

Magdalena Olczyk

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Gdańsk Tech Professor

Gdańsk University of Technology

Faculty of Management and Economics

email: Magdalena.Olczyk@zie.pg.gda.pl



Referee report on the doctoral thesis

**“THE DETERMINANTS OF THE RISE OF PV PROSUMERS IN
GERMANY FROM THE PERSPECTIVE OF TRANSACTION COST
ECONOMICS” written by Patrick Rausch**

submitted for the doctoral degree in the social field of science, in Economics and Finance
as the science discipline at University of Gdańsk

The subject of this review is the doctoral dissertation entitled "The determinants of the rise of PV prosumers in Germany from the perspective of transaction cost economics" written by M.Sc. Patrick Rausch under the supervision of Monika Bąk, Ph.D., D.Sc. Associate Professor and Michał Suchanek, Ph.D. D.Sc. Associate Professor (assistant supervisor). The review is to be used in the procedure for obtaining the Ph.D. degree of M.Sc. Patrick Rausch and it is requested by the Chairman of the Department Council of Economics and Finance at the University of Gdansk, referring to the resolution (no 39/22/RDEif) of the Faculty Council dated March 24, 2022

1. General opinion

The dissertation submitted for review is an interesting study of the debate in the field of energy economics and empirical research on macroeconomic determinants of investments in PVs. The dissertation written by Mr. Patrick Rausch, is a study that I assess positively. It is a work that demonstrates the author's competent orientation in designing and conducting quantitative research, analyzing data, and drawing conclusions. In addition, the research

problem addressed is very current and important for energy economics. In view of the above, I consider the Ph.D. student's research on the impact of macroeconomic variables on investments in photovoltaics in the German market to be justified and to have a contribution to the development of economics.

2. The significance of the research topics

Climate change and the ever-growing demand for energy are forcing us to find new ways to manage energy production, distribution and consumption. This energy transition is made possible, among other things, by the digitalisation, decentralisation and democratisation of the energy system. The energy system is already in transition from generation based on fossil fuels and large power plants to a flexible system based on renewable energy sources. Traditional transmission grids are being replaced by smart grids enabled by digitalization, which facilitates the bidirectional flow of information and energy. On the consumer side, smart energy metres, energy monitoring devices and applications, and renewable energy technologies such as solar PV and battery storage are enabling energy consumers to become prosumers. The EU and other key players have strongly promoted the idea that consumers will be the 'active hearts' of the energy system in the future, enabling a low-carbon transition through prosumption and flexible consumption. A low-carbon energy transition involves technologies and economic considerations, but it is equally important to understand the millions of citizens who will need to change their purchasing decisions, user practices, beliefs, cultural conventions and capabilities. This thesis, which focuses on exploring the role of macroeconomic factors in prosumers' decisions in the PV market, is a part of this extremely important research scope.

3. The structure & language

The reviewed dissertation has 273 pages including the appendices. The dissertation consists of six chapters. The structure of the dissertation follows the traditional structure (theory - method - empiricism - discussion and conclusions), although there is no separate chapter with methodology. The dissertation consists of a theoretical and an empirical part, although the proportions between the two parts are not respected. The purely theoretical part

(the first chapter) is only 27 pages long. A large part of the dissertation is strictly descriptive, but with very solid conclusions

In terms of language and form, the reviewed dissertation can be considered good. As in any study of this kind, one can find errors in the work presented by P. Rausch MA (e.g. a wrong tense, no article before a noun). However, my experience shows that such errors occur even in renowned publishing houses after two professional editorial and authorial corrections, so I do not think we should attach great importance to them. The PhD student has ensured that the reader always knows at which stage of the research process he is by recalling the research design at the beginning of each chapter. I think this approach is very accurate and increases the transparency of the thesis. I also appreciate the rich bibliography (340 bibliographic references) and 24 legal references

