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WROCLAW UNIVERSITY OF ECONOMICS AND BUSINESS

GREEN INDUSTRIAL POLICY FOR THE ESTABLISHMENT AND DEVELOPMENT OF THE FUEL CELL ELECTRIC VEHICLE MARKET IN THE US STATE OF CALIFORNIA FROM THE PERSPECTIVE OF THE ECONOMICS OF SUSTAINABLE DEVELOPMENT

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Summary of the Doctoral Thesis in Economics and Finance

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Climate change mitigation and sustainable development require multidimensional socio-economic transformations, notably in the energy transition. This process involves quantitative and qualitative shifts in how energy is sourced, processed, and used across sectors to improve efficiency and meet climate objectives. As an example of a structural change, the energy transition can be, therefore, impacted by industrial policy. In this context, the economics of sustainable development, evolving from neoclassical economics, offers normative postulates for environmentally oriented industrial policymaking. This dissertation explores the economics of sustainable development, focusing on green industrial policy, which can be perceived as a contemporary paradigm in pro-environmental industrial policymaking. It investigates how this policy approach can be further developed considering those postulates, particularly in transitioning the transportation sector towards low-carbon energy carriers like clean hydrogen. The study emphasizes fuel cell electric vehicles (FCEVs), a promising alternative in transportation decarbonization, despite being a niche market compared to battery electric vehicles (BEVs) and plug-in hybrid electric vehicles (PHEVs). The dissertation examines California, which has pioneered green industrial policies for zero-emission vehicles, including FCEVs. California's vehicle emissions standards and policies, established based on the federal waiver, which granted this state a unique independence in enforcing more restrictive vehicle emission standards than in other states, had laid the foundation for the FCEV market development since 1990, when the first instruments were enacted. However, replicating California's efforts in FCEV market establishment and development poses challenges for less prosperous jurisdictions like other US states and countries, such as Poland. The dissertation aims to extract evidence-based observations from California's experience for these follower jurisdictions, considering their likely different resources and needs, particularly in light-duty passenger, bus, and truck segments.

Research problem and the scope of the research

Based on the abovementioned synthesis of the initial deliberations, the author developed the cognitive research problem, which can be formulated as a synthesized question - **How did selected green industrial policy instruments impact the establishment and development of the FCEV market in the US state of California from the perspective of the economics of sustainable development?** Therefore, to solve this research problem, this dissertation has a theoretical and empirical dimension – the theoretical dimension studies the relevance between the green industrial policy framework and the normative postulates of the economics of sustainable development. The empirical dimension investigates the impact of green industrial policy instruments on establishing and developing the FCEV market. The spatial (geographical) scope covers the US state of California. The time scope covers the period from 1990 until 2022. Lastly, the scope of the research in the context of research subjects includes two groups of California's FCEV market participants and four groups of market stakeholders. The structure of the research subjects includes the FCEV market participants on the supply and demand side, as well as the market stakeholders representing the academia, industrial organizations and associations, hydrogen suppliers, and, lastly, the state and federal governments that implement diverse industrial policy instruments.

The research objectives and research questions

The primary research objective of this dissertation is **to evaluate the impact of selected green industrial policy instruments on establishing and developing the FCEV market in the US state of California from 1990 to 2022 from the perspective of economics of sustainable development.** Achieving the dissertation's primary objective required the completion of four detailed research objectives (RO) that are presented and discussed in the four subsequent chapters of this dissertation, thereby reflecting its structure. Hence, this dissertation was developed to:

- **RO 1.** determine the relevance between the green industrial policy assumptions and the normative postulates of the economics of sustainable development;
- **RO 2.** determine the significance of FCEV market growth for the hydrogen economy development from the perspective of the normative postulates of the economics of sustainable development;
- **RO 3.** identify the green industrial policy instruments aimed at the establishment and development of the FCEV market in the US state of California from 1990 to 2022;
- **RO 4.** evaluate the impact of selected green industrial policy instruments on establishing and developing the FCEV market in the US state of California from 1990 to 2022.

As part of conceptual deliberations about this research problem, the author developed a set of research questions corresponding to individual research objectives (marked in the brackets).

