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Geopolitical factors influencing the rightsizing of combustion engines

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Just a year ago, there were suggestions and even demands about the "death of the combustion engine. Such considerations were conducted in both the fields of science and engineering, where the prospects of electric drive dominance in the next 10–30 years were highlighted. Only a few exceptions supported a moderate approach to the issue of phasing out the combustion engine. Some individuals personally paid the price with their positions for the delay in implementing the so-called zero-emission drives. Today, as the pace of electric vehicle purchases has significantly slowed, and fans of many brands express a desire to stick with combustion engines, and as more factories are struggling to maintain production, it is crucial to thoroughly reassess opinions on propulsion, modern technologies, and legal regulations. Compromise seems to be the downsizing technology of the internal combustion engine as an independent drive or in a hybrid system aligned with the rightsizing development trend. The article aims to present various perspectives on the application of rightsizing in relation to technique, legal issues, ecology, and economy, as well as social connections between different automotive groups and regions throughout the world.

Key words: *rightsizing combustion engines, geopolitics, PESTEL*

1. Introduction

Despite numerous predictions, mainly ecological in nature, regarding the so-called "death of the combustion engine", the development of this heat machine continues, which still serves as the basic source of power for many machines and devices, but primarily for motor vehicles [23]. The more than 160-year history of the internal combustion engine is rich in multidisciplinary considerations aimed at improving its operational efficiency. One of the development trends is rightsizing, which evolved from downsizing and is aimed at reducing engine displacement to lower fuel consumption and consequently limit carbon dioxide emissions from exhaust gases into the atmosphere. Rightsizing an internal combustion engine involves more than simply altering the geometry of the combustion chamber, as it pertains to adjusting the engine (reducing or increasing the displacement) to meet the user's needs, which are often reflected in the vehicle's size and its intended purpose [4, 36, 37].

Although theoretical foundations and numerous applications confirm the validity of implementing rightsizing, propulsion systems developed under this trend do not always receive user approval [1]. Nevertheless, the so-called fashion for rightsizing cannot be stopped, as evidenced by the fact that all car brands offer this type of drive, although with varying levels of technical sophistication.

This raises a research question: what causes certain brands to prioritize rightsizing, while in others it is a minor aspect of development? The answer should be sought not only in the level of technological advancement of a given company but also in geopolitical conditions. This is associated with the location of the company's headquarters, production volume, management policy, worker diligence, influence on domestic and foreign markets, etc. In short, it results from geopolitics, which – through a specific geographical location and, along with it, through political, economic, sociological, technical, ecological, and legal influences – can provide a multidisciplinary assessment of a process or product; in this case, an assessment of the rightsizing development trend.

This study attempts to identify changes in the development of the automotive market related to downsizing/rightsizing technology using the PESTEL methodology, although by design it refers to the identification of opportunities and threats at the stage of strategy development for the implementation of process or product, and not necessarily to the evaluation of what already exists [3, 12, 54].

2. Global automotive market vs. transport sustainability

Currently, it is estimated that there are 1.47 billion cars worldwide. The largest players in this field are China, the USA, and broadly defined Europe. The share of continents is as follows: Asia, 543 million, of which over 340 million are in China, and about 110 million are in India. Europe with 413 million units, North America 358 million, of which more than 300 million cars are on the roads in the USA, South America 84 million, and Africa 26 million [55, 56]. In Poland, following the database update by the Ministry of Digital Affairs [57], which eliminated the so-called "dead souls", there were nearly 23 million passenger cars in 2024, accounting for approximately 76% of all vehicles. This represents about 8% of vehicles operating on European roads, which means that there are over 610 cars per 1000 inhabitants – one of the highest rates. Forecasts indicate that by the year 2040, the number of cars may exceed 2 billion, with 45–55% still being combustion engines [58]. The anticipated increase in the number of cars, and with them the engines, results from the demand for passenger and freight transport. The former is driven by global population growth, especially in Asia, and is expressed by the increase in the passenger-kilometre index, which in 2012 amounted to 40×10^{12} and is expected to rise to 74×10^{12} in 2050 [29]. Freight transport, in turn, is a consequence of

developing economies. It therefore seems logical to intensify the production of motor vehicles along with the definition of the type of propulsion.

Based on Walsch's prediction [49], the annual total production of passenger cars, trucks, and buses will increase from approximately 70 million to over 107 million units in the year 2050. Various propulsion systems will power these, and their proportions will be dictated by multiple factors, with ecology being the dominant. The development of the automotive industry has taken the direction of so-called zero-emission – or more accurately, emission-neutrality – which is based on long-term research showing that approximately 25% of total CO_2 emissions originate from the transport sector, of which over 70% comes from road transport [29]. This is the case globally and in Europe – Fig. 1.

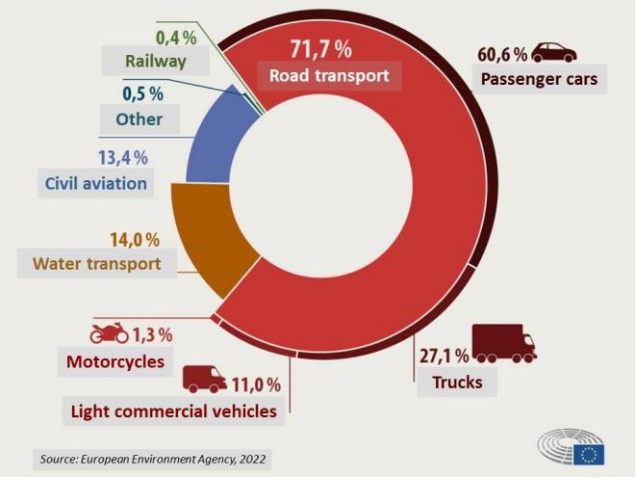

Fig. 1. Distribution of greenhouse gas emissions by type of transport [59]

All efforts to limit emissions of carbon dioxide and other compounds found in exhaust gases lead to setting various cutoff dates that define the timeline for the elimination of the internal combustion engine from the market – i.e. its aforementioned "death". However, it was assumed erroneously – without considering the full life cycle of the product – that CO_2 emissions are only attributable to internal combustion engines, which is a topic for separate consideration. In various government, regional, and automotive development association documents, the most frequently cited milestones are the year 2035 (Europe, USA) or 2040 (Turkey, India, New Zealand) [60]. However, China has also set the end of sales for combustion engine vehicles for the year 2060. Norway, on the other hand, began implementing a ban (or rather a restriction) on the sale of internal combustion engine vehicles in 2025, with the perspective of eliminating this type of propulsion from roads over the next 10 years – see Fig. 2.

Ultimately, for example, in Europe, a scenario has been adopted that by 2030 car manufacturers should reduce CO_2 emissions from passenger vehicles by 55% and from delivery vehicles by 50%. After 2035, it will be possible to register a new car with an internal combustion engine only if it is powered exclusively by synthetic fuel or hydrogen. This is a serious challenge for manufacturers, but not the only one when considering the assumptions of sustainable transport [16, 30], as in addition to meeting legislative requirements concerning product (car) and production ecology, it is also necessary to consider:

– ensuring the success of launching a new product on the market while maintaining sales of traditional models
– ensuring production quality
– ensuring profit
– ensuring the supply chain
– implementation of new technologies
– providing service for machines and equipment.

