Electric Cars in Brazil

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Brazil has been successful to reduce its carbon footprint using biofuels, but it is facing a dilemma in vehicle electrification. It cannot shift abruptly to battery electric vehicles, as current consumers are unable to afford them and investment in recharging infrastructure is uncertain. However, it has a significant manufacturing base, and it cannot isolate itself from global industrial trends. The emergence of a dominant design (set of core technologies defining a product category and adopted by the majority of players in the market) in small and affordable segments is essential for the diffusion of electric cars in developing countries. Biofuel hybrid technologies may support the transition. The Brazilian industry can engage in electric vehicle development by designing small cars based on global architectures, targeting consumers in emerging markets.

Keywords: electric car ; technology transition ; dominant design ; vehicle electrification

1. Decarbonization of Light Vehicles in Brazil

Brazil has a successful history of using biofuels in transport. The 1973 Oil Crisis motivated the creation of the National Alcohol Program (Proalcool), establishing ethanol as an alternative to oil-derived fuels. The program contributed to reducing air pollution by replacing lead as an anti-knocking agent and reducing carbon monoxide and hydrocarbon emissions [1]. Biofuels are considered carbon-neutral on exhaust emissions as the emitted CO_2 has been previously captured from the atmosphere by photosynthesis. However, there are greenhouse gas emissions in fuel production and transportation. The first Brazilian ethanol-powered automobile was launched in 1979.

Automotive gasoline in Brazil is a blend of 27.5% anhydrous ethanol (E27). Ethanol for vehicles (E100) contains up to 4.5% of water. Flex fuel engines can run on any mixture between E27 and E100. There are about 44 million active light vehicles in the domestic fleet and 74% of them are flex fuel [2]. It is estimated that 70% of flex fuel vehicles run on gasoline. Ethanol consumption is influenced mainly by the ethanol to gasoline price ratio. Ethanol prices are affected by weather, government policies, international sugar prices, crude oil prices, and transport costs [3].

Out of 1.98 million new light vehicles registered in 2021 (79% passenger cars and 21% light commercial vehicles), 84% were fitted with flex fuel engines, 3% with gasoline engines, and 13% were diesel-powered [2]. Only 2,851 electric cars were sold in 2021, just 0.14% of light vehicle sales [4]. In 2020, 85% of electric power in Brazil was generated from renewable sources, led by hydropower 63.8%, followed by wind generation 9.2%, biomass 9.0%, and solar energy 1.7% [5].

The Vehicle Emissions Control Program (PROCONVE) started in 1986, and it progressively reduces new vehicle emission targets [6]. Although it sets targets for carbon monoxide, nitrogen oxides, hydrocarbons, soot, aldehydes, and sulfur oxides, it does not establish CO_2 limits directly. New phases in 2022 and 2025 will introduce progressively more stringent limits on non-methane organic gas and nitrogen oxides, both ground level ozone forming substances [1][7]. Although there is no current legislation explicitly mentioning vehicle electrification as a route to energy efficiency and decarbonization in Brazil [6], the PROCONVE requirements will demand improvements in current engine technology and possibly an increase in the share of electrified vehicles [1].

Vehicle electrification is the transition from pure internal combustion engine vehicles (ICEVs) to full battery electric vehicles (BEVs), often with intermediate stages of electric hybridization—the combination of combustion engines and electric motors [8][9][10]. Electrification is inevitable for carbon neutrality in transport [1][8][9][10][11]. Besides climate damage, sticking to carbon fuels would isolate a country from the global industry, which would seriously affect its competitiveness and access to technology [8][9][12][13]. However, Brazil is not ready to shift abruptly to pure battery electric vehicles, as most of its population would be unable to afford them, and the massive investment in infrastructure is beyond its current capacity [1][8][9][14][15].

2. Technology Evolution and Dominant Design

Green innovations are technologies and practices that improve the quality of human life and reduce the impact on the environment. They minimize the usage of energy and materials, as well as reducing pollutant emissions and waste [16]. Incremental innovation (continuous change) occurs along an existing technology path, while radical innovation (discontinuous change) is related to the emergence of a new technology [17]. A new technology path usually starts with an *innovation shock*, a rupture from the existing technology [18].

