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Nemzetközi tudományos konferencia
a Magyar Tudomány Ünnepe alkalmából
International Scientific Conference
on the Occasion of the Hungarian Science Festival

Sopron, 2025. november 6.
6 November 2025, Sopron

FEJLŐDÉSI PÁLYÁK ÉS ÚJ TÖRÉSVONALAK A FENNTARTHATÓSÁGI ÁTMENET IDŐSZAKÁBAN

DEVELOPMENT TRAJECTORIES AND NEW DIVIDES IN TIMES OF SUSTAINABILITY TRANSITIONS

Szerkesztők / Editors:
RESPERGER Richárd, SZÉLES Zsuzsanna, TÓTH Balázs István

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Alternatives, Challenges, and Opportunities in the Automotive Industry of the 21st Century

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Abstract:
Currently, a comprehensive review of the operational mechanisms, manufacturing technologies, and infrastructural systems of 21st-century industry is underway, aimed at reducing environmental impact. The automotive industry is required to combine alternative approaches to utilizing available technologies with the introduction of new technical solutions. In this process, existing industrial and transport infrastructure, as well as supply chains, are becoming more efficient and environmentally friendly through the adoption of new artificial intelligence tools. By now, this has also become an expectation at the user level, projecting long-term strategies that emphasize sustainability and an ecological perspective. This aspiration extends beyond individual consumer needs. The challenges of future mobility can be addressed by considering current systems while harnessing the opportunities presented by emerging technical solutions. The aim of this study is to outline the applicability, interrelations, and potentials of present and future technological solutions from the perspective of the development of European mobility.

Keywords: European mobility, self-driving technology, artificial intelligence, industry 4.0, automotive industry
JEL Codes: Q01, L91, R41, O330, R42

1. Introduction: current challenges of the automotive sector

The restructuring of 21st century industry requires new approaches to reduce the environmental burden on the global ecosystem. Although the already developed infrastructure which was based on the technological inventions of the 20. century, in most cases doesn't give space to alternative approaches. To handle the ever urging problems of the industrial civilization is only possible through the refinement and rethinking of the already existing technical solutions. It is necessary to review the energy sources required for road freight and passenger transport, as well as the methods of producing raw materials essential for production and operation. This will prioritize the application of solutions in the future that rely more heavily on green energy and technical solutions that accurately measure efficiency. In order to reach more sustainable solutions in the future, it is a necesssity to review supply chains and prioritize local resources above global, and also to utilize recycled materials on a larger scale. The industry of the future has to become more effective while the consumption needs to be reduced, in order to reach the goals of sustainibility.

The finite nature of materials available for production and the increasingly obvious appearance of harmful environmental effects require a systemic transformation of industrial solutions. The technical innovations of our present century although in contradiction is aiming to replace the most largely available resource: the human resource. In order to reduce economical

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impact, the automotive industry as a prior economical driver is undergoing a major transition. With the wide range application of artificial intelligence it could be possible in the near future to monitor the products through the whole lifecycle: this includes the monitoring of lifecycle and wear of various different components, and also makes possible to indicate the necessary maintenance in a predictive way. With this in mind an expected result is to reach a higher efficiency in waste management, and the repairability of each product and component of the automotive industrial field, as so, the production and utilization can reach an overall efficiency never expected before (Piepoli et al., 2024).

2. Significance and challenges of self-driving technology

The continously evolving systems although doesn't only apply to production technology: with the real time monitoring of the user, by the production of high quality databases from the recording of user habits, the systems of the future could analyze even the functionality and the characteristics during use of the products on an individual level (Liu et al., 2024). The data obtained in this way, as well as the integration of advanced spatial sensing systems, have made it possible to apply partially or even fully self-driving technology. These innovations although are emerging legal and ethical questions in the European Union (Xu et al., 2023). Self-driving technology aims to reach three different goals in the near future: more efficient transportation, the massive reduction of road accidents, and the access to transportation for disabled individuals. However, it is questionable how this can be reconciled with the current transport infrastructure and traditional driving: current self-driving vehicles require the continuous operation of complex systems, and in addition, accidents caused by incorrect decision-making or violations of traffic rules cannot be ruled out (Salvini et al., 2024). For these particular cases the legal framing is not yet fully developed: if a self-driving vehicle commits traffic rule violation, the responsibility cannot be exactly determined (Hansson et al., 2021). While under the current regulations in these cases the responsibility of the driver can be usually accurately assessable, in the case of a self-driving vehicle it is impossible to determine: it's difficult to judge if the systems operator or the owner of the vehicle have to be held accountable, and besides that, who should be penalized in particular cases.