Fig. 2. Cutoff dates for the sale of internal combustion engine vehicles worldwide (based on [60, 90])

On the other side of this puzzle is the user, for whom sustainability is associated with their expectations, i.e.:

– achieving satisfactory performance indicators (engine power, maximum vehicle speed, etc.)
– reducing operating costs by ensuring low fuel consumption
– ensuring ergonomic use, most often expressed in driving pleasure, ease of operation, and low noise levels
– a sense of fulfilling the mission of environmental protection
– ensuring fuel (energy) availability
– guaranteeing the reliability of the transport medium.

In a relatively simple comparison, it can be considered that the trend of rightsizing fulfils the above assumptions of sustainable transport. Formulating this thesis requires evidence, which can be provided through an assessment of the geopolitical conditions of automotive development.

3. Technology downsizing/rightsizing

A measure of modernization, and at the same time of technical innovation in rightsizing, is the recognized level of the downsizing trend, which is defined by the degree of change, indicating the residual effect after the reduction or increase of engine displacement volume [4, 37, 41]. The author defined the downsizing index (W_d) based on the degrees of change of the components describing the cylindrical combustion chamber (substitute volume), which dominates in the construction of internal combustion engines [24, 27]. According to this definition, the downsizing index can be described as in formula (1).

$$W_d = 1 - AB^2$$

for $$A = \frac{S_d}{S} \qquad B = \frac{D_d}{D} \tag{1}$$

In graphical interpretation, three versions of displacement changes can be distinguished – see Fig. 3.

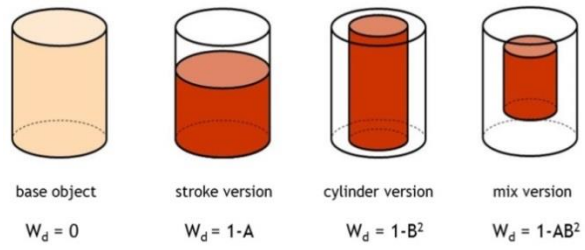

Fig. 3. Versions of downsizing [43]

Evaluating the values of the W_d index showed that it is possible to obtain the same values for different changes in piston stroke and cylinder diameter. Possible combinations of downsizing/rightsizing are presented in the form of a matrix of changes in coefficients A and B – see Fig. 4. Two zones of index variability were identified: downsizing and upsizing, which constitute the essence of rightsizing.

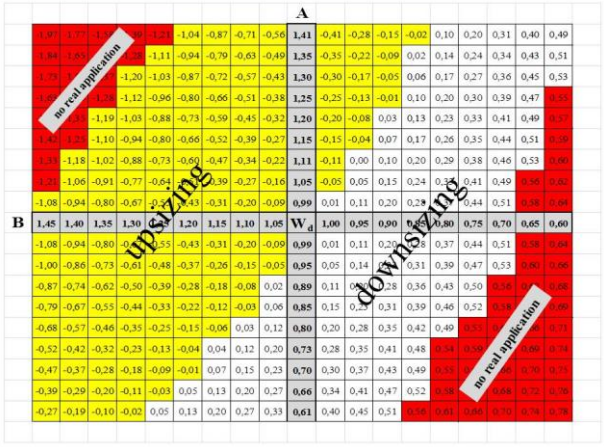

Fig. 4. Matrix of changes in the rightsizing index according to various combinations of coefficients A and B

Having knowledge of internal combustion engine design and based on commonly accepted relationships between cylinder diameter and stroke [37, 39, 42, 45], as well as based on actual relationships of these parameters [15, 39] it was possible to determine real variability intervals from 0.77 to 1.30, which results in W_d index values ranging from –1.20 to +0.51. Changes at the extreme ends of this range are referred to as "aggressive", while values outside the range are considered physically impossible or uneconomical.

Implementing rightsizing technology requires the implementation of new or the intensification of existing design-functional systems in the engine. Among these, significant roles are played by boosting, direct fuel injection, variable valve timing, and variable compression ratio. Electronics control the entire system in a local or global configuration [15, 25, 26, 42].

An indispensable support system for rightsizing, especially when reducing volume, is boost, whose presence is essential for proper cylinder filling [20, 33, 41]. Various forms of charging in practice, such as mechanical, pneumatic, electric, or turbocharging, as well as their combinations, provide support in mitigating power losses and creating conditions for the combustion of lean mixtures, which is essential for meeting environmental requirements. The technological transition from Auguste Reteau's first turbochargers in 1916 to Ted von der Nuell's 1951 solutions on variable nozzle turbine blade settings (VNT) is evident, although the proper implementation of this solution only occurred in 1991. VNT technology is currently the most dynamically developing, and through research conducted by Honeywell, the dominant aspect is scaling down and adaptation to increasingly smaller engines, in line with the rightsizing concept. Today, a two-stage turbocharging system ensures high system efficiency, resulting in low fuel consumption and reduced heat losses to the atmosphere, thereby contributing to the fulfilment of environmental requirements. The development of charging systems serves as an example of how prolonged research and development efforts can be.

Another system related to the idea of rightsizing is direct fuel injection [3, 20, 38]. In compression-ignition engines, this technique has been used almost since the beginning, but the implementation of the Common Rail system by the Denso/Toyota corporation played a particularly significant role. This occurred in 1995, although the idea was already known in 1916 (Vickers company) [14]. In that time, however, the technology to achieve high pressures, fuel droplet atomisation, and the possibility of multiple fuel injections in one cycle was lacking. The effect is reduced fuel consumption and a significant cut in harmful exhaust emissions due to the lower temperature in the combustion chamber. An added value is the lower noise level, which improves operational comfort [27]. The implementation of direct gasoline injection in spark-ignition engines has resulted in more positive development outcomes for engines than for diesel engines. The first attempts to inject gasoline directly into the combustion chamber were made by Jonas Hesselman in 1925, but it was the solution proposed by Mitsubishi in 1996 that brought developmental success. The solution is known as GDI [13, 24, 26]. Gasoline injection, carried out in at least two phases, allows for stratified combustion, including the combustion of very lean mixtures without the effect of knocking combustion. The specially shaped combustion chamber facilitates this in the piston crown, which ensures charge swirl. A drawback of this system is the increase in nitrogen oxides emissions, which requires the engine to be equipped with a reduction catalyst and an exhaust gas recirculation system. GDI requires proper control, including adaptive systems [26, 52]. The fuel direct injection application integrates very well with the engine technology involved in downsizing/rightsizing, as it directly compensates for the power losses resulting from geometric changes.

Improvement in volumetric efficiency is also achieved by implementing variable valve timing systems. The variable valve timing system ensures the adjustment of angles and the opening and closing times of the valves to match the current engine load and rotational speed. Many variable valve timing systems undergo successive design transfor-

mations, and depending on the manufacturer, they have different names [10, 47]. The first variable valve timing system appeared in 1981 in Alfa Romeo engines, but it was not until Honda introduced electronic control in 1989 that this design, known as VTEC, began to develop, with the latest version being i-VTEC. Porsche demonstrated further evolutions with the VarioCam system, BMW with Valvetronic, and Ford with Ti-VCT.

The variable valve timing system is a good complement to downsizing/rightsizing technology by reducing flow losses due to smaller valve sizes and ensuring proper combustion chamber filling to maintain or increase effective efficiency of the engine [18].