4. Detailed assessment of the dissertation content

The introduction of the reviewed dissertation contains all the essential elements, including the rationale for the choice of the topic of the dissertation, the methodological assumptions (objectives, research questions), and a description of the work structure as well as a research design. I like the division into parts, which makes the introduction easy to read. The dissertation does not define the one general goal. The author gives 7 central objectives, which makes it somewhat difficult to assess the achievement of all of them. The research questions are clear, i.e. the two main research questions and 6 sub-questions that focus on the specific topic and address important problems. The hypotheses have unfortunately not been formulated

Chapter 1 shows the relationship between classical and neoclassical theories and energy economics. The fundamentals of transaction cost theory (TCT) are also well described through the lens of new institutional economics. The weakest point in this chapter is 1.5 "Application of transaction cost theory in an empirical context", where the author actually tries to show how TCT can be used in a macroeconomic context. The analysis carried out leaves the reader unsatisfied as the results are based on a few selected articles. It was necessary to conduct author's own systematic review analysis based on WoS or Scopus databases and to use some bibliometric analyses (such as the citation network, term co-occurrence, main path analysis, and key path analysis) to try find the main link between TCT and

macroeconomic phenomena, i.e. most important papers, authors and the analyzed macroeconomic topics by TCT).

In Chapter 2, the author compares the three main renewable energy markets to identify best practices related to the expansion of renewable energy use, especially photovoltaics. The second chapter, which is 44 pages long, presents in great detail and thoughtfulness the characteristics of the German renewable energy market (market design, energy transition in the light of regular, political and empirical facts). The PhD student also describes the Chinese and Californian markets and points out other solutions that make the difference between these markets and the German market. The chapter ends with an interesting summary of the empirical material written by the author.

Chapter 3 shifts the focus of the thesis to prosumer concepts, photovoltaic systems and their development. The author begins with a definition of the prosumer in economic theory. This part (subchapter 3.1.1) is far too superficial. It would be quite useful to show how the term "energy prosumer" is defined/interpreted differently in the literature. I refer to the following concepts: (1) Producer - consumer who produces and consumes goods and services (Toffler, 1981; Ritzer and Jurgenson 2009), (2) Provider - consumer who provides resources for flexibility purposes (Kotilainen et al., 2019); (3) Professional-consumer who co-creates innovative solutions and acquires professional equipment (Kotler, 1986; Prahalad and Ramaswamy, 2004); (4) User-producer/user-consumer/user-legitimator, -mediator who produces, innovates, tests, advocates, or collaborates at various levels of sociotechnical change (Schot et al. 2016), (5) Energy citizens, user-citizens who advocate for change in the energy system (Kampman et al. 2016; Schot et al. 2016), and finally (6) Active consumers who produce, buy, sell, and participate in the flexibility of energy marketers (European Commission 2016). Later in the dissertation, the author presents the technical characteristics of PV systems in 3.1.2. I consider this point superfluous to achieve the main objectives of the dissertation. On the other hand, the next subchapter 3.2 "Prosumers market (solar PV) in Germany, where market size, the legal and financial aspects of German prosumers" is excellent and confirms author's profound knowledge of the German PV market.

In the following chapter 4, factors assumed to be related to governance structures and transactions and to influence PV investments are presented in order to build an econometric model in chapter 5. In my opinion, this is the weakest part of the thesis. There are dozens of social, economic and political indicators in the literature for which data are available at the regional level (provinces) that can be considered for a quantitative study. There is definitely a

lack of a very detailed overview of previous empirical analyses that confirms the legitimacy of using a particular indicator in econometric analysis and at the same time indicates whether a particular indicator is a stimulant or a destimulant for PV investments. Of course, the author describes each indicator in great detail and provides the source of his data, but as I have already indicated, the lack of a deep documented rationale for the use of each indicator may leave the reader unsatisfied.