3. Autonomus driving in road freight transportation

Because of a self-driving system always reacts accurately according to traffic situations, in the case of any exact malfunction, neither the owner, nor the operator cannot be held accountable in the way as the current traffic regulations determine. The effectivenes of such a technology is also questionable, where and how could the technology be applied usefully, and how can it be adapted to the current, mostly traditional, human driven vehicle fleet. Some companies are already running cars equipped with this kind of technology on an experimental level, but from the convenience aspect it is not a necessity to implement such a solution (Le & Circella, 2024). A partially self-driving function could be an acceptable compromise: not only for personal car usage but more likely could be a useful companion for road freight transportation. At this level, as for the transport vehicles weighting above 3.5 tonnes more strict rules are applied than to passenger cars, a partially or fully self driving function can be more effective, as current regulations allow only 9 hours per day driving time. If applied, self driving can extend the operating time of a transportation vehicle. Real time monitoring of the drivers readiness could also be useful for warning or even taking control if necessary. The responsibility questions in case of eventual accidents although still remains unanswered: as the system could allow operation during the drivers rest time, if an accident happens during this period, it's hard to decide the drivers responsibility.

4. Autonomous passenger vehicles

From the passenger vehicle aspect, further questions arise. While all of the currently road legal, traditional human-driven vehicles are capable of crossing speed limits, a self-driving vehicle is programmed to keep traffic regulations in all cases. Besides that, partially or fully self driven technology is capable to react accurately at its current level of development, where avoiding road accident is only possible by violating traffic regulations, including excess of speed limit to successfully finish an overtaking maneuver or unauthorized lane crossing, in order to avoid traffic collision (Rydzewski & Czarnul, 2021). In this emphasis though, the future of self driving mobility is still looking for it's place: although this technology can already exceed the speed of human perception, as so, it can be efficient in urban or suburban traffic, there are situations where human abilities and reflexes can operate differently: with a self-driving vehicle in every cases has to be programmed where to go or how to react, with this in mind in some cases it can be slower than a human drivers instant and direct rephlex. It is also questionable whether the use of fully autonomous vehicles, partially autonomous vehicles, and traditional, human-controlled vehicles will be mutually exclusive in the long term: the pre-ordained zero accident to 2050 goal envisioned by the European Union could most likely be achieved with banning the traditional vehicle usage. This could urge the complete transformation of the automotive industry, and also would make questionable the further usage of approximately 1,5 billion existing motor vehicles. Besides that, as the structural bases, and operating characteristics of a self-driving vehicle is are more or less the same as a traditional vehicle, an accident caused by malfunction or even a tyre puncture. Because of this fact, the ambitious zero accident goal is not too realistic, though the strive for reducing road accident can be useful.

An important and progressive solution could therefore be to introduce self-driving and partially self-driving techniques not exclusively, but in certain, separate areas: the utilization should be focused on those particular areas where it could be truly effective and expedient. Such an area could be the above mentioned road freght transportation, where partially or fully self driven technology could reduce the workload of the driver, and could result faster and more efficient transportation. Furthermore it could be worth to consider the application in urban traffic also. Current tendencies envisage the car-free status of larger cities: a necessary step not only to reduce harmful emissions, but also to relieve the burden on crowded, overloaded road networks. In order to reach that goal, European metropolises are looking forward to take effect via different approach of regulations. (Currently there is no unified consesus regarding to reduce vehicle usage to an approriate level, however, the effort is in every case directed towards making inner cities car-free. With this in mind, it could be a subservient solution to develop and apply smaller, fully self-driven vehicles, which usage could be exclusively limited to inner city traffic, especially in low speed limited areas. Important is the fact though, that the characteristics of fully self-driven vehicles are more likely similar to public transportation than regular, traditional vehicles, how will the wide spread of application of such vehicles could affect the private ownership, which is a specific trait of regular motor vehicles. Individuality, which is a decisive factor and a driving factor in the design of a traditional passenger car is less important for such means of transport. This may raise a number of other related economic issues in the future.