During the turbocharging of spark-ignition engines, there may be a risk of autoignition, which is naturally undesirable. To prevent this, it is necessary to reduce the compression ratio, which in turn determines the pressure value in the combustion chamber, and this affects the engine power throughout the operating range. A solution to this problem is a Variable Compression Ratio (VCR) system, where changing the volume of the compression chamber alters the load. There are several technical solutions to this issue. One of them is, for example, changing the stroke in the crank mechanism - Peugeot. Another solution defines the angular displacement of the engine head – SAAB (SVC – Saab Variable Compression). Yet another solution is the dynamic displacement of the entire crank mechanism (Cortina VC). It should also be noted that some consider the variable compression ratio system to be a form of dynamic downsizing/rightsizing, rather than a support system [5, 46].

From engineering practice, a number of successful examples of the development of downsizing/rightsizing ideas can be highlighted. For example, one could mention the engines installed in Ford vehicles featuring the EcoBoost solution, with displacement changes from 2.3 dm^3 V6 to levels of 2.0 dm^3 and 1.6 dm^3, ultimately achieving a spectacular value of 0.999 dm^3 with power ranging from 75 to more than 100 kW. In Volkswagen engines, the displacement was changed from 2.8 dm^3 to 1.4 dm^3, fulfilling the downsizing requirement, and with sustainable development (rightsizing), it was replaced with 1.5 dm^3 TSI. In the Mercedes-Benz engine, through rightsizing modernisation, a power output of nearly 155 kW was achieved from 1 dm^3.

From a broader perspective, the trend of downsizing over the years can be seen by evaluating engines entered into the international Engine of the Year competition, which was organized in 1999 by the magazine Engine Technology International – UK & International Press [66]. The "winners" in all categories demonstrate a clear trend of displacement change over the years. This is reflected in increased specific power (Fig. 5) and reduced carbon dioxide emissions (Fig. 6).

Alongside the enthusiasm for technology, there are also concerns about downsizing/rightsizing, which relate to engine durability. The smaller engine in terms of dimensions potentially delivers greater power, making the unit more strained and, as a result, its durability is limited. This was the case with the Peugeot 1.2 dm^3 engine, where the lubrication system failed, and the implemented so-called wet timing belt often delaminated or snapped [62].

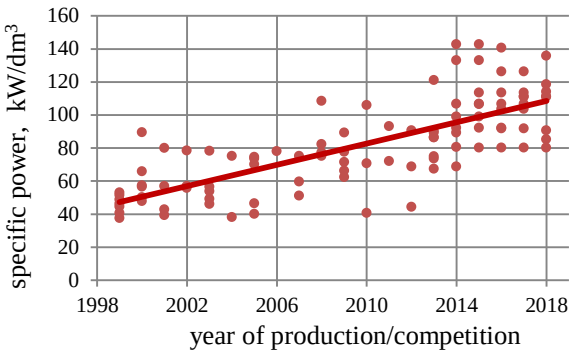

Fig. 5. The specific power of combustion engines – „winners" in the Engine of the Year competition in all categories [43]

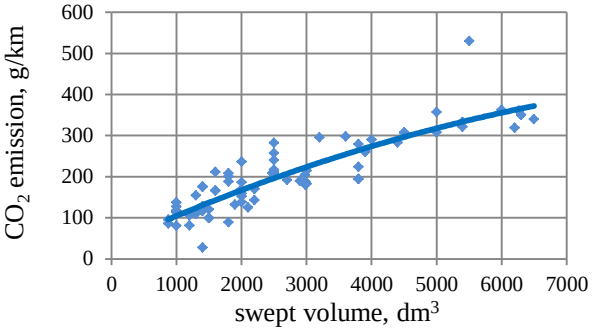

Fig. 6. The carbon dioxide emissions of combustion engines – „winners" in the Engine of the Year competition in all categories [43]

The description above indicates that the successful application of the rightsizing concept in combustion propulsion is a synergy of internal efforts, related to the history and technical culture of the manufacturer and suppliers who have access to support systems, ensuring high efficiency of engine performance characteristics. Many manufacturers in Europe and the USA, who have been shaping automotive history right from the very beginning, as well as new brands, particularly in Asia, are able to realise the rightsizing trend. The level of engine modernisation, whether current or future, depends on various factors, the identification of which is supported by the PESTEL methodology.

4. PESTEL methodology

4.1. A brief overview of the PESTEL methodology

The PESTEL methodology is an analytical platform used to assess the external environment of a company facing a development decision. The internal elements that define the current state of the company are also important. It involves implementing or assessing what follows after the product or process implementation. Multifactor analysis pertains to the evaluation of political, economic, social, technological, environmental and legal factors – hence the acronym of the PESTEL methodology [3, 12, 44].

4.2. Political factor (P)

In general terms, the analysis of the political factor means assessing numerous elements, among which the most commonly considered are political stability, labour law, tax regulations, trade regulations, and international relations.

Political stability is the result of the configuration of political parties and the associated division and balance between legislative, executive, and judicial powers. Depending on the country, this system is clearly defined and sometimes very blurred. Political stability is largely defined by tax policy, which determines tax rates and directly impacts a company's profitability. Any changes in tax rates, as well as the introduction of new charges, often without prior notice, affect financial strategies, which are vital in the development of a company.

It is widely emphasized that the human factor is paramount, and therefore concern for human rights is essential. Political factors are expressed in regulations concerning working conditions with particular emphasis on safety and minimum wages, forms of employment contracts, etc., which directly affect operating costs and human resource management strategies.

In political considerations, it is impossible to overlook international relations, which are an external factor. For a business, trade agreements, import and export regulations, as well as sanctions and embargoes, play a significant role. Often, international factors have a greater impact on a company's strategy than internal relations, as they shape the policy of competitiveness conditions and the availability of goods on the international market.

4.3. Economic factor (E)

Economics is a social science that focuses on the production, distribution, and consumption of goods and services. Economic factors therefore include the economic conditions that impact business operations. The analysis considers various factors: interest rates, inflation, GDP, exchange rates, and unemployment levels. Knowledge of these factors is important and ensures the development of the company's financial strategy. This also implies that the transparency of government support for an enterprise, process, or individual product is partly political in nature. With a general understanding, and in some cases a very detailed insight into the national and international economy, the government can make decisions regarding credit policy, subsidies, and stimulate innovation and economic growth, for instance, by supporting research activities.

4.4. Social factor (S)

Sociology is a science that deals with the functioning and changes that occur in society. It can be understood both globally and locally. Sociological factors include demographic indicators, the lifestyle of social groups, and the behaviours and preferences of consumers, which can be constant or variable. It is impossible to overlook the assessment of the level of education and cultural behaviours. Analysing these factors helps companies adapt their products and services, as well as create marketing channels that align with customer needs and expectations.

4.5. Technical factor (T)

This factor should be considered through the lens of research and development in the field of technology. The ability to implement new products or processes, that is, to introduce innovations to the market, plays an important role. Market recognition and assessment of one's capabilities, both in terms of human potential and infrastructure, as well as the analysis of technology adoption speed, create opportunities for technique optimisation at various levels of advancement.

