Distributed Ledger Technology for Collective Environmental Market Action

Roman Beck[1], Marco Schletz[2], Alvise Baggio[3] and Lorenzo Gentile[1]

[1] IT University of Copenhagen, 2300 Copenhagen, Denmark
[2] Technical University of Denmark, 2800 Lyngby, Denmark
[3] Politecnico di Milano, 20133 Milano, Italy

Abstract. The Paris Agreement tracks national contributions towards the goal of limiting global warming to well below 2 °C. To achieve this goal, collective actions are needed among economically competing countries. In this research, we propose a distributed ledger technology (DLT) based system that allows sovereign states to stay in control of their data while enforcing CO_2 emissions monitoring and reduction rules among all states. Taking the implementation of vehicular fuel consumption metering in the European Union as an example, we use coopetition theory to illustrate how diverging interests can potentially be aligned to achieve a common goal while protecting autonomy. We demonstrate a DLT prototype, created following a design science approach, for monitoring and reducing automotive CO_2 emissions within Europe to illustrate how competing interests can be overcome by the use of innovative solutions on an international level.

Keywords: Blockchain Data Management, Blockchain Data Distribution, Paris Agreement, Decarbonization.

1 Introduction

To meet the objectives of the Paris Agreement (UNFCCC, 2015), all member states of the European Union (EU) jointly committed to reducing greenhouse gas emissions by at least 40 percent below 1990 levels by 2030. The transport sector is critical to achieving this goal, as it represents more than a quarter of European CO_2 emissions, with road transportation alone responsible for over 70 percent of transport sector emissions (EEA, 2019). In this context, the EU Commission mandates through Regulation (EU) 2019/631 (EU, 2019) that starting in 2021 all new light-duty vehicles must be equipped with On-Board Fuel Consumption Meter (OBFCM) devices, which measure and collect individual vehicle data on distance travelled and fuel consumption.

However, although member states share a common understanding of what needs to be done and thus a common objective, they also have divergent interests. Political organizations such as the EU have to deal with these differences, along with increasing economic, social and ecological trade-offs, as member states compete and collaborate on markets at the same time. Some countries, for example, may wish to protect a strong export-oriented automotive industry, while others that are more affected by global warming at their coastlines may look for stricter reductions in CO_2 emissions, which leads to different actions on global markets. For example, current vehicle emission certification procedures, driven by the economic interests of the automotive industry, underestimate vehicles' emissions by between 30 and 50 percent (Duarte, Gonçalves, & Farias, 2016; Fontaras, Zacharof, & Ciuffo, 2017; Todts, 2018). Other examples are the "dieselgate" scandal (European Court of Auditors, 2019) and the generally low quality of emissions data in the official European Environment Agency (EEA) database (Kollamthodi, Kay, Skinner, Dun, & Hausberger, 2015).

A supranational organization such as the EU is critical for aligning the actions of nations despite their diverging interests. The CO_2 emission metering system on a European level is an example of this dilemma: countries must cooperate if they are to significantly reduce CO_2 emissions while at the same time, they wish to pursue their own, often competing economic interests. This is also the reason why countries wishing to manage their CO_2 emissions are unwilling to render their data sovereignty and decision power to a centralized system. This situation can be described as coopetition at an international level.

We propose a distributed ledger technology (DLT) based system to enable data sharing that is both transparent and decentralized. Shared information systems that monitor and predict CO_2 emissions are essential for smart government decision-making (Tang, Wang, Dai, & Liu, 2020). DLT allows for an innovative, decentralized, verifiable, and transparent data monitoring system that establishes a "trust-free system" among participants (Beck, Stenum Czepluch, Lollike, & Malone, 2016; Schletz, Franke, & Salomo, 2020; Treiblmaier, 2018). Based on these features, we explore how new coopetition forms at the international level can be enabled. Thus, our research question is *how can a DLT system enable countriesto manage and ultimately reduce CO_2 emissions?*

This paper is structured as follows. Section 2 discusses the literature background on DLT systems. Section 3 describes the design science methodology applied, and section 4 will introduce the developed DLT prototype. Section 5 discusses the implications of the prototype evaluation. Section 6 provides a conclusion.