5. The advancement via electrification

The challenges related to the continously increasing population and the thirve for reducing environmental impact are demanding a different approach than the current one. Since the planet's carrying capacity will not allow a larger population than the current one to have an acceptable standard of living in the long term, the industrial civilization needs a restructuring in a way that it gives place to other, alternative lifestyles (Jungk, 1991).The changes in the area of mobility, the introducing of electrification gives answer only partially to the problem, as by the

utilization does not necessarily demand crude oil, so the local emission is lowering indeed, the materials needed for manufacture are still depending on the mostly emissive industrial solutions (steel and aluminium manufacturing). Besides that, the electricity which is crucial for operation is still mostly produced in coal-fired powerplants. The current automotive trends are still continue to operate on a growth-based approach: not only from the aspect of profitability, but extending to the different traits of the products: performance as well as the gross weight are continously increasing, as so, in some cases it can be questionable whether some automotive products are really satisfy the demanded lower emission levels and cleaner transportation expected from electrification (Koroma, et al. 2025). Concerning the gross weight of the vehicle, fully electric (BEV) vehicles are significantly heavier than the regular internal combustion engine (ICE) powered ones. This fact comes from the energy energy density of the type of fuel used by the vehicle: fossil fuels hold still much higher energy according to volume compared to the current electric battery solutions (*Figure 1*).

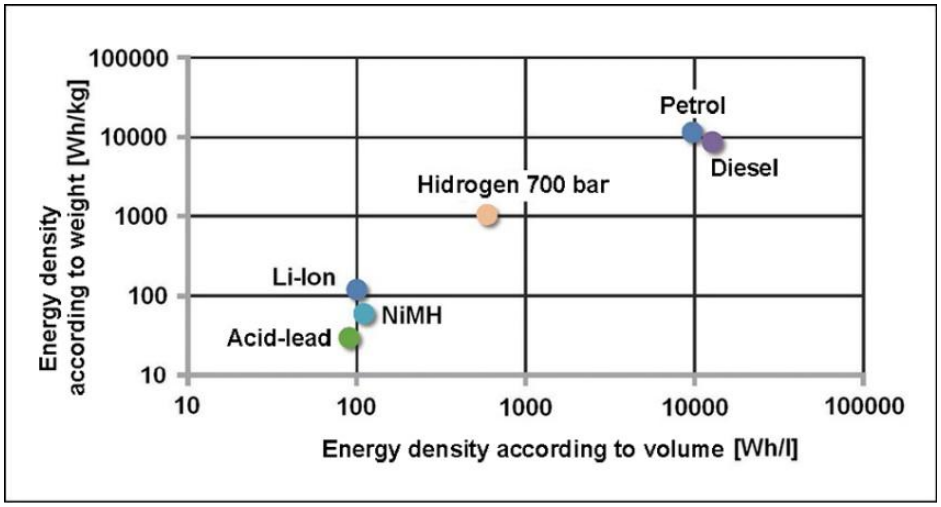

Figure 1: Tendencies of vehicle drive systems, 2010
Source: Szabados (2010)

While the adoption of electric vehicles is underway, this fact is still a major disadvantage, as so, the question of greenwashing is not yet adequately answered to the customer. Fully electric vehicles (BEV) could partially solve the demand of crude oil for operation and maintenance, considering the electric engine's higher efficiency and lower demand of hidrocarbon products, yet the weight question is still a challenge: comparing two different generations from the same segment and similar models, 35 years of evolution came with a massive 700 kgs of weight increase. In practice that means that an average family carries 700 kgs of extra weight for each trip they take by car (*Figure 2*).

