer the simplicity and flexibility offered by the MIT License for their projects.

For *organizations*, the data indicates (see Fig. 4) that organizations primarily use the "GNU General Public License v3.0" and the "Apache License 2.0" for their repositories. However, an interesting trend emerges in recent years, where the usage of the "Apache License 2.0" by organizations has significantly decreased compared to previous years. Simultaneously, the adoption of the "GNU General Public License v3.0" has been on the rise. This shift in license preference may indicate a change in how organizations perceive licensing requirements, open-source collaboration, or compliance considerations.

The observed trends in licensing for both individual users and organizations suggest a multifaceted influence on the choice of license, potentially hinging on numerous factors including project size, the breadth of collaboration, inherent licensing restrictions, and the prevailing preferences within the community. For instance, there appears to be a discernible

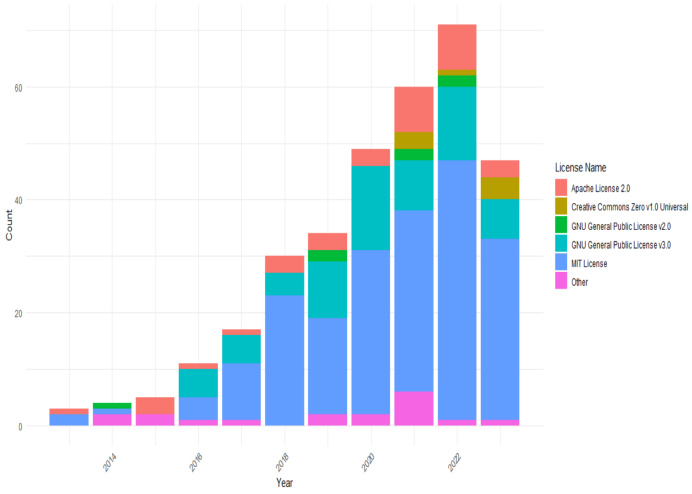

Fig. 3. Yearly preference of Top 5 Licenses for Users

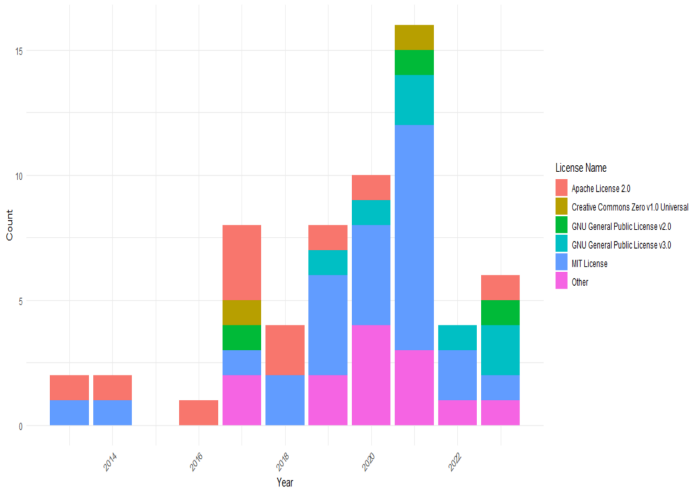

Fig. 4. Yearly preference of Top 5 Licenses for Organizations

decline in the utilization of the "Apache License 2.0" by organizations, prompting speculation as to the factors behind this shift. It is plausible that the decrement in its usage is attributed to transformations in legal frameworks, modifications in business requisites, or shifts in community norms and preferences, necessitating a more nuanced and detailed investigation to understand the underlying reasons fully. This investigation is crucial as it may reveal how evolving landscapes in legal, business, and community realms impact organizational preferences and decisions regarding license choices. Simultaneously, the gleaned data offers critical insights, delineating the licensing patterns prevalent among GitHub repositories pertaining to both individuals and organizations. It emphasizes the transient nature of license preferences, showcasing variations in choices across diverse timelines and highlighting the necessity to understand these dynamic patterns as they reflect the evolving needs, preferences, and constraints of both user types. In essence, the comprehensive insights obtained from this data

Programming Language	# repositories	M watchers	M forks	M Days from creation until last update
Python	248	4.98	1.38	451.17
JavaScript	149	1.59	0.67	326.26
HTML	134	1.35	0.68	202.44
C++	99	3.09	1.79	667.38
Java	79	3.91	2.24	486.54
MATLAB	71	7.53	1.63	642.73
C++	62	4.9	2.85	624.66
CSS	44	1.2	0.27	180.95
R	32	0.5	0.5	311.78

TABLE I
TOP PROGRAMMING LANGUAGES OF REPOSITORIES.

are invaluable for discerning the intricate tapestry of factors influencing license choices, offering a deeper understanding of the motivations and constraints shaping these selections in the continuously evolving landscape of software development.