2 Literature Background

In this section, we give an overview of coopetition theory, introduce DLT, and discuss DLT as a foundational technology for coopetition among sovereign nations. We use coopetition theory to analyze the case of a DLT-based project to meter CO2 emissions on European roads.

DLTs provide a decentralized, immutable, and tamper-resilient log, which offers all network participants access to all ledger information (Beck, Müller-Bloch, & King, 2018). These features make DLT a potential coopetition enabler if correctly implemented. DLTs achieve disintermediation from trusted third parties through consensus mechanisms and protocol rule enforcement; these mechanisms allow network participants to interact with each other even in the absence of trust (Bano, Sonnino, Al-bassam, Azouvi, & Mccorry, 2017), creating a context in which parties motivated by contrasting economic incentives can safely interact or even cooperate. Network participants (i.e., nodes) need to agree on what constitutes valid transactions. DLT uses cryptography, timestamping, and hashing to record all transactions in a chronological chain that is permanent and extremely difficult to defraud (Narayanan & Clark, 2017); over and above that, smart contracts automate the coordination under predetermined transparent rules that are not directly dictated by a single entity, but instead agreed upon by the interacting users. The rapid development of IoT (Internet of Things) technologies, such as the on-board units in this case, facilitate analysis and prediction in government policymaking (Ismagilova, Hughes, Dwivedi, & Raman, 2019). DLT supports the integration and dissemination of this IoT technology data (Dai & Vasarhelyi, 2017).

In DLT systems design, there are trade-offs between scalability, security, and decentralization (Yu, Wang, Zha, Zhang, & Liu, 2018). Scalability, security, and decentralization also depend on the ownership and accessibility of a DLT system. The ability to submit new transactions and access the stored data in the DLT system is determined by the type of DLT protocol. In permissionless public DLTs, all nodes can validate transactions and maintain the ledger, while in permissioned public or private DLTs, only nodes that have been preregistered and approved can fulfill these tasks (Peters & Panayi, 2016). As permissionless and permissioned DLT systems can employ different consensus mechanisms, the type of DLT affects scalability, security, and the degree of decentralization of the system. Which type of DLT system is most suitable for a given task or process can be identified following the decision path developed by Pedersen, Risius, & Beck (2019). Helliar, Crawford, Rocca, Teodori, & Veneziani, (2020) found that permissioned blockchains generally lag behind permissionless blockchains in terms of diffusion.

3 Design Science Research Methodology

In this research, we follow a design science research (DSR) methodology by constructing and evaluating an IT artefact (March & Smith, 1995; Orlikowski, Wanda J.; Lacono, 2001), while also building a knowledge base that can guide future artefact design in related areas (Gregor & Hevner, 2013; Gregor & Jones, 2007). We add to the current stock of DLT design knowledge (which is fairly scant) by developing some first insights (Gregor & Hevner, 2013) for applications in decentralized, multi-jurisdictional environments. We follow the four-step guidelines for theory-generating design science research by Beck, Weber, & Gregory (2013): (1) creating awareness of the problem and suggesting an approach to solve it; (2) developing the artefact; (3) evaluating the artefact; and (4) abstracting design knowledge. In theory-generating design science research, the artefact should have practical relevance, and its development should be influenced by both the environment (people, organizations and technology) and the knowledge base (foundations and methodologies); therefore, the researcher needs to be well informed when building the artefact (Hevner, March, Park, & Ram, 2004).

First, we worked with the European Commission's Joint Research Centre (JRC), which initially suggested the problem and outlined the details of our use case. Based on their input, we derived tentative design requirements, which were reiterated in several discussions with experts from the JRC. The JRC subject matter experts were available during the development, evaluation, and theory-generation stages of the research. They helped with open questions regarding the use case and design requirements and provided feedback and insights.

The development and evaluation of a DLT artefact enabled the improvement of design characteristics in response to use case requirements, but also enabled a better understanding of the application's potential and limitations. Further iterative developments took place after the development sprint to further improve the design. Naturalistic evaluation with real vehicles in a real-world driving scenario was not possible within the scope of this research. We implemented a testing environment considering the logics followed to record, store, and interact with the information processed by the envisioned DLT system. Therefore, we chose an evaluation approach with a focus on formative and artificial evaluation methods (Venable, Pries-Heje, & Baskerville, 2016).