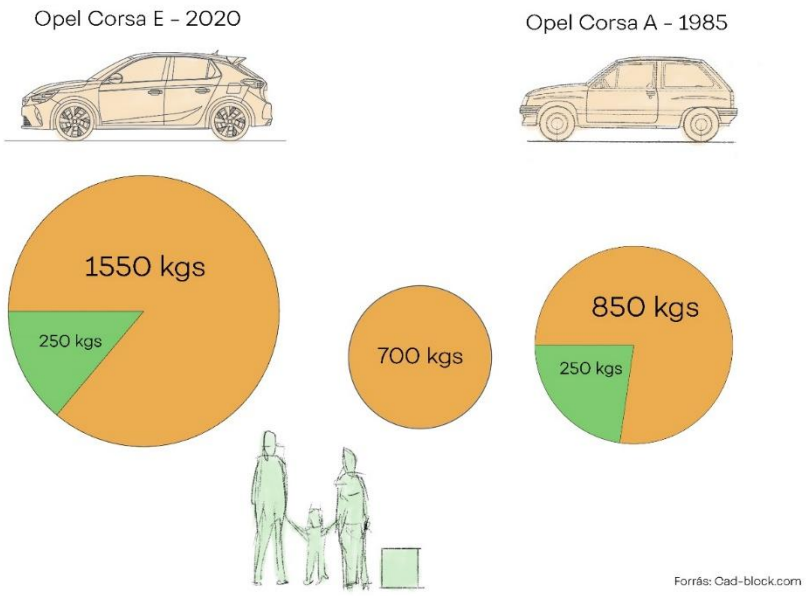

Figure 2: Weight comparison diagram, 2023
Source: General Motors, Original illustration by the author

6. Development of manufacturing technologies

The industrial use of artificial intelligence, and the throughoutly applied automatization is leading to transform or in some cases cease of professions, digitalization and the emerge of comfort features are leading to decrease of human capabilities, thus raising questions about the effects of new technology on society. The undergoing electrification in automotive industry and the phasing out of fossil fuels is leading to rearrangement on the market, but doesn't necessarily gives solution with the former free market approach (Keil & Steinberger, 2023). With the regulation of internal combustion technology, a race is emerging for the extraction of rare earth materials, while the production, refinement and transportation is still relying on heavy machinery mostly operated by fossil fuels. Desertification in certain regions and water shortages due to climate change also pose challenges for manufacturers, as the production of the necessary batteries demand industrial amount of water. The application of artificial intelligence though could bring a solution for reaching carbon neutrality: if it operates from adequate, high quality databases, in the future it could be possible for it to specify the carbon footprint regarding the whole lifecycle of the product. This can be achieved with a more comprehensive, multi-area perspective than the current carbon footprint measurements, which are primarily generated during only production and use: it has to consider the source of the used materials, the energy needs of production, the source of that energy, and also the emission generated by transportation and processing, as well as the recycling at the end of the lifecycle. While these factors are not yet fully measureable exactly at the current level, by the application of artificial intelligence we can get a more comprehensive picture of the entire process, so it may become possible to determine appropriate, truly environmentally friendly solutions in the industry of the future.

More important step though is the conversion of heavy industry and machinery from fossil fuels to alternative solutions, which is yet hard to imagine according to current technological knowledge, as the industry is still operating mostly based on internal combustion solutions (Mattioli et al., 2020). Further challenge is to maintain the worlds increasing passenger vehicle fleet, which by forecasts will reach the number of 2 billion by 2030 (*Figure 3*), and also accordingly the reuse of waste coming from used car wrecks.

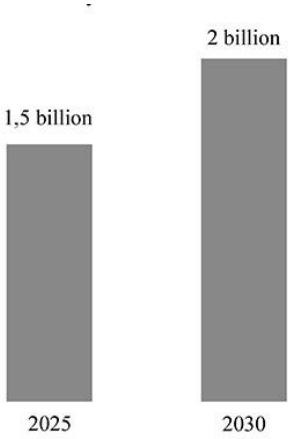

Figure 3: Estimated projection of the gross vehicle population worldwide, 2025 and 2030
Source: Own representation based on data from Statista (2023)

Forward looking solution would be to the standardization of main components of the vehicles, such as structural platforms and various suspension elements, the reuse of various cast steel parts, and recycling the waste material generated in a closed system: iron and aluminum castings, thicker pressed sheet elements can be used for a long time with sandblasting and subsequent appropriate surface treatment. The exchangeability of certain parts of the vehicle is not a new approach: the platform strategy introduced by the Volkswagen Group in the 1990s ensured the group's success well beyond the early 2000s (Wilhelm, 1997). Various models from the same segments built on identical platform is not only cost effective, but also could be effective from the aspect of enviromental impact. At this point it is worth to inspect the process: would it be worth to dismantle scrap vehicles for still useable parts by human labour, and how the reuse of such parts would affect the enviromental burden of car manufacturing. The predictive systems based on artificial intelligence could give a satisfying answer in the near future, more enviromentally effecitve solutions could redefine the manufacturing processes.