4.6. Ecological factor (E)

This element of analysis refers to the assessment of the impact of a product, process, or enterprise on the natural environment and the regulation of trends related to environmental protection. It is therefore closely linked to the legal and political factors, and in many evaluations, laws, management, or regulations become dominant in this regard, whereas it should essentially be an indicator derived from the scientific discipline of environmental engineering. Therefore, it is not the substantive descriptions related to this factor, but environmental regulations that impact scientific and/or economic activities. In any case, at the stage of product development or process implementation, environmental law must be taken into account, because if not, then penalties and sanctions will appeal to the imagination. Ecological balance involves the need to assess so-called best practices related to waste minimisation, recycling, efficient resource utilisation, or renewable energy. This also builds the product's image, which translates to customer trust, but also leads to securing the company's business future.

4.7. Legislative factor (L)

The legislative factor indicates the legal framework that defines the functioning in a broadly understood environment. It may concern companies, individuals, and products, regulating various issues such as compliance with trade regulations, including business ethics. The legal element may also be interpreted with regard to intellectual property protection or setting the boundaries of privacy through the protection of personal data. The law establishes both the procedures and the consequences (punishments) for disregarding regulations. This factor undergoes frequent changes that paradoxically result from changes in other factors included in the PESTEL methodology.

5. Rightsizing technology according to selected car manufacturers

5.1. Rightsizing at Volkswagen

Similarly to other sectors of the economy and politics, the Volkswagen Group demonstrates consistent actions in the automotive field. VW, as one of the first companies (alongside Ford), began mass implementation of cylinder capacity change technology in combustion engines to meet exhaust gas and CO_2 emission standards. VW introduces new solutions for turbocharging and fuel direct injection under the commercial names TSI and TDI. The 1.8 dm^3 T and 1.4 dm^3 TSI engines, extending to 1.2 dm^3 TSI, became alternatives to the 2.8 dm^3 VR6 and 2.0 FSI engines. Rightsizing in Volkswagen's implementation is represented by the 1.5 dm^3 engine, which is a response to the 1.4 dm^3 unit, aimed at safely achieving performance indicators and improving reliability and operational refinement.

In the case of compression ignition engines, the 1.9 TDI engine was replaced by the rightsizing-oriented 1.6 TDI unit.

In terms of technology, evaluating the technical aspect of the PESEL methodology, Volkswagen Group is highly

advanced, and consequently, there are no obstacles in implementing the concept of rightsizing. Turbocharging, crucial for this technology, such as in the form of a twin-charger, significantly positively affects engine performance indicators at low and medium rpms.

The main implementation factors are the ecological aspect, with awareness of the positive impact on the natural environment, and the legal aspect, with penalties for non-compliance with Euro emission standards. Bearing in mind the illegal activities disclosed in 2015 regarding engine operation control, known as Dieselgate (EA189 engines in popular versions 1.2 TDI, 1.6 TDI, and 2.0 TDI [40, 63], VW focused development work on real, rather than fictitious, results with a range of mechanical design solutions (geometry changes, fluid and gas flows), not just software-electronics, although these are also used. The initial designs of turbocharging and variable valve timing were underdeveloped and led to negative associations [66], which impacted the company's prestige, making the political factor more significant. The technological factor returned to the game with the development and implementation of new solutions.

In 2018/2019, Volkswagen successfully carried out numerous design modifications within the scope of downsizing/rightsizing technology. The 0.9 dm^3 TSI unit was withdrawn due to being considered overly aggressive downsizing. The engine construction was enhanced with superior materials and the flow dynamics in the 1.2 dm^3 engine were improved. In the 1.5 dm^3 Evo engine, cylinder deactivation was introduced – a technique popular in American solutions, although based on different technical principles.

The VW Group is heading towards hybridisation and full electrification of its drive systems. In this first action, the role of the rightsizing technology with e-TSI (mild hybrid) engines is crucial, providing CO_2 emissions ranging from 21 to 115 g/km depending on the engine size [65].

Volkswagen is an automotive conglomerate that includes various car brands. The prestigious Bentley, which also features rightsizing technology, is among them. To meet environmental requirements (environmental factor), the "W" shape – W12 engine with a displacement of 6.0 dm^3 was replaced by a V6 engine with a displacement of 4.0 dm^3, equipped with twin-charger technology, which – along with other solutions, reduces CO_2 emissions from 300 to below 250 g/km. The unit is more than 100 kg lighter, which translates to lower fuel consumption. For affluent users of this brand (a sociological factor), the vehicle must have an eco-friendly unit. Additionally, driving comfort has been improved by improving the dynamics, which is a result of a more favourable external characteristic in areas of low engine speeds. The implementation of downsizing/rightsizing techniques has improved the company's prestige after Dieselgate, reflecting on the political assessment at both a local and international level.

The Volkswagen Group manufactures and exports units, including those with downsizing/rightsizing technology, to almost every country in the world, which makes geopolitics extremely significant in the group's development strategy, as sometimes different plans need to be considered, for example, between Europe and countries in Africa or South America.

In summary, it is important to note that Volkswagen is adopting downsizing/rightsizing technology mainly because of political reasons – the aspiration to become a world leader with a significant impact on international markets. Then, due to the ecological factor – pro-environmental awareness and the resulting need for climate protection and the economic factor, combined with the sociological factor – smaller engines mean lower operational costs, as well as production costs, with a very well-functioning technological factor due to years of experience and continuous investments in the R&D sector.

5.2. Rightsizing at Ford

One could argue that the idea of downsizing/rightsizing started at Ford with the introduction of environmentally friendly initiatives under the collective name EcoBoost. The cascade of displacement changes is indeed spectacular, starting from the 5.4 dm^3 V8 engine through various forms, down to the 0.999 dm^3 engine. EcoBoost is a collection of innovative technical solutions that include not only a change in displacement, but also fuel direct injection, turbocharging, and variable valve timing. In some units, such as 1.5 dm^3, with a 3-cylinder construction, cylinder deactivation has also been implemented. The use of lightweight aluminium alloys was a significant factor, undeniably improving both the thermal efficiency and the mass balance. The set of solutions that have been implemented allows for operation with lean mixtures, lowering fuel consumption, and thus reducing CO_2 emissions. In the PESTEL analysis, the technological factor for Ford appears evident due to the company's tradition and continuous investment in R&D. However, the most crucial criterion for implementing rightsizing technology is ecology and the legal factor, with potential penalties for exceeding emission standards. In the American environment, and not only there, the social factor gains importance, where operating costs, as well as insuring vehicles with lower engine displacements, play a significant role [6, 11]. For the numerous Ford factories scattered around the world, maintaining jobs and combating unemployment is also significant. Therefore, the sociological factor, along with the implementation of new technical solutions, becomes crucial. Ford is a leading global player in the automotive sector, and with the implementation of downsizing/rightsizing, the company's prestige has been maintained or even enhanced. Awards, such as multiple victories in the Engine of the Year competition [66], serve as proof of this.

Since 2021, Ford's vehicle propulsion development strategy has been moving towards hybridisation using units with altered displacement volumes. An example might be the F150 Powerboost Hybrid with a 3.5-litre twin-turbo engine and cylinder deactivation compared to the earlier V8 5.0 dm^3 (Coyote – which already used cylinder deactivation) and the later 3.7 dm^3 V6 engine.

To conclude, it is worth mentioning that the technical factor with EcoBoost technology has positioned the Ford brand in the group of the most aggressive downsizing in the A, B, and C automotive segments. This leadership is also

the result of political influences that elevate the company's prestige and sustain international markets.