RQ 1. What are the origins, problem domains, and normative postulates of the economics of sustainable development? **(RO1)**

RQ 2. How can industrial policy be implemented considering the normative postulates of the economics of sustainable development? **(RO1)**

RQ 3. How does the FCEV market's establishment and development contribute to developing a hydrogen economy? **(RO2)**

RQ 4. How does establishing and developing the FCEV market fit into the normative postulates of the economics of sustainable development? **(RO2)**

RQ 5. What green industrial policy instruments were implemented at the state and federal levels to establish and develop California's FCEV market between 1990 and 2022? **(RO3)**

RQ 6. How did the California's FCEV market structure evolve between 1990 and 2022? **(RO3)**

RQ 7. What stakeholders contributed to the establishment and development of the FCEV market in the state of California between 1990 and 2022? **(RO3)**

RQ 8. Why has the state of California been supporting FCEV market establishment and development, even though the other ZEVs, such as BEVs, have seen higher deployment numbers? **(RO4)**

RQ 9. Which selected green industrial policy instruments were the most effective in establishing and developing the FCEVs market in the state of California between 1990 and 2022? **(RO4)**

RQ 10. Looking back in the past on the design and implementation of the selected green industrial policy instruments, what could have been done differently to accelerate the establishment and development of the FCEV market in California? **(RO4)**

RQ 11. Should there be any future corrections in the assumptions, objectives, and design of the selected green industrial policy instruments implemented in the state of California for the further development of the FCEV market? **(RO4)**

RQ 12. What less-prosperous jurisdictions can learn from the experience of the state of California in establishing and developing the FCEV market? **(RO4)**

Research methods

The study utilized a mixed-method approach combining quantitative and qualitative research methods. Initially, based on a critical literature review, the author formulated the research problem. Next, a reductionist approach within a **method of analysis and logical construction** was employed to isolate and analyze the research problem's critical components. The author then used a holistic approach to synthesize the findings. The **case study** method was another essential method, utilizing secondary data from various sources supplemented by expert perspectives. This was supported by a **comparative method** for structured analysis of green industrial policy instruments in California's FCEV market. Additionally, a method for establishing cause-and-effect relationships was employed to establish and understand the impact of these instruments. The core method in the empirical study was a **diagnostic survey** conducted through structured interviews and questionnaires *via* the Computer-Assisted Web Interview (CAWI) mode. Participants were selected through

purposive sampling, ensuring representation from various groups involved in California's FCEV market. The data was analyzed using NVivo software. The study also included a **statistical method** to analyze primary data from surveys, focusing on the effectiveness of policy instruments in achieving the strategic objectives.

The structure of the dissertation

The dissertation is structured into four chapters, addressing detailed research objectives and questions. The first chapter demonstrates the relevance between the normative postulates of the economics of sustainable development and green industrial policy, exploring their evolution, foundational concepts, and the role of state intervention. Chapter two examines the FCEV market model, integrating the hydrogen economy and the economics of sustainable development, and analyzes the market's development barriers and structures. The third chapter focuses on California's FCEV market, scrutinizing its establishment, development, and the role of green industrial policy at the state and federal levels. The fourth chapter evaluates the impact and effectiveness of green industrial policy on California's FCEV market through empirical research. The dissertation concludes with a summary, research limitations, and future recommendations, supplemented by appendices related to the empirical study.

Summary of findings

The dissertation began by establishing a theoretical foundation, linking the assumptions of green industrial policy with the normative postulates of the economics of sustainable development. The first chapter provided a critical overview of the evolution and problem domains within this economic theory, a consequent evolution of neoclassical economics and environmental economics, paving the way for an informed discussion on policy implementation. It can be stated that green industrial policy became a new environmentally-oriented paradigm in industrial policymaking. Therefore, in the context of structural changes, green industrial policy is a multidimensional approach to tackling market failures beyond traditional market-based industrial policy instruments. It navigates complex uncertainties and long-term horizons in socio-economic systems, embracing innovative instruments like feed-in tariffs, emission trading systems, or tradable permits. The green industrial policy is instrumental in breaking path dependencies and carbon lock-in effects and fostering advanced low-carbon technologies that contribute to and shape energy transitions. Simultaneously, it challenges entrenched, environmentally harmful industries, promoting a structural horizontal shift through a strategic mix of incentives and disincentives. This comprehensive strategy is crucial in addressing stranded assets and reducing carbon emissions, positioning itself as an indispensable tool for guiding economies toward sustainable development. At the same time, the economics of sustainable development can provide a detailed analytical framework for further developing theoretical foundations and operationalizing the concept of sustainable development in economic sciences. However, the author identified discrepancies between the studied theory and the green industrial policy approach. In this context, it can be concluded that green industrial policy, while a significant component of sectoral strategies, is not a panacea for all challenges identified in the economics of sustainable development. It represents a focused approach, impacting specific

sectors or industries horizontally or sectorally. Nevertheless, it serves as a crucial framework for transitioning towards more sustainable industrial practices, aligning with the principles of this evolving theory. This is exemplified in applying green industrial policy in promoting hydrogen-powered fuel cell electric vehicles. Such a policy fits within the theoretical constructs and catalyzes a shift towards a hydrogen economy and a market for ZEVs, details of which were elaborated in subsequent chapters of this dissertation.