4 DLT Prototype Construction and Evaluation

This section describes the construction and evaluation of a DLT artefact for the EU transport emission monitoring case study. The aim is to demonstrate how DLT can act as a foundational layer to overcome the challenges posed by coopetition among EU member states.

4.1 Prototype Design Components

The prototype consists of two main components, the DLT network and the on-board units in the road vehicles. We deem a permissioned public DLT architecture to be the most suitable network configuration for this application. In such a permissioned DLT system, all EU member states and eligible agencies share the ownership of the system by distributing the network's controlling nodes equally amongst themselves, creating accountability and fostering collaboration. These infrastructural network nodes maintain the system's status by ordering and validating data entries and recording them permanently in the DLT system. In a permissioned DLT system, access to data, both for reading and writing, is brokered by the peer nodes. This means that new information sent by the client nodes (for example, the vehicles' distance travelled or fuel consumption) must be written so as to comply with network rules, which are granted and enforced by the peer nodes. The same is true for any requests to read data that must go through the peer nodes. Accordingly, a DLT system can be designed to query functions that provide access to specific data levels, such as aggregated data (Manjunath, Soman, & Gajkumar Shah, 2018). In this way, sensitive or confidential data will be accessible only to individuals with the required authorization. Other data queries could be used to access information to be reported to the EEA or other relevant environmental or statistical agencies.

For the implementation and evaluation of a DLT-based emission monitoring system, we used Hyperledger Fabric. Hyperledger Fabric is based on three types of network actors: (i) clients, (ii) peers, and (iii) orderers. Each of these actors has a verified identity within the DLT system and is in charge of performing specific tasks. The initial transactions are proposed by client nodes to a subset of peer nodes, according to so-called endorsement policies. Once this subset of peer nodes has validated the transaction, the client nodes submit the information to orderer nodes; these orderer nodes reach consensus on the sequence of transactions, package the information into a single unique new block, and send it to all peer nodes in the system, thereby updating the ledger. Peer nodes hold the transaction log, i.e., the chain of blocks, as well as the smart contracts that automatically execute the application when correctly invoked.

In our case, the DLT system is organized as follows: each of the EU member states and the agencies or institutions representing them (e.g., the Ministry of Transport), as well as European institutions (e.g., the European Commission and the EEA), will own at least one peer node and one orderer node. This means that each country will participate in the computation and validation of transactions from the blockchain infrastructural layer. The system's client nodes will be the vehicles themselves; these are uniquely identifiable as belonging to a specific country through its national vehicle registration system. In this distributed system, each state or designated agency can be certain that each member state is accurately participating in the CO_2 emission monitoring system, and all information is synchronized at the same time to eliminate information asymmetry, providing a consistent and reliable source of data.

The other component of this system is the vehicle's on-board unit that sends transactions containing vehicle and emission information. Current EU on-board unit specifications (EUC, 2019) require that units transmit information about the distance travelled and fuel consumption. This data is used to derive the kilometric efficiency and CO_2 emissions for the vehicle (Grant, Choate, & Pederson, 2008). After the vehicle travels a predefined distance, the on-board units upload their individual verified data directly to the DLT system to prevent potential manipulation by third parties.

Based on cryptographic authentication procedures, the individual vehicle can be identified, and only the specific vehicle can use the designated public key to submit transactions. The permissioned DLT system connects on-board units with the vehicle's specific characteristics (such as manufacturer, model, and fuel type). The DLT system receives transactions, verifies them, and then updates the system's state accordingly. This design provides a secure accountability system for recording vehicle metrics and transparently tracking performances of individual vehicles.

4.2 Prototype Functional Logic Components

In the DLT system, the on-board unit of each vehicle acts as an individual transactive node. For each node, the DLT system contains a specific state entry, as well as all successive transactions of the specific vehicle. This aggregated series of transactions provide a clear view of the vehicle history in terms of kilometers travelled and fuel consumed. In our implementation, transactions can be twofold. The first transaction records are travelled kilometers (KmTx) and are conducted on the basis of distance (for example, each 100 km). The second transaction is the gas station transaction (GsTx) that registers purchased fuel each time a vehicle refuels at a gasoline station (Figure 1). Each transaction represents a discrete event containing aggregated information about vehicles' metrics since the previous transaction (that is, that the vehicle has travelled 100 km, or that a certain quantity of fuel has been added). By analyzing the specific vehicle data entry, it is possible to extrapolate the total number of travelled kilometers, total fuel consumed, and average fuel efficiency. The DLT system assures the consistency of data and uses smart contracts to enforce the monitoring rules.