The emergence of a dominant design is a landmark in the transition of technology from the stage of radical innovation to incremental innovation [19]. A dominant design is a set of product features that defines a product category and is widely adopted by the industry as a de facto standard competitors must adhere to [16][17][20]. The phase prior to the dominant design is called the era of *ferment* and is characterized by discontinuous innovation, many competitors, intense experimentation, and high growth rates [19][21][22]. Electric cars are in the fermenting stage of industrial evolution [17].

A dominant design marks the transition from a focus on product innovation to process innovation [17]. Although the radical product innovation phase is over, there is an increase in incremental product variations. A key aspect of the emergence of a dominant design is the dramatic reduction in product costs [19][21]. The increase in production volumes accelerates learning, standardization, and modularization of components [22][23]. Prices fall and most potential consumers adopt the new product.

A systems view provides a better understanding of technology innovation and dominant designs [16][23]. Dominant designs emerge not at the product system level but first in components or subsystems [24]. When dominant designs in the set of central or core subsystems consolidate, a system dominant design emerges. Core components are those that affect the largest number of product characteristics or features, i.e., they have many connections [16][23]. Peripheral components, affect few characteristics and thus have fewer connections. The larger the number of connections in a product, the higher its complexity (i.e., it has many variables) [16].

Architecture is the way components of a system are connected and organized [24]. A dominant design is a family of designs with common and stable core subsystems and architecture [25]. However, dominant designs are unlikely to be present in all components (subsystems). Once the core components of a design are settled, development shifts to peripheral components. Core components become invariants that are not revisited in a new design [24][26], reducing the design space, and restricting variations to peripheral features [23]. A replacement of core components implies a change in the dominant design and new technology.

Adner and Kapoor [27][28] expanded the notion of technology evolution by adding the *ecosystems* dimension. Most technologies depend on complementary technologies to come to fruition, delivering value. An ecosystem is a community of multiple actors and activities aligned to create and deliver value to customers. It includes producers, suppliers, competitors, distributors, customers, and other stakeholders, and adds *complementors*, such as BEV recharging infrastructure, energy utilities, battery reutilization, and recycling firms [29].

Beyond products, competition happens among ecosystems. Substitution depends on the capacity of a new technology to overcome its challenges, and on the existing technology to keep improving [30][31][32]. In *creative destruction*, the new technology overcomes its challenges quickly and the old technology is unable to catch up, being rapidly superseded. The *illusion of resilience* happens when the existing technology is unable to evolve, but it lives a bit longer because the new technology struggles to solve its challenges. However, it is a matter of time before the old technology is disrupted.

When a new technology faces significant entry barriers and the incumbent technology still has room for significant improvement, substitution tends to be slow, with *robust resilience*. Battery electric vehicles in emerging countries are such a case. There are considerable barriers for the dissemination of battery vehicles, and internal combustion engine vehicles can still be improved. However, if the new technology surmounts its difficulties quickly but the incumbent also improves vigorously, replacement is gradual, in a period of *robust coexistence.* The relation between pure internal combustion engine vehicles and hybrid vehicles is akin to that situation. The need to create a new ecosystem for battery vehicles can generate considerable tension and resistance. Hybrids may bridge the gap using existing manufacturing and fuel infrastructure.

Electric vehicle technology depends on the development of batteries with enough energy storage and power delivery, vehicle design (electric motors, control systems, architecture), on recharging infrastructure, power supply from the grid, battery reutilization, and recycling. The competition is not only between technologies but between the ecosystems supporting internal combustion vehicles (manufacturers, oil industry, biofuels industry, suppliers, dealers) and electric vehicles (manufacturers, battery makers, charging firms, power suppliers, battery reuse, and recycling firms).

Those vehicles should be affordable but practical, comfortable, and safe for small family usage, including enough driving range for holiday trips. The significant cost reduction necessary to make battery electric vehicles accessible to current automobile buyers can only be achieved with the economies of scale that follow the emergence of a dominant design [24]. The transition to electric cars promises more efficient use of energy and materials in the automobile industry. As the industry moves from fuel intensive to materials and energy intensive [33][34], battery reutilization and recycling—still in the early stage and with no established standards and procedures—will also be a key element in the transition.

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