7. Opportunities for circular economy in automotive industry

The innovative solutions of the future therefore should consider such system based approaches, which handles the problems of civilization not only based on new technical solutions, but rather envisages a more even distribution and sustainability of existing technical solutions and resources - especially human resources. Besides the precise definition of energy demand and the generated emission of a product during the whole lifecycle, emphasis should be placed on the proper storage and reuse of the waste generated, and its circulation in a closed system. An important step could also be to reuse the packaging of industrially produced products, especially plastics. In this endeavour such systems should be emerged which lay greater emphasys not only on recycling and natural enviromental degradation, but on the prevention of waste release into the enviroment. A system designed to make PET bottles of lubricants and cleaning products used in industry and households refillable and returnable could also be a significant step. Further considerance should be placed on every possible alternatives, which could reduce contradiction of todays societies must be taken into account, regarding especially to the younger generations, so it could be possible for them to think again on the long term: a possible solution to this could be to rethink the prestige and social value of individual areas of activity. The posthuman approach no longer places humans and the environment in a hierarchical, but rather juxtaposed relationship (Wakkary, 2021).

In this context in the products and vehices of the future the right material usage will appear more emphatically. The role of each different material will change, as previously it contained mainly functional and decorative function, by today above sensibility, the sensory perception, it will carry a more important message: the material connects the product with the

enviroment in such way that the origin of the object's components becomes visible and perceptible through the surface formation. The use of the material has to be correct from the principal aspect, as the users become more conscious on their decisions, recycling is becoming an increasingly important aspect of purchasing, unlike before. As the main aspect of mass production was to use materials and components at lowest price possible, the consumer culture of today and the future will change fundamentaly: products made from recycled materials could become more popular choices, as so, the change in attitude may pay off from both a social and, in this context, a market perspective. This could result a new approach and a new perspective for manufacturers as well, as todays industry applies recycling on the product's components at a slightly low percentage. An illustrative example for this is the smartphone market: there are 1.4 billion pieces are sold annually worldwide and only 15 percent of this gets recycled by 2025 (*Figure 4*). Recognizing this fact, the company called Fairphone could reach profitability in a slightly short period of time, with products optimailzed for recycling and minimizing steel mining inputs. This example is a proof for the enterprises based on circular economy could become more efficient and popular in the future: with localization the availability of jobs could increase, the recycling of materials that cover as many elements as possible provides long-term opportunities in terms of both environmental impact and ethical product manufacturing. Market participants must recognize and apply the opportunities offered by the circular economy.

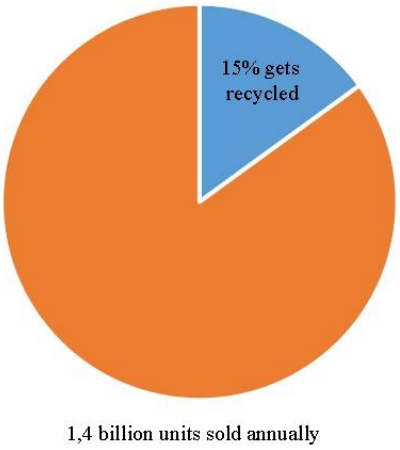

Figure 4: Considering plastics: percentage of recycling in the smartphone market, 2025
Source: Own representation based on data from Fairphone (2025)

8. Conclusions

As for the products of the automotive industry there are final physical limitations of gross weight, performance and handling characteristics, this applies also for the source of materials and energy consumption: for the vehicles of the future rationality and adaptibility to nature could play a deceisive role, the visual manifestations of this could appear in the automoitve industry: „imperfection is future perfection" as Chris Lefteri says, could shape the aesthetics of the future. In correlation with the mission of 21st century's humanity whose task is to restore biodiversity, this attitude will reflect in the product culture, as a kind of bio-organic appearance, with the application of more strict geometrical structures. This approach doesn't necessarily leads to worse living standards. If there is a possibility to apply more efficient tools in order to measure the actual enviromental impact of the performed activity, and thus the conspumtion and the personal needs could be balanced with a greater emphasis on ecological aspects, then the society of the future can achieve sustainability. In order to reach this goal though, it is an important step to have precise information on consumer responsibility: the person of the future must have accurate information about the impact of their purchases and activities on the environment, and depending on this, they must be able to gradually adapt to changing circumstances through

conscious decisions. However, the responsibility cannot be entirely shifted to the consumer: industry and the service sector must accordingly offer solutions that truly achieve the common goal of a sustainable civilization.

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