Figure 1 illustrates the steps of a fuel purchasing transaction. The procedure for recording fuel consumption starts in parallel with the refueling process. After payment, the data regarding the purchased liters of fuel is recorded by the vehicle's on-board unit. Fuel verification requires a verification not only from the vehicle but also from the gas station, so rather than having the gas station send data to the DLT system separately, the data triangulation between the vehicle and the gas station is established as follows: Vehicle and gas station exchange a signed payload certificate that travels from the vehicle to the gas station (in the form of VSD=Sign(SHA256(liters, time-stamp))), and then back to the vehicle again (in the form of GSSD=Sign(SHA256(VSD))). Finally, the transaction data is uploaded to the DLT system. In addition, the gas station stores the information as proof that the vehicle confirmed that it received a certain amount of fuel at a specific time. If necessary, that information can be triangulated with the uploaded data to detect any manipulation or fraudulent behavior. For such a system to work correctly, gas stations must be able to communicate with vehicles' on-board units. While this technology is not in place yet, gas station providers are already working on such an infrastructure(see (Deutsche Tamoil GmbH, 2020)).

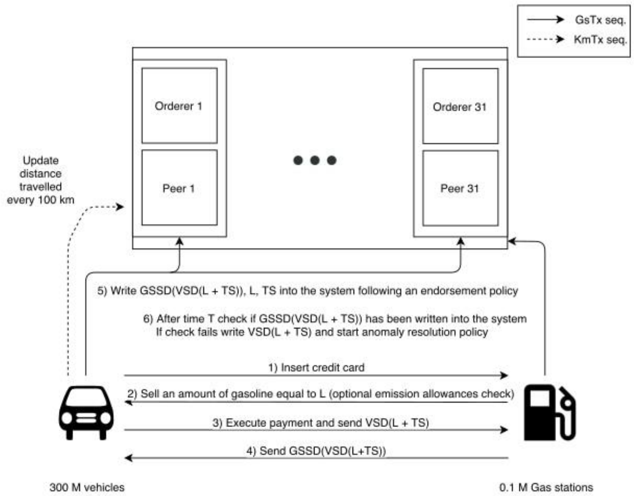

Fig. 1. Architecture and sequence diagram of the emission monitoring system

4.3 Prototype Evaluation

We evaluated the prototype using vehicle data from the EEA database [EEA, 2020]. This database provides detailed information about the manufacturer, model, mass in running order (kg), and the specific CO_2 emissions in g/km for a specific vehicle model.

To ensure comparability between the different vehicle models, we used data only from vehicles with gas combustion engines in our evaluation. Based on the specific CO_2 emissions in g/km we calculated the gas consumption in l/100 km.

We generated a simulated vehicle population of N = 500, in which the model is randomly sampled from a set of 10 possibilities. The script simulates the vehicle behavior in terms of distance travelled and fuel consumption, which is represented by transactions, KmTx and GsTx respectively, that are periodically submitted to the testing DLT system. Based on the KmTx and GsTx transactions, CO_2 emissions (g/km) are calculated using the EEA emission factor [Ntziachristos & Samaras, 2019]. The data of each individual vehicle is aggregated by vehicle model, and the results of the simulation data are displayed in Table 1.

Table 1. Test vehicle types and aggregated data.

Model	**N**	**Distance (km)**	**Fuel (l)**	**Consumption (l/100km)**	**Emissions (g/km)**
Audi-A4	59	644,650	39,324	6.1	145
Audi-Q2	55	624,350	31,218	5	119
Fiat-500	51	555,450	27,217	4.9	116
Fiat-500L	41	468,850	28,131	6	143
Ford-Fiesta	48	535,500	22,491	4.2	100
Ford-Focus	46	515,600	23,718	4.6	109
Nissan-Micra	55	598,550	25,738	4.3	102
Nissan-Qashqai	54	583,200	31,493	5.4	128
VW-Golf	46	524,300	26,739	5.1	121
VW-Tiguan	45	471,750	30,192	6.4	152

Based on this simulation data, we generated the vehicle emission data. Figure 2 depicts this simulation data to identify vehicle types that are currently complying with the EU fuel consumption efficiency standards (below the orange average line) or that currently do not comply (above the orange average line) and thus will be charged with a penalty.