5.3. Rightsizing at Toyota

Toyota, in its core strategy, successfully creates vehicles with drives in the mass segment. A glance at the sales statistics reveals that three models from this brand are among the top 10 best-selling cars globally, securing the 2nd, 3rd, and 8th positions [59]. The same applies to the Polish market [68].

Downsizing/rightsizing at Toyota occurred with consideration for the political factor, stemming from a unique position in the fleet market with low operating costs, as well as the technological factor due to a high level of reliability. By introducing 1.2 dm^3 turbo engines to replace the 2.0 D-4D, as well as 1.0 dm^3 VVT-i and 1.5 hybrid instead of 1.3 dm^3, the CO_2 emission level was effectively reduced to just 75 g/km. The technique of variable valve timing, encapsulated in the acronym VVT-i, has gained significant importance, ensuring an improvement in the filling coefficient [45].

An interesting technological solution is the TNGA system with the Miller/Atkinson cycle in 1.8 and 2.0 dm^3 Hybrid units. Higher thermodynamic efficiency was achieved with energy recovery and improved engine operating flexibility. This ensures more favourable ecological and economic indicators, which positively influence customer perception, positioning the sociological factor well in the implementation of rightsizing technology. Another example of downsizing is the 1.0 dm^3 engine, where the added value in the technological factor turned out to be the reduced weight, which translates to lower operating costs, and this is reflected in the social factor through user satisfaction.

Another example of Toyota's operations using downsizing/rightsizing technology is the niche model 0.6 dm^3, produced in collaboration with Daihatsu. These engines are used in the segment of so-called kei cars, which meet local regulations concerning engine displacement and vehicle dimensions. Smaller Toyota engines also respond to legal regulations and environmental conditions in the European and American markets.

In summary, when implementing downsizing/rightsizing technology by Toyota, it is important to highlight the significance of the following factors: political (the company's prestige in global markets, especially in the mass sector, and the purchasing support of the Japanese government for domestically produced cars), sociological (popularity among Japanese people), economic (low operating costs), ecological (conscious environmental responsibility with low CO_2 emissions), and technological (a range of innovative technical solutions quickly implemented to maintain the company's prestige and significant investments in the R&D sector – recently in alternative fuels involving ammonia and hydrogen within the Japan Petroleum and Carbon Neutral Fuels Energy Centre) [69].

5.4. Rightsizing at Mercedes-Benz

Mercedes-Benz, as a group (Mercedes, AMG, EQ and Maybach) with a recognised high standing in terms of reliability, quality, and luxury, approached the issue of downsizing/rightsizing primarily by considering two PESTEL factors: political and sociological. These actions have been supported by others and classified under legal and environmental factors. In this way, one can distinguish, for example, the development work on the modernisation of the V6 2.5 dm^3 unit and the creation of the downsized R4 2.0 dm^3 engine, powering, among others, the popular Mercedes E model. Another example of downsizing is the V8 engine with a displacement of 4.7 dm^3, with a biturbo charging technique, which was replaced by the R6 3.0 dm^3 unit with twin-scroll turbocharging, supporting a mild hybrid system to achieve the full effect of rightsizing.

Implementing modern turbocharging systems has become a marketing hallmark of downsizing technology as executed by Mercedes-Benz, which, together with improving the direct injection system, has reduced CO_2 emissions from 300 to 180 g/km or less [70].

In geopolitical considerations regarding the determinants of rightsizing in Mercedes-Benz vehicle drives, the local market with the so-called flagship user plays an important role. Mercedes-Benz customers often have their own cost policy known as TCO, where rightsizing is the answer to low operating and service costs, as well as emission costs of CO_2, in the overall context of a given institution. Mercedes-Benz follows such corporate strategies, but places greater emphasis on analysing the development of regional markets, particularly the Asian and American ones, where the so-called drive modularity plays a significant role. The economic aspect is crucial in China, as it is linked to high consumer expenses due to elevated tariffs and CO_2 emission taxes. Therefore, Mercedes-Benz launched the downsized 1.5 dm^3 engine equipped with ISG technology. On the other hand, the USA is prestigious for Mercedes-Benz. To a large extent, this market must be considered from the social factor perspective, arising from the habitual preference for so-called large capacities in big cars, which is in opposition to the ecological and legal factor, related to penalties for non-compliance with CO_2 emission standards. After all, it was in the USA, specifically in California, that numerous efforts to protect our climate began, alongside today's standards and various forecasts developed by CARB as well as CAFE which define fuel consumption and indirectly indicate CO_2 emissions. Environmental standards in the USA serve as guidelines for the developmental work of Mercedes-Benz. Some Americans accepted the mentioned switch from a V8 engine to an R4, but Mercedes-Benz went further and developed EQ Boost hybrid units, observing the work of competitors such as Ford and Toyota and sales results in the USA [71].

The transition (although not completely) from the almost flagship V6 and V8 units to inline engines, reinforced by a range of technical systems to maintain performance levels, has also been expressed in the prestigious S-class models, where the environmental awareness of users is significantly higher than the others. This therefore has a sociological dimension in the PESTEL framework.

In summary, following a broad assessment of the political factor regarding the continued prevalence of internal combustion propulsion as a still significant source of vehicle drive, Mercedes-Benz in 2024 altered its seemingly rigid “electric first” declaration in favour of developing

hybrid designs incorporating internal combustion engines within the rightsizing concept [72].

6. Geopolitical conditions of rightsizing in selected regions of the world

6.1. Rightsizing in Europe

The implementation of the downsizing/rightsizing concept in Europe is primarily associated with the Volkswagen Group (chapter 4.1), whose power units are found in vehicle brands forming the group such as VW, Audi, Skoda or Seat. Dominant factors are ecology and law. The same applies to other companies: Peugeot, Citroen, Opel, and Fiat, which formed the Stellantis group, possessing their own technologies and having a significant place in the history of automotive development. The Stellantis group also includes American companies: Chrysler, Dodge, Jeep, which strongly contribute to the development strategy with a social factor. The development package includes modifications such as 1.6 or 1.8 dm^3 units to 1.2 or 1.0 dm^3 units in Opel or Peugeot models. The effect is a reduction in CO_2 emissions from 160 to approximately 120 g/km.

Rapid implementation of certain technical solutions, along with downsizing such as the wet timing belt and insufficient lubricant flow, caused the 1.2 dm^3 Pure Tech engine to earn a very poor reputation due to numerous damages and failures. The prestige of the Peugeot company has been severely damaged. Hence, the significant effort and creation of the 1.2 PureTech GEN3 model in a hybrid solution, thereby enhancing the technical factor. Additionally, to improve the company's image, the sociological factor was altered by extending the warranty period from 6 to 10 years.