The programming languages that are used in software that exists in the repositories are summarized in Table I. From this data we can observe that the most commonly used programming language is Python. This comes as no surprise as Python is one of the most popular languages and it is among the first options for scientific computing. Other general purpose languages such as C++ and Java are also quite popular. Additionally, web languages such as JavaScript, HTML and CSS also have high frequency. Finally, other specific languages such as Matlab and R also exist in a number of repositories. Apart from the number of repositories, interesting insights can be drawn from the data related to watchers and forks. Watchers are GitHub users who have asked to be notified of activity in a repository, but have not become collaborators, whereas forks are new repositories that share code and visibility settings with the original "upstream" repository. In both cases we observe that the average number of watchers and forks for all languages is relatively low which could be rendered to the limited collaboration of different users in this area. Interestingly, for both metrics general purpose languages such as Python, C++, Java and also Matlab have higher values. An interpretation to this could be that these developers are, up to now, more involved in developing EV-related software. In terms of the average number of days from the creation of the repository until the last update, we can observe that this period is rather long for all popular languages, meaning that the repositories were not just created and then quickly abandoned, but remain active. This is an interesting insight related to the continuity of work and interest by the community in the filed of electric vehicles.

B. RQ2: Which are the types and the geographical distribution of the users?

Out of a total number of 1881 repositories related to EVs, we collected 21776 commits. Among these commits, we have 1457 unique committers, out of which 1179 have indicated their type in their profiles, which could be either "User" or "Organization". The majority of committers are of the "User" type, accounting for 99.6% of the total.

To gain first insights for the contributors in EVs related repositories, it is meaningful to refer that there is a total number of 168 unique committers, with 28.5% being committers who contribute to different EVs repositories, and 71.5% of committers remain in the same repository and don't transmit to others. Additionally, from the individual contributors in commits, 46.3% indicated their location.

Another interesting insight pertains to the geographical location, or country, of contributors to the repositories. Fig. 5 illustrates the countries with the highest number of contributors. Unsurprisingly, the United States emerges as the source of most repositories. This is anticipated, considering the high concentration of researchers and numerous companies in the country actively engaged in developing EVs or related infrastructure. Other countries with significant contributions include India, Canada, and Germany, with the rationale being somewhat similar. Additionally, the population of each country is a contributing factor, as higher populations can harbor more individuals interested in EVs. Notably absent are countries like Norway, which boasts one of the largest fleets of EVs. It is essential to note that not all repositories have disclosed their country of origin, as it is an optional field, preventing a complete picture of contributor origins. Nonetheless, the findings align with the global state of EV deployment, revealing leaders in adoption and others with substantial progress yet to be made in embracing EVs.

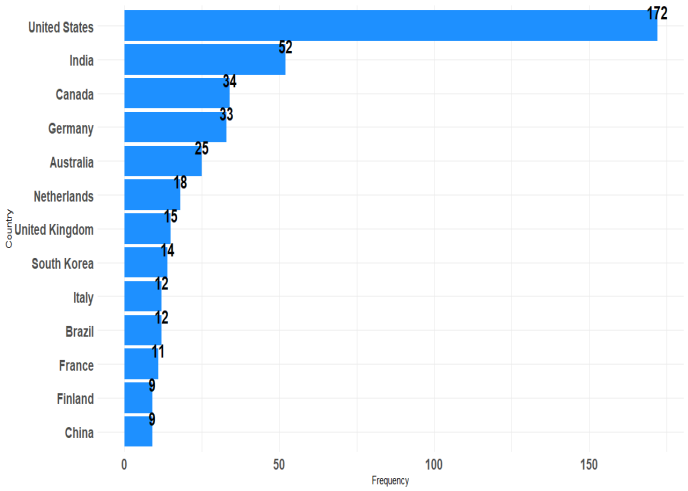

Fig. 5. Top countries with individual committers

V. CONCLUSIONS AND FUTURE WORK

In seeking to address the Research Questions (RQs) outlined earlier, our aspiration is to furnish initial insights into how GitHub projects could act as a rich reservoir for understanding trends in Electric Vehicles, potentially informing a more robust and multifaceted research agenda [26], [27].

In the current study, our methodology involved leveraging the generalized term "electric vehicle*" during the data collection phase. This choice was strategically made considering its prevalent use and resonance within the community and its capability to deliver straightforward, unambiguous insights. Looking ahead, we envisage developing an exhaustive list of keywords. This endeavor, however, is intricate and mandates

meticulous cross-validation of keywords among domain experts to ensure relevancy and comprehensiveness. To refine the precision of our research queries further, collaboration with a domain expert, especially one well-versed in the mechanical intricacies and routing algorithms of EVs, will be essential to ascertain and finalize a list of pertinent keywords.

Our roadmap for future research also entails broadening the scope of our data analysis framework. This expansion aims to include not just commits and issues that are directly associated with the identified keywords but also to probe into repositories where discussions or developments related to EVs may be a part of a broader context, such as in projects focusing on smart city solutions. Additionally, exploration of software repositories beyond GitHub will also be pursued to ensure a more holistic understanding of the landscape.

Focusing on the repositories identified through our current research approach, we intend to perform a more granular code analysis. This will enable us to uncover specific trends related to coding practices and routines in the realm of EVs, allowing us to move beyond high-level, generic insights and delve deeper into the technical nuances. We acknowledge the inherent complexity and specialized knowledge required in processing and interpreting code; therefore, the outcomes of this study will serve as foundational pillars guiding our approach to mine nuanced coding trends and routines effectively.

Finally, a critical aspect of our forward-looking research strategy will be to compute a collaboration network among GitHub users aiming to delineate the landscape of existing collaborations and to unearth opportunities for new, synergistic collaborations. Such a network will be instrumental in fostering a more interconnected and collaborative ecosystem, ultimately propelling advancements in research and practical applications within the EV domain. transportation.

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