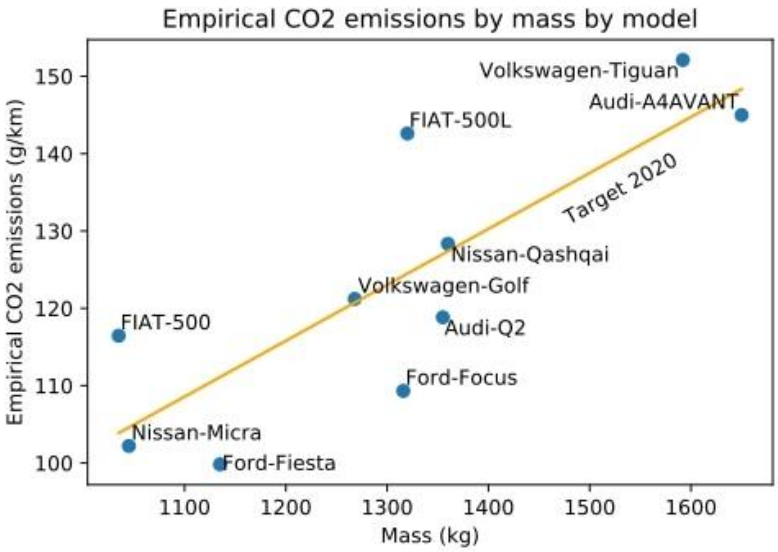

Fig. 2. CO2 emission data compared to vehicle mass

The prototype automates the integration of data from the on-board units in the DLT system and enables detailed monitoring of individual vehicle emissions, as well as aggregated data by vehicle manufacturer or by country. Countries stay in control of the data and thus can protect information about individual vehicles, while the system will report to all nodes how many vehicles are not in compliance and the size of the excess penalty fee. In this way, CO_2 emissions monitoring is enforced, while sensitive individual data remains protected.

5 Discussion of Empirical Findings

The proposed DLT system supports coopetition among participating sovereign member states. While states work collectively on monitoring and reducing CO_2 emissions, and thus enhancing fair cooperation through transparent data sharing, the information pertaining to individual vehicles is kept private, thanks to the permissioned nature of the implemented system. As a result, the monitoring system provides a complete and correct record of the real fuel consumption of each vehicle made by the manufacturer, allowing authorities to enforce the policy-based incentives supporting the joint EU transport sector emission goal. Accordingly, the suggested DLT system enables coopetition by maintaining national data sovereignty and increasing trust, despite ongoing competition. The coordination of policy actions through a shared information base is key to achieving the shared EU objectives.

Our system allows the tracking of individual vehicles and automates data validation through gas station triangulation. The system is a significant improvement compared to the existing fragmented EU emission data management systems. The availability of nearly real-time data for individual vehicles has several practical implications for the entities and actors considered in this paper.

The DLT system provides regulators and policymakers with direct feedback to improve the market mechanism design and provide stronger incentives for reducing CO_2 emissions in a coordinated and cost-effective manner. Currently, it is difficult to assess and plan future policies as data quality is insufficient, and the reduced emissions predicted in certification procedures do not translate into actual emission savings (Fontaras et al., 2017). Poor data quality and the ”dieselgate” scandal clearly show that legacy data management processes and systems do not address the challenges of a coopetitive environment.

In the DLT system, uniform data collection and verification methods are automated across all EU member states, accountability is enhanced, and the pressure exerted by European law becomes stronger. Also, the pricing of more harmful vehicles could become more nuanced with an adjusted fee structure, instead of the fixed EUR 95.- per gram of CO_2. Better data quality could allow for the design of market mechanisms to improve the effectiveness of policies and incentivize the introduction of new fuel efficiency technologies. Such granular and transparent action is key to achieving the joint objectives of the EU climate contributions, as governance transparency is vital for ensuring trust and accountability (Pappas et al., 2019).