In turn, Renault has focused its attention on underdeveloped countries located in Africa, Asia or South America, where it is possible to "bypass" restrictive legal regulations and maintain existing product technology, thus surviving in the market, which proved to be effective during the COVID-19 coronavirus pandemic. In this way, the high labour costs (an economic and sociological factor) have also been transferred from Europe to Turkey and Morocco. This move aligns with the framework of so-called “bad bank structures,” which are used to survive difficult times and avoid the risk of company collapse [73]. The second development path for the Renault company, including downsizing/rightsizing products, is a venture carried out jointly with the Chinese company Geely as Geely Horse Powertrain Ltd [75]. Among the products, there are ultra-low emission CO_2 engines as standalone power units: 1.0 dm^3 TCe and 1.2 dm^3 TCe as well as used in hybrid systems: 1.2 E-Tech full hybrid. They are sold, among others, to Africa and Asia – India [74]. The Stellantis group adopts a similar practice [76]. This indicates that when evaluating downsizing/rightsizing technology from both an economic and partly political standpoint, the entire approach can only be seen as temporary rather than permanent. The sociological factor, in turn, has a positive dimension through the reduction of unemployment and the creation of new jobs – although only a few of these concern Europe, such as Spain and Romania.

Europe, having faced several fuel crises, clearly emphasises the economic factor in numerous development strategies, taking fuel prices into account. Investments in research on alternative fuels for combustion engines, such as historically LPG or CNG, but also currently ammonia and hydrogen, play a crucial role, as these, combined with downsizing techniques, contribute to meeting European emission standards. An example might be the Fiat 0.9 dm^3 TwinAir (Multi-AIR) CNG engine, which has been awarded multiple times in the Engine of the Year competition [68]. The presented unit is a twin-cylinder with a JTS injection system, dual spark plug, and an innovative timing system ensuring combustion of mixtures close to stoichiometric. In practical engineering terms, this leads to about 10% decrease in fuel usage. Such aggressive downsizing requires strong support from other systems, like the SCR system for nitrogen oxides reduction and the GPF – particulate filter. This all results in increased operating costs, which affects user enthusiasm and is reflected in sociological factors.

In summary, it can be noted that in Europe, the main factors determining the implementation of downsizing/rightsizing technologies are environmental, legal, and economic regulations. The economic factor has a clear dimension in tax and insurance reliefs, which additionally introduces a sociological factor into effect – the client's choice.

6.2. Rightsizing in the USA

The automotive industry in the USA, with giants such as GMC, Ford, Chevrolet, and Cadillac, plays a crucial role in implementing numerous technological innovations. History places American automotive companies at the top podium in terms of technology. Hence, the technical factor did not raise any doubts during the implementation of downsizing/rightsizing technologies, especially considering that cylinder deactivation – classified as downsizing technology – was first introduced in the Cadillac V8 as early as the 1980s [77]. Ecology is the main driving force behind the implementation of the rightsizing concept. The government agency EPA, as well as the Californian state environmental body CARB, and CAFE regulations have a significant potential to influence environmental awareness and shape the foundations of automotive development. American standards (Californian) are considered the strictest in the world – Table 1.

Table 1. Sample exhaust gas emission standards in different regions around the world

Region	Current standard	Sample emission values, g/km			CO_2 emissions	Test
		CO	NO_x	PM		
USA	Tier 3	0.62	0.018	0.0019	82.5 – activities CAFE from 2026	FTP-75 and US06
Europe	Euro 6(d)	1.00	0.060	0.0050	93.5 for the fleet	RDE
Asia – China	China VI B	1.00	0.035	0.0045	93.6	RDE

The ecological factor in the USA is clearly intertwined with the sociological factor, expressed by the growing

awareness of car users towards climate protection. The full support of the state for maintaining the prestige of American companies, including automotive ones, is not without significance, as evidenced by the significant dedicated resources and subsequent federal takeover of GM and the creation of GMC. For Americans, the economy is also of significant importance and it may even parallel ecology in the development of the automotive industry, as customers demand low-cost operation of their vehicles. Although inexpensive operation primarily means cheap fuel, design solutions that ensure lower fuel consumption are also taken into account. Fuel for combustion engines comes from various sources, which the USA strongly seeks, sometimes involving itself in armed conflicts over oil and gas deposits. Energy security of a country and region is an important development factor, represented by both political and sociological dimensions [32].

In summary, the USA acts as a distinctive catalyst for innovation in the field of downsizing/rightsizing technology, demonstrated by the increase in the market share of engines with a capacity below 3.0 dm^3 from around 30% in 2000 to approximately 59% in 2020 [19]. Nevertheless, in the context of strong lobbying for electromobility, the idea of rightsizing combustion engines is seen as a transitional phase.

6.3. Rightsizing in Asia-China

For 20 years, the automotive market in China has been one of the most rapidly developing markets in the world. The most important factor in development is the broadly understood "policy" that defines the local market, Asian markets, and influences the strategic decisions of other producers on a global scale. China strongly influences legal and economic regulations, as well as consumer preferences, reinforcing the position of the sociological factor. For Chinese, the overall national strategy "Made in China: New Energy Vehicles" is important [31, 78]. Actions for environmental protection are included in the country's development strategy and in individual sectors. However, they are selective and do not consider the entire product life cycle. Hence, for example, the fight against low emissions from transportation means while simultaneously having high emissions at the stage of automotive component production [7, 8]. China, with government support, has ensured technological development by providing education at various levels, establishing an international grant system, and building dedicated research and development centres. This brings tangible results, as well as downsizing/rightsizing technology. Implementing the idea of rightsizing involves discussions on the country's prestige and technological dominance in the world, as well as fiscal policy. It should be emphasized that in China, the market for manufacturers of cars with internal combustion engines is made up of well-known global brands such as Toyota, Mercedes-Benz Group, BMW and VW [79].

Chinese manufacturers such as BYD, Geely, and Great Wall focus primarily on an electric strategy for vehicles [76]. Similarly, it is the case with corporations like BAIC Motor or SAIC, although they are supported by global companies – Mercedes-Benz in the former case, and VW and GM in the latter. The implementation of downsizing/rightsizing technology in China is influenced by financial and sociological factors due to taxes (such as the Consumption Tax as well as Vehicle and Vessel Tax Law), which are heavily dependent on engine displacement. In the range from 1% for units below 1.0 dm^3 to 40% – above 3.0 dm^3 [12, 31, 48]. Naturally, these two extreme scenarios are not compatible with each other regarding performance indices and technically cannot be aligned, yet the tax system significantly impacts customer choices, shaping production policy as a result. The current exhaust emission standard in China, China VI B (Table 1) practically eliminated large displacement internal combustion engines in favour of smaller turbocharged units, supported by aftertreatment systems such as SCR. The Chinese customer expects a prestigious car today with low operating costs – hence various responses from the external market such as the Mercedes E (1.5 dm^3 R4 Turbo – EQ Boost). In the popular car segment, Toyota (1.5 dm^3 R3 Hybrid) or VW (1.4 dm^3 TSI).

It is worth noting the production of combustion engines beyond the automotive sphere, i.e., for power generators. This is an important production sector due to the highly diverse energy infrastructure in China and the need for power in areas lacking transmission lines or due to power instability [80]. The engines are intended for stationary devices, and in this case, no one has attempted to implement the downsizing/rightsizing concept, unlike mobile units, which are designed not only with environmental protection in mind, but also with weight reduction in mind. In this case, technical and sociological factors play an important role.