In Chapter 5, the author first conducts a factor analysis to identify the latent variables from the indicators presented in the previous chapter. The idea to use PCA on this stage of analysis is very good. A panel model is then constructed to test the impact of the identified factors on the independent variable, the expansion of solar PV over the period 2009 to 2019. In my opinion, this chapter is crucial for the whole dissertation because it gives us the answer to the two main research questions: (Q1) What are the socio-economic factors that influence the level of private investment in solar PV? (Q2) Is there a correlation between socioeconomic indicators in different German provinces and the level of private investment in photovoltaics? To this parts I have many remarks

The weakest point of this chapter is the lack of a detailed research methodology, i.e. there are no precisely described steps of the empirical analysis or a mathematical procedure that would allow to quickly check the accuracy of the empirical analysis carried out. In many places I had to guess what had been done and what had not.

Notes on PCA analysis.

- - The first step in PCA analysis is to check the appropriateness of conducting the analysis. So we start by defining a correlation matrix of the variables and analyzing the obtained correlations using Bartlett's test and the KMO coefficient. In the text we do not find detailed information about the Bartlett test, i.e. we only know that the test (probably the Bartlett test) was significant (p. 157), and we have no information about the KMO coefficient (greater or less than 0.5 ?)
- - I could not find any information on whether the data were standardized before PCA. Since the different variables in the data set have different units of measurement, it is necessary to normalize the data to get a reasonable analysis of covariance between all these variables. PCA calculates a new projection of the data set and the new axis is based on the standard deviation of your variables. So a variable with a high standard deviation has a higher weight for the calculation of the axis than a variable with a low standard deviation. When data is normalized,

all variables have the same standard deviation, so all variables have the same weight and your PCA calculates the appropriate axis.

- Table 35 does not contain all the information. I wonder how many factors explained 100% of the variance?
- To assess the correctness of the Varimax rotation, it will be nice first show the original loadings of the 20 variables in the five principal components and then present the loadings after the Varimax rotation. It might be also helpful to check the total variance explained by the first five factors for both the rotated and the non-rotated factors.

Notes on panel analysis.

- The results of the panel analysis (Table 38) are difficult to read. Providing the full table of results from the statistical program with the test statistics in the main text would make it much easier to assess the models.
- I believe that the classic determinants of consumer investment in PV (such as the average price of PV modules) should be included in the model as control variables. Otherwise, the problem of omitted variables could arise, which could lead to overestimating or underestimating the impact of the explanatory variable on the dependent variable.
- - The study ignores the question of endogeneity. Is there a possible two-way relationship between investment in PV and the latent variables (named Quality of life, Urbanization, etc)? Also, in formulating the hypothesis (p/160), the author uses the term 'impact' to describe the relationship between investment in PV and 5 latent variables. The question is whether the GLS estimator could verify the causality?

Chapter 6 is a very valuable and unifying chapter. It combines the concepts proposed in the theoretical chapter (TCT) with the results of the descriptive characteristics in chapters 2 and 3 with the results of the empirical analysis from chapter 5. To this end, the author uses Williamson's 4-layer scheme and a holistic approach to describe the needed adoptions in the German prosumer market. I find this part of the thesis extremely interesting and the proposed solutions have a high utility value.

The last section of the thesis contains an original summary of the empirical material together with the author's own original recommendations as well as some elements of a scientific discussion, i.e. a linking of author's findings with the research results of other researchers. The original recommendations are interesting, valuable, very mature, and deserve recognition.

Nevertheless, the reader might be unsatisfied with the scientific discussion and the references to the work of other researchers. Importantly, the author has set the direction for further research on this topic, which undoubtedly demonstrates his scientific maturity.

5. Final conclusions

The above suggestions and criticisms do not change my positive opinion of the thesis. **The dissertation fulfills the legal criteria and I recommend its admission to public defense.** In particular, the author has demonstrated general theoretical knowledge in the discipline of economics and finance, the ability to solve the scientific problem (concerning the relationship between macroeconomic factors and PV investments made by prosumers) and the ability to conduct scientific work independently.

The most important strengths of a dissertation include:

- the importance of the research topic,
- the high transparency of the work and an appropriate scientific argumentation,
- the correct choice of research methods
- original model for analyzing the relationship between investments in photovoltaics and macroeconomic factors
- the formulation of very good recommendations.

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Magdalena Oczko

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