6 Conclusions

DLT is a harmonizing technology for enabling coopetition at an international level. Despite states' often diverging and heterogeneous interests, the system provides a shared information base, guarantees each party ownership and control over their own data, yet enforces commonly agreed on rules across legally independent actors. This "trusted" data layer allows for coordinated action while maintaining national data sovereignty.

In our research, we focused on designing, developing, and evaluating a DLT prototype for emission monitoring on European roads. However, as DLT remains a nascent technology, more empirical testing is required. The developed prototype is at a proof-of-concept level, and we followed an empirical testing approach that in the absence of naturalistic testing relies on expert interviews with the European Commission JRC to assess the robustness of the artefact and its practical use and usefulness.

To empirically evaluate the scalability of this DLT approach, a large-scale network of distributed nodes would be required. Any EU-wide emission monitoring system would need to handle several million vehicles. In times of high transaction loads, scalability limitations might potentially delay the execution of transactions. Our general architecture is platform-agnostic and thus can be applied to any DLT. For our practical illustration of the DLT system, we used Hyperledger Fabric, which offers an "end-to-end throughput of more than 3,500 transactions per second in certain popular deployment configurations, with sub-second latency, scaling well to over 100 peers" (Androulaki et al., 2018, p.1). If we assume a total of 300 million vehicles, with an average annual mileage per vehicle of 15,000 km and an average reporting interval per vehicle of 1,000 km, this would result in approximately 150 transactions per second. This number will fluctuate, being significantly higher during rush hours and lower during times of low traffic. Hyperledger Fabric's 3,500-transaction-per-second capacity limit is adequate to handle this level of transactions. Also, it is fair to assume that the technology will mature even further, and new DLT technologies will present further improvements (Glaser, 2017).

All tests were based on Hyperledger Fabric testing tools. Thus, while we have been able to test and assure functional integrity, an evaluation of the system's latency time due to the difference in the size of the data uploads, or congestion caused by time-of-day fluctuation of data submissions, is yet to be done. Another potential issue is that in the current implementation, the available ordering-service consensus algorithms are only CFT (Crash Fault Tolerant) and not BFT (Byzantine Fault Tolerant). While this could create a problem in other implementations, in our case, all ordering nodes of the permissioned public emission monitoring system are controlled by known entities such as the EU member states. The likelihood that a BFT attack would occur in our implementation is very low, however, in general, a BFT algorithm would be a better choice for applications that do not require trust.

References

1. Androulaki, E., Bortnikov, V., Cachin, C., Caro, A. De, Enyeart, D., Muralidharan, S., … Yellick, J. (2018). Hyperledger Fabric: A Distributed Operating System for Permissioned Blockchains. ArXiv:1801.10228. https://doi.org/10.1145/3190508.3190538
2. Baggio, A., & Grimaccia, F. (2020). Blockchain as Key Enabling Technology for Future Electric Energy Exchange: A Vision. IEEE Access, 8, 205250–205271. https://doi.org/10.1109/ACCESS.2020.3036994
3. Bano, S., Sonnino, A., Al-bassam, M., Azouvi, S., & Mccorry, P. (2017). SoK: Consensus in the Age of Blockchains. ArXiv:1711.03936. Cornell University, v2. Retrieved from https://arxiv.org/pdf/1711.03936.pdf
4. Beck, R., Müller-Bloch, C., & King, J. L. (2018). Governance in the blockchain economy: A framework and research agenda. Journal of the Association of Information Systems, 19(10), 1020–1034. https://doi.org/10.17705/1jais.00518
5. Beck, R., Stenum Czepluch, J., Lollike, N., & Malone, S. (2016). Blockchain - The gateway to trust-free cryptographic transactions. 24th European Conference on Information Systems, ECIS 2016, 1–14.
6. Beck, R., Weber, S., & Gregory, R. W. (2013). Theory-generating design science research. Information Systems Frontiers, 15(4), 637–651. https://doi.org/10.1007/s10796-012-9342-4
7. Dai, J., & Vasarhelyi, M. A. (2017). Toward Blockchain-Based Accounting and Assurance. Journal of Information Systems, 31(3), 5–21. https://doi.org/10.2308/isys-51804
8. Deutsche Tamoil GmbH. (2020). "Pay at pump"-Smart fueling using Connected Fueling HEM and PACE cooperate in mobile payment at the fuel pump. Retrieved from https://www.pace.car/press/press_releases/200602_-_HEM_and_PACE_cooperate_in_mobile_payment_at_the_fuel_pump.pdf
9. Duarte, G. O., Gonçalves, G. A., & Farias, T. L. (2016). Analysis of fuel consumption and pollutant emissions of regulated and alternative driving cycles based on real-world measurements. Transportation Research Part D: Transport and Environment, 44, 43–54. https://doi.org/10.1016/j.trd.2016.02.009