In fulfilling the "Made in China" strategy, the Chinese aim to also dominate the shipbuilding industry, accounting for 50% of the global order book [81]. In this context, the technology of downsizing/rightsizing internal combustion engines, which remain a primary source of propulsion, gains significant importance. There are three reasons. The first, mentioned above, is political in nature, stemming from Chinese pride and the nation's prestige. The second is an ecological factor due to the movement of ships across different zones, where international IMO standards apply, especially concerning NO_x emissions and the sulphur content in fuel [82]. There are also local standards like DECA, concerning the emissions of harmful substances, sulphur content in fuel, and noise levels in ports, along the coast, and rivers, where combustion engines are also used. Environmental factors have led to the implementation of downsizing technology, primarily in hybrid systems and additionally using LNG or ammonia as secondary or primary fuel. This is the case in companies such as CSSC Guangzhou Marine Diesel Engine Co., Ltd. or the R&D CSSC Power Research Institute, although many do not consider it 'classic' downsizing, but rather actions aimed at environmental protection in models with smaller engine displacement. Research and domestic production have led China to take steps towards independence from major players in the field of marine propulsion technology like MAN or Wartsila, thereby making the political factor the third reason for the changes being made. Currently, there is full cooperation between the Chinese industry and foreign companies, such

as the MAN-B&W 11G95ME-C engine, which was replaced with the 8G90ME-C10.5 model with a reduced number of cylinders and, although with limited power, completely sufficient to drive container ships – a classic example of rightsizing.

China produces many engines for external markets, specifically for countries with a similar economic structure, where the economic factor plays a significant role, focusing on operating costs, service, and low taxes, as well as small insurance premiums, much like other Asian and African countries.

In China, there is another important area that concerns vehicles and their propulsion systems – the issue of military solutions. It is classified as a political factor. In the military, emissions and fuel consumption standards do not apply, so ecological and economic factors are irrelevant. However, the equipment must be reliable and easy to service. Downsizing/rightsizing technology does not favour such criteria, but if one considers the drive mass and the widespread (not only in China) miniaturisation of military vehicle platforms to reduce the target area for enemy missiles, downsizing should be considered. Thus, the miniaturisation and reliability demonstrated by the creation of twin systems with hybrid configurations are an intriguing solution, such as the Mengshi EREV (Range Extender), where a 1.5 dm^3 turbo engine is used as a generator to charge the main electric drive motors, or the ISDe 200-41 Cummins 6.7 dm^3 engines, which replaced the L-series units with a volume of 8.9 dm^3, but through turbocharging (HPCR system) along with electronic control, comparable performance indicators were achieved.

In summary, the deployment of downsizing/rightsizing technology in China ensures:

- industrial sovereignty, expressed as a political factor
- impact on global markets – political factor
- reduction of harmful substance emissions – factors: technical, ecological, and legal
- reduction of fuel consumption – factors: economic and sociological
- social prestige – a sociological factor.

6.4. Rightsizing in Asia–India

India is a country classified as part of the developing nations, with the largest population and the highest birth rate. This means that the transportation needs for people and goods in India are increasing exponentially from 4.25×10^{12} in 2005 to nearly 25×10^{12} in 2025, and if the current pace is maintained, the passenger-kilometre (PKM) ratio could reach an astronomical value of 588×10^{12} [83].

All PESTEL factors in the automotive sector, and downsizing in particular, gained significant importance after 2000, when the first emission standards known as BS-I (Bharat Stage) based on European standards were introduced – hence the economic factor [84]. In the history of these actions taken by the government of India, the omission of the BS-V standard and the introduction of BS-VI – the equivalent of the Euro 6 standard, but not only in large cities, rather across the entire country (political and sociological factor) was spectacular. The current standard requires the use of higher quality fuels (lower sulphur content of 10 ppm instead of 50 ppm) and advanced exhaust purification systems – an ecological factor. The ecological factor is not widely recognised and is considered a necessary evil, particularly in the context of the use of older vehicles, which stems from the poverty of the population. The government announced a programme to revitalise transportation resources, thus introducing a strong political and legislative factor. The concept of rightsizing fits well into this scenario, especially because the dominant modes of transport in India are two- and three-wheeled vehicles, which require small power units. Engines with a capacity of 0.8 to 1.2 cubic decimetres are very popular and should be improved by adding support systems to reduce fuel consumption and emissions. An example might be the Maruti Suzuki 1.2 dm^3 engine modified with turbocharging, fuel direct injection, and reduced displacement to 0.998 dm^3, known as Boosterjet [85].

A similar action was taken by the local car manufacturer Tata by changing the 1.5 dm^3 engine to a 1.2 dm^3 GDI or a 1.2 dm^3 powered by natural gas CNG. Ever stricter emission standards are eliminating compression ignition engines and replacing them with petrol engines featuring new modification packages, including downsizing. The ecological factor combined with the sociological one can be observed in the attitude of the new generation of Indians, who are better educated than their parents, taking into account pro-environmental actions, which is expressed both in government initiatives and in the lives of ordinary citizens. Another factor influencing the implementation of downsizing/rightsizing technology is taxation – a smaller engine displacement means a lower tax. Therefore, the sociological and economic factors are taken into account. In summary, India is tracking innovative solutions in foreign markets, striving to achieve a higher level of technological independence similar to that of China. The downsizing/rightsizing of the combustion engine primarily stems from economic factors combined with social and ecological reception, in conjunction with government policy on lower taxes.

6.5. Rightsizing in South America

In terms of the implementation of automotive and new technology, South America is mainly based on four factors: political, economic, sociological, and technical. Emission standards for exhaust gases are less stringent than in Europe and the USA and apply to a wide range of engines primarily powered by ethanol. The use of this biofuel was not and is not driven by environmental concerns, but rather by economic reasons and regional policy, from which arose the desire to develop agricultural regions and reduce unemployment [86]. Unfortunately, on this path, there was a loss leading to environmental degradation due to monoculture cultivation, primarily of sugarcane and corn used as a base for alcohol production. In addition, Brazil, for example, applies the highest amount of agricultural chemicals globally, improving crop yields but adversely affecting groundwater, rivers, and air quality. In such conditions, the sociological factor expressed through the work for farmers is positive, but the overall balance is diminished due to poorer financial results, i.e., the economic factor which takes into account the reduction in soil quality, leading to lower yields. Nevertheless, South America is focusing on biofuels, seeing it as an eco-friendly initiative [86].

In South America, there are no legal penalties for non-compliance with emission standards, or at least no one enforces them, which means there are no incentives to implement new technologies such as rightsizing. What is important, however, is the low costs of purchasing, operating, and servicing vehicles. In South America, small units prevail, which is why it serves as a good research ground for companies like VW and Stellantis.

Additionally, by placing factories on this continent, unemployment is reduced and such actions are supported by the governments of individual countries offering various tax reliefs to manufacturers. Therefore, an essential factor in endorsing the concept of downsizing/rightsizing is political and social influence. An example is the Rota 2030 programme in Brazil [87]. Fiats equipped with 1.0 dm^3 FireFly engines (either turbocharged or mHEV in a hybrid setup), VW 1.0 dm^3 TSI with BlueMotion technology, or Chevrolet 1.0 dm^3 16V M-TEC II, are driven on South American roads.

In summary, South America is receptive to adopting downsizing/rightsizing technology, but it carries this out with the participation of international firms, heavily influenced by economic and political factors.

6.6. Rightsizing in Africa

Having a general understanding of the political, economic, and social structures, as well as the climate in Africa, it is clear that the continent views automotive issues quite differently compared to Europe or the USA, and even more so when it comes to implementing new technologies. However, when considering the development of the automotive industry, it should be viewed through the lens of economics, with high car costs and low fuel prices, as well as through the sociological factor (unemployment, low levels of education) [88].