The investigation then transitioned to demonstrating a hydrogen economy concept that opened the second chapter. Hydrogen, as a secondary energy source with specific characteristics that pose numerous opportunities and risks, may soon become one of the dominant energy carriers. However, it requires a comprehensive value chain encompassing hydrogen production, transportation, storage, and final usage. In this context, the author demonstrated the significance of the FCEV market establishment and development in developing its value chain, broadened by emphasizing the synergy between market growth and normative postulates of the economics of sustainable development. Comparative analyses between FCEVs and other ZEVs underscored the unique potential of FCEVs in this domain by highlighting the more extended range, shorter refueling times, and higher operational efficiency of fleets where these vehicles are deployed (in contrast to the BEVs). At the same time, the author identified the main barriers to spurring FCEV market development, which he framed in a conceptualized FCEV deployment trilemma. As a response to the need to overcome the market development barriers, the green industrial policy approach is proposed and further elaborated based on the example of the US state of California.

In the third chapter, the study provided a detailed account of the green industrial policy instruments implemented in California both at the federal and state levels, with the consideration of the federal waiver that granted this state a unique independence in shaping its standards of the GHG emissions from transportation. The overview of the evolution of the green industrial policy approach in the context of policies for the FCEV market establishment and development provided a detailed analytical framework by identifying the main instruments and assumptions set out in 1990 – 2022 (with the consideration of the policy acts adopted between 1967 and 1990). The author also identified the four strategic policy objectives in this domain, which included the sustainable and low-cost supply of hydrogen fuel, developing accessible and reliable refueling infrastructure, as well as increasing FCEV market supply and demand. This policy analysis was followed by the FCEV market's structural evolution across three market segments – passenger FCEVs, fuel cell electric buses (FCEB), and fuel cell electric trucks (FCET). It highlighted the pivotal role of numerous OEMs, such as Toyota, Hyundai, Nikola Motor Company, Hyzon Motors, and New Flyer, as well as described the categories of individual, commercial, and institutional consumers. In addition, the author demonstrated the advancements of the hydrogen refueling infrastructure and identified the main FCEV market stakeholders, including academic and research entities, governmental and regulatory bodies, and industrial organizations and associations. This overview provided a piece of comprehensive information about the structure of this market, its evolutions, and its status at the end of 2022, which was marked as the end of the studied period.

Finally, the dissertation culminated in the fourth chapter, which demonstrated a detailed evaluation of the effectiveness and impact of selected state green industrial policy instruments on the FCEV market establishment and development. It offered critical insights into the successes, shortcomings, and potential improvements while extending observations and suggestions for other jurisdictions inspired by California's pioneering efforts. These insights were possible thanks to 46 structured interviews with selected FCEV market participants and stakeholders. First, the author identified the crucial role of the Low-Carbon Fuel Standard, which exemplifies a tradable CO_2 emission permit mechanism introduced to stimulate the reduction of GHG emissions from transportation fuels. Significantly, this mechanism, in the opinion of the interviewees, effectively increased the supply of clean hydrogen, thanks to offering additional LCFS credits in case of refueling stations that offer the high installed capacity of the hydrogen storage tanks (even though they do not sell enough fuel to sustain its operation on market basis). Secondly, the author identified the fundamental role of grants for constructing hydrogen refueling stations alongside an array of necessary regulations and safety standards and practically valuable tools, such as permitting guidebooks, consultations offices, and geospatial analytical tools, which can serve as a source of recommendations for setting the locations for future stations based on the existing shortages. Based on the interviewees' opinions, the author developed detailed suggestions of how the policy could have been implemented in the past and what should be done to improve its effectiveness. Based on this, the author developed general observations, which might be helpful for other jurisdictions considering introducing their likely different policy approaches to establishing and developing the FCEV market development.

Research limitations, implications, and recommendations

While contributing to the understanding of green industrial policy impact on the establishment and development of the FCEV market in California between 1990 and 2022, the study has **research limitations**, including its narrow scope, the emerging state of the economics of sustainable development theory, and a limited geographical and temporal range. It also acknowledges the complexity of the FCEV market and potential biases from the selected interview participants. The study has several **research implications**. Theoretically, it enhances understanding of the relevance between green industrial policy and the economics of sustainable development. Empirically, it provides insights into the hydrogen economy, documenting the evolution of the FCEV market development and policy impacts in California in the studied period. Methodologically, it employs a mixed-method approach and structured interviews, setting a precedent for further policy impact assessments. Future **research recommendations** include expanding the geographical scope, examining the transferability of California's green industrial policy model approach, conducting long-term studies, exploring consumer preferences and technological advancements, and analyzing the interdependencies between the FCEV market and the industries of complementary and substitutional goods. Conducting such further research could offer a more comprehensive understanding of the broader implications of green industrial policies beyond the demonstrated impact of these policies on the FCEV market in California.