10. EEA. (2019). Greenhouse gas emissions from transport sector in Europe. European Environment Agency, 2. Retrieved from https://www.eea.europa.eu/data-and-maps/indicators/transport-emissions-of-greenhouse-gases/transport-emissions-of-greenhouse-gases-12
11. EUC. (2019). REGULATION (EU) 2019/631 OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL setting CO2 emission performance standards for new passenger cars and for new light commercial vehicles, and repealing Regulations (EC) No 443/2009 and (EU) No 510/2011. Official Journal of the European Union. Retrieved from https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32019R0631&from=EN
12. European Court of Auditors. (2019). The EU's response to the "dieselgate" scandal. Briefing Paper, (February). Retrieved from https://www.eca.europa.eu/lists/ecadocuments/brp_vehicle_emissions/brp_vehicle_emissions_en.pdf
13. Fontaras, G., Zacharof, N.-G., & Ciuffo, B. (2017). Fuel consumption and CO2 emissions from passenger cars in Europe – Laboratory versus real-world emissions. Progress in Energy and Combustion Science, 60, 97–131. https://doi.org/10.1016/j.pecs.2016.12.004
14. Glaser, F. (2017). Pervasive Decentralisation of Digital Infrastructures: A Framework for Blockchain enabled System and Use Case Analysis. HICSS 2017 Proceedings, 1543–1552. https://doi.org/10.1145/1235
15. Grant, M. D., Choate, A., & Pederson, L. (2008). Assessment of Greenhouse Gas Analysis Techniques for Transportation Projects. The National Academics of Sciences. Retrieved from https://trid.trb.org/view/848709
16. Gregor, S., & Hevner, A. R. (2013). Positioning and presenting design science research for maximum impact. MIS Quarterly: Management Information Systems, 37(2), 337–355. https://doi.org/10.25300/MISQ/2013/37.2.01
17. Gregor, S., & Jones, D. (2007). The Anatomy of a Design Theory. Journal of the Association for Information Systems, 8(5), 312–335. https://doi.org/10.1.1.232.743
18. Helliar, C. V., Crawford, L., Rocca, L., Teodori, C., & Veneziani, M. (2020). Permissionless and permissioned blockchain diffusion. International Journal of Information Management, 54(October 2019), 102136. https://doi.org/10.1016/j.ijinfomgt.2020.102136
19. Hevner, March, Park, & Ram. (2004). Design Science in Information Systems Research. MIS Quarterly, 28(1), 75. https://doi.org/10.2307/25148625
20. Hughes, L., Dwivedi, Y. K., Misra, S. K., Rana, N. P., Raghavan, V., & Akella, V. (2019). Blockchain research, practice and policy: Applications, benefits, limitations, emerging research themes and research agenda. International Journal of Information Management, 49(February), 114–129. https://doi.org/10.1016/j.ijinfomgt.2019.02.005
21. Ismagilova, E., Hughes, L., Dwivedi, Y. K., & Raman, K. R. (2019). Smart cities: Advances in research—An information systems perspective. International Journal of Information Management, 47(January), 88–100. https://doi.org/10.1016/j.ijinfomgt.2019.01.004
22. Kollamthodi, S., Kay, D., Skinner, I., Dun, C., & Hausberger, S. (2015). The potential for mass reduction of passenger cars and light commercial vehicles in relation to future CO2 regulatory requirements: Appendices. Ricardo-AEA. Report for the European Commission – DG Climate Action, Ref. CLIMA. Retrieved from https://ec.europa.eu/clima/sites/clima/files/transport/vehicles/docs/ldv_downweighting_co2_appendices_en.pdf
23. Manjunath, P., Soman, R., & Gajkumar Shah, D. P. (2018). Iot and block chain driven intelligent transportation system. Proceedings of the 2nd International Conference on Green Computing and Internet of Things, ICGCIoT 2018, 290–293. https://doi.org/10.1109/ICGCIoT.2018.8753007
24. March, S. T., & Smith, G. F. (1995). Design and natural science research on information technology. Decision Support Systems, 15(4), 251–266. https://doi.org/10.1016/0167-9236(94)00041-2
25. Narayanan, A., & Clark, J. (2017). The concept of cryptocurrencies is built from forgotten ideas in research literature. Communications of the Acm, 15(4), 1–30. https://doi.org/10.1145/3132259