Automotive giants dominate Africa, and they set the tone for all changes. Africa itself is not interested in implementing eco-friendly technologies, given the general economic difficulties. Small vehicles dominate the roads in Africa, not necessarily because of downsizing, but due to the economic situation. The most popular brands with small engines in the range of 1.3 to 1.5 dm^3 belong to companies such as Toyota, VW, Nissan or Renault [89]. Only in slightly more developed countries such as South Africa, Egypt, or Morocco, social factors related to the awareness of unemployment and policies determining the location of factories and services are beginning to play a role in the choice of vehicle types. In addition, there is some pressure (not much, but still) from tourists who, when arriving in Africa, are environmentally conscious and would like to travel in vehicles that meet emission standards. This is a factor at the boundary of sociology and ecology. The lack of definitive research on the automotive industry in Africa means that analysts rely solely on estimated data, indicating that more than 60% of cars and their engines in Africa are old machines and are used until they reach technical failure, with little or no service support [2]. This creates a major challenge in terms of modernising these units (retrofit) with the implementation of downsizing/rightsizing technology. This must be a systemic action that takes into account a whole range of other activities, such as the development of education to improve the overall technical culture. This strategy has potential given the global preference for electromobility, due to the severely limited availability of electricity, even when using solar sources in Africa.

In summary, the development of the automotive industry in Africa should be viewed through the lens of the growth of foreign companies. Small power units that serve as the driving force for numerous cars are the result of economic measures and have nothing to do with the development of downsizing/rightsizing technology, which contrary to appearances, is very demanding.

7. Conclusions

The entire world is declaratively moving towards climate neutrality, which in the case of transportation means stricter emission standards for harmful substances and carbon dioxide, as well as setting deadlines for the sale of new combustion engine vehicles. In this area of activity, there is a collision between the challenges faced by manufacturers and the expectations of vehicle users, referred to as sustainable transport, all within a specific geo-environment.

Although electromobility is named the future of automotive innovation, its role in climate protection is questionable when considering the full lifecycle of products and processes. This ensures that the world will continue to recognise combustion engines as an important source of vehicle propulsion, which in turn means maintaining the continuity of work on improving the design and technology of this heat machine. One of the development trends that should be considered is engine downsizing, which was introduced into engineering practice more than 15 years ago. Today, it operates in the form of rightsizing and, depending on geopolitical conditions, may occur independently or in conjunction with hybrid systems.

This study evaluates the current status and development potential of downsizing/rightsizing combustion engines, viewed through the PESTEL methodological framework, with examples from selected manufacturers across different global regions.

The analysis of individual factors and their elements among the automotive manufacturers evaluated above showed that downsizing/rightsizing is considered by all, namely VW, Ford, Toyota, and Mercedes-Benz, but to varying degrees. For every company, prestige is important: a political factor. Each of these companies wants or needs to include all technological trends in their offerings, and therefore downsizing/rightsizing, which leads to improved drive efficiency. It is important to maintain a strong position in both the local market and international relations and potentially shape this market.

The political factor is consistent with the economic and social, where people with their purchasing preferences predominate, influencing consumption. The contribution of these factors varies between individual companies. VW, Ford, and Toyota are heavily reliant on the economical vehicle operation formula provided by downsizing /rightsizing, making the development of this technology more significant than for Mercedes-Benz. The evaluation of a vehicle user's education with a certain level of technical culture and thus the awareness of what downsizing /rightsizing technology involves (a technical factor) is im-

portant for VW and Ford customers, but is less significant or not at all important for Toyota and Mercedes-Benz customers.

Evaluating the technical factor and the ecological awareness of manufacturers, each of the analysed companies has a high level of development and invests in the R&D sector, which is most evident during successive automotive trade fairs, where solutions related to combustion engines are presented, and rightsizing is included in each of these solutions.

All evaluated manufacturers consider the legislative factor, and VW pays the most attention to it, especially after the Dieselgate scandal, which instilled a particular respect for legal frameworks and the penalties associated with them. Each of these companies protects its intellectual property, which is expressed, for instance, through marketing names such as VW – TSI or TFSI, Ford – EcoBoost, with information on engine displacement. Mercedes-Benz incorporates downsizing in the EQ Boost hybrid unit, while Toyota does not use a trade name, considering downsizing/rightsizing as part of the overall development strategy for combustion engines.

The analysis of geopolitical conditions for downsizing /rightsizing technology in different regions of the world highlights the importance of political stability and tax regulations, as well as the significance of international relations for the development of this trend in Europe, the USA and China.

The political factor of the government practically does not influence the development of downsizing/rightsizing technology in South America and Africa, where car manufacturers already present in the market play a leading role in this respect. In India, international relations are important because this market is one of the fastest growing in the automotive sector, but is highly dependent on user preferences, where purchase and running costs play a significant role.

The social factor, considering demographics, education, and lifestyle, is very strong in Africa compared to other PESTEL factors, where, for example, awareness of climate protection, legal frameworks, or intellectual property protection related to new technologies are not considered at all or only to a minimal extent.

A significant factor for Africa, as well as South America and parts of Asia, is the combined political and social element related to unemployment. Relocating factories to these regions not only provides social support but also offers the opportunity for the gradual implementation of new technologies due to customer preferences for low-cost operation, which downsizing/rightsizing ensures. However, these must be driven by a lower level of technological advancement, particularly in relation to variable valve timing systems or complex turbocharging systems, which is due to the low level of service or the lack of infrastructure in this area. However, this is a significant area for development, especially in the context of modernising old units that are being imported in large quantities from Europe and the USA.

This analysis does not claim to be the definitive interpretation of the material; on the contrary, it is expected to spark a wide-ranging discussion, and the Author himself promises a more in-depth evaluation.

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Nomenclature

A, B	change coefficients in downsizing
CAFE	Corporate Average Fuel Economy,
CARB	California Air Resources Board
CNG	compressed natural gas
C-TEC	engine code
D	cylinder diameter – initial stat
D_d	the cylinder diameter in an engine after downsizing
DECA	China Domestic Emission Control Area
EcoBoost	Ford's brand name for gasoline engines
EPA	Environmental Protection Agency
FSI	fuel stratified injection
GDI	gasoline direct injection
GDP	gross domestic product
HPCR	high-pressure common rail
IMO	International Maritime Organization
ISG	integrated starter generator
i-VTEC	intelligent system VTEC operating proactively
LPG	liquefied petroleum gas
PESTEL	methodology due to Political, Economic, Social, Technological, Environmental and Legal factors
PKM	passenger-kilometre
PureTech	Stellantis's (formerly Peugeot and Citroen) brand name for gasoline engines
R&D	research and development
S	piston stroke – initial state
S_d	piston stroke in an engine after downsizing
SCR	selective catalytic reduction
SVC	Saab Variable Compression
TCO	total cost of ownership
TDI	turbocharged direct injection
Ti-VCT	twin independent variable camshaft timing
TNGA	Toyota New Global Architecture
TSI	turbocharged stratified injection
VCR	variable compression ratio
VNT	variable nozzle turbine
VTEC	variable valve timing and lift electronic control
VVT-i	variable valve timing with intelligence
W_d	downsizing index

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