26. Orlikowski, Wanda J.; Lacono, S. C. (2001). Research Commentary: Desperately Seeking the “IT” in IT Research - A Call to Theorizing the IT Artifact. Information Systems Research, 12(2), 121–134.
27. Pappas, I. O., Mikalef, P., Dwivedi, Y. K., Jaccheri, L., Krogstie, J., Mäntymäki, M., … Ilavarasan, P. V. (2019). Digital Transformation for a Sustainable Society in the 21st Century. Lecture Notes in Computer Science (including subseries Lecture Notes in Artificial Intelligence and Lecture Notes in Bioinformatics) (Vol. 1). Springer International Publishing. https://doi.org/10.1007/978-3-030-29374-1
28. Pedersen, A. B., Risius, M., & Beck, R. (2019). Blockchain Decision Path: “When To Use Blockchain?” – “Which Blockchain Do You Mean?” M I S Quarterly Executive, 18(2), 24. Retrieved from https://pure.itu.dk/ws/files/83594249/MISQe_BC_in_the_Maritime_Shipping_Industry_Revision.pdf
29. Peters, G. W., & Panayi, E. (2016). Understanding modern banking ledgers through blockchain technologies: Future of transaction processing and smart contracts on the internet of money. New Economic Windows, 239–278. https://doi.org/10.1007/978-3-319-42448-4_13
30. Risius, M., & Spohrer, K. (2017). A Blockchain Research Framework: What We (don’t) Know, Where We Go from Here, and How We Will Get There. Business and Information Systems Engineering, 59(6), 385–409. https://doi.org/10.1007/s12599-017-0506-0
31. Schletz, M., Franke, L., & Salomo, S. (2020). Blockchain Application for the Paris Agreement Carbon Market Mechanism – A Decision Framework and Architecture. Sustainability, 12(5069), 1–17. https://doi.org/https://doi.org/10.3390/su12125069
32. Tang, M., Wang, S., Dai, C., & Liu, Y. (2020). Exploring CO2 mitigation pathway of local industries using a regional-based system dynamics model. International Journal of Information Management, 52(November 2019), 102079. https://doi.org/10.1016/j.ijinfomgt.2020.102079
33. Todts, W. (2018). CO2 Emissions From Cars: the facts. Brussels. Retrieved from https://www.transportenvironment.org/sites/te/files/publications/2018_04_CO2_emissions_cars_The_facts_report_final_0_0.pdf
34. Treiblmaier, H. (2018). The impact of the blockchain on the supply chain: a theory-based research framework and a call for action. Supply Chain Management: An International Journal, 23(6), 545–559. https://doi.org/10.1108/SCM-01-2018-0029
35. UNFCCC. (2015). Paris Agreement, United Nations Framework Convention on Climate Change. 21st Conference of the Parties. Paris. https://doi.org/FCCC/CP/2015/L.9
36. Venable, J., Pries-Heje, J., & Baskerville, R. (2016). FEDS: A Framework for Evaluation in Design Science Research. European Journal of Information Systems, 25(1), 77–89. https://doi.org/10.1057/ejis.2014.36
37. World Bank Group. (2019). Summary Report: Simulation on Connecting Climate Market Systems (English) (No. 144022). The World Bank Group. Washington D.C., USA. Retrieved from http://documents.worldbank.org/curated/en/128121575306092470/Summary-Report-Simulation-on-Connecting-Climate-Market-Systems
38. Yu, G., Wang, X., Zha, X., Zhang, J. A., & Liu, R. P. (2018). An Optimized Round-Robin Scheduling of Speakers for Peers-to-Peers-Based Byzantine Faulty Tolerance. In 2018 IEEE Globecom Workshops (GC Wkshps) (pp. 1–6). IEEE. https://doi.org/10.1109/GLOCOMW.